Study of Radionuclide Present in Air and Soil around Narora Atomic Power Station (NAPS), Uttar Pradesh, India

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Abstract: The publication of research reports the results of systematic studies focused on generating scientific data for the concentration level and the distribution of the radionuclide around NAPS. It is essential to estimate the natural levels of radioactivity in the soil to examine the extent up to which the population in the surrounding is exposed. The ambient gamma absorbed dose rates is measured using portable "Digital Geiger Muller Counter Nuclear Radiation Detector. The activity equivalent to Radium only, the air absorbed dose rate (AAD), the effective dose equivalent (AEDEC), the gonadal dose equivalent rate (AGDE), the external risk index, the internal risk index, the index for gamma level, cancer risk for an average lifetime, etc. were calculated and compared with the international standards. It indicates that the overall air of the study region around NAPS is found within the safety range of radiological risk and is not harmfully affecting the environment. The activity concentration of the ^{226}Ra, ^{232}Th and ^{40}K in the soil samples were measured by the use of HPGe Gamma Spectrometry method. The activity of the ^{226}Ra, ^{232}Th and ^{40}K in the soil varied in the range of 29.23 – 43.56 Bq/Kg, 23.41 – 37.52 Bq/Kg and 455 - 553 Bq/Kg, with the corresponding median values are found 36.29 Bq/Kg, 28.59 Bq/Kg and 514 Bq/Kg respectively. The results observed in the present study were compared with the literary values reported for other parts of India and the worldwide average values, and discussed.

Keywords: NAPS, Ambient Gamma Absorbed Dose, HPGe Spectrometry, Radiological Risk.

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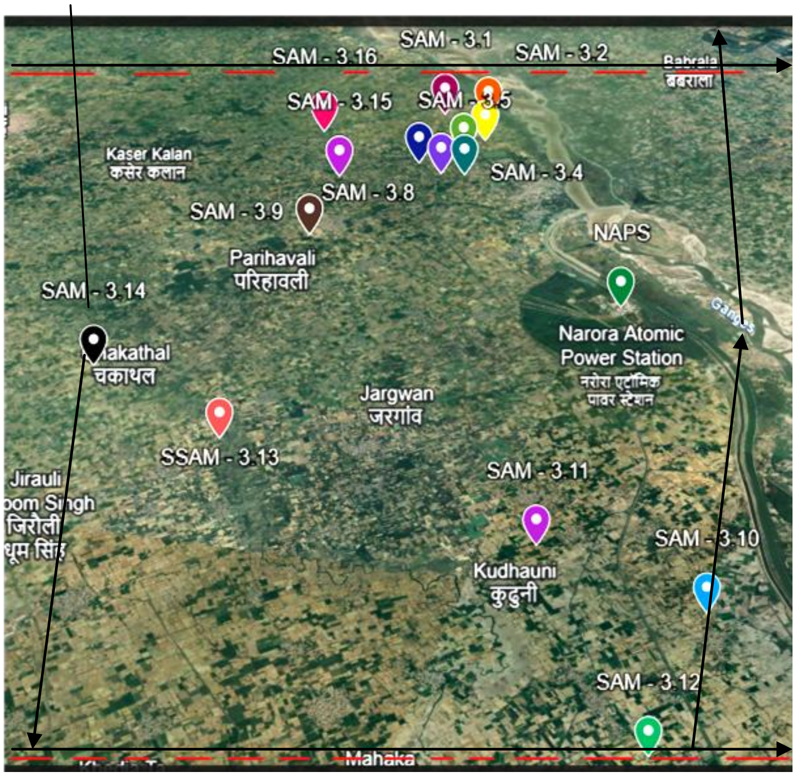
1. Introduction

The effect of radiations on human health has been dangerous[1]. Up to some level the radiations are natural, like solar radiations and cosmic radiations. The NBRE (Natural Background Radiation Exposure) is 1.1mSv/y, Cosmic rays (0.35mSv), air background radiation (0.05 mSv), etc may also contribute significantly[2,3] to the natural dose. The bioaccumulation of the radionuclide and the related biogeochemical processes are threatening to the human health.[4] The internal organ of humans, like lungs, stomach are exposed to the internal radiations.[5] Primordial radioactive elements, such as ^{40}K, gamma rays, ^{238}U and ^{232}Th radioactive series in the soil, water and rocks, may expose humans to ionizing radiations.[6,7,8,9] The NBRE accounts for about 80% of a person's Annual Effective Radiation Dose.[10] It becomes the top reason for the focus of most of the radioactivity quantification studies on NBRE due to primordial radionuclide.

The higher level of radiation has been attributed to the volcanism and metamorphism while the lower level of the radiation has been linked to the sedimentary rock systems.[11,12] A significant variation in the exposure to the natural and extra-territorial radiation level has been observed in terms of intensity in different regions. It has been due to differences in geological and radiochemical characteristics.[13,14] In my study, the soil has been attributed the essential linkage for bioaccumulation between human and surrounding biological systems. The radionuclides enter the food chains continuously to the biological systems and humans.[15] In this study, an estimation of the radionuclide concentrations are made around NAPS (Narora Atomic Power Station). The existence and the activity levels of natural ^{226}Ra, ^{232}Th and ^{40}K radionuclide in the surface soil around NAPS are done by estimating the absorbed dose rate, Radon equivalent (Ra_{eq}), yearly effective absorbed amount, gamma radiation hazard indices and alpha radiation hazard indices.



2. Study Area around NAPS

The NAPS is situated in Narora, a town of Bulandsahar district of Uttar Pradesh State in India. The study area is in 9km radius around NAPS. It is divided into three zones (0-3km, 3-6 km, 6-9 km). The sites of sample collection are assigned their latitudes and longitudes using GPS (Global Positioning System). The study area is shown below in Fig. 1. It extends from $28^0 04'28''N$ - $28^0 13'45''N$ (Latitudes) and $78^0 19'54''E$ - $78^0 26'00''E$ (Longitude). It lies in the Ganga River Valley. The site of nuclear power, i.e. NAPS lies in the western region of Uttar Pradesh, India. It is very fertile and has been a part of Green Revolution. The area under investigation is cover with alluvial soil. As the NAPS is situated in the area on the right bank of river Ganga so it is given priority for sample collection.

3. Materials and Methods

3.1 Field and Laboratory Preparation

The samples of the surface soil profile were collected from 52 locations. Each sample weighing not less than 500g is collected along with its geo-location. All samples were made free from grass husks and stones (kankar) then oven-dried at 110 ^{0}C for at least 6 hours to remove moisture from the samples, grinded them to make homogenous then sealed in polyethylene air-tight containers, weighted and stored for four weeks to allow the Radon and Thoron, and their descendant having small half-lives, to achieve the consistency with their parents. The samples were processed following the standard procedures prescribed by BARC, 2008[16]. The activity concentration of the ^{226}Ra, ^{232}Th and ^{40}K in the soil samples were measured by the use of HPGe Gamma Spectrometry method.

3.2 Instrumentation and Spectrum Measurement

The Co-axial p-type High Purity Germanium (HPGe) detector has been used in this investigation. The instrument's relative efficiency (with respect to a 3'' X 3'' NaI(Tl) Scintillation detector and a point source of ^{60}Co positioned 25cm height from the detector) for

1.332 MeV peak is 50 per cent. Its full-width half maximum is 0.009 MeV for the photo peak 1.332 MeV emitted from ^{60}Co. The samples and the background were counted for 80,000 seconds.

At 1461 KeV (10.7% abundance) a gamma emission was used to directly qualify the activity level of ^{40}K. The ^{226}Ra activity was calculated by the Gamma energy 0.609 MeV (45% abundance) and 1.764 MeV (16% abundance) photo peaks of its daughter ^{214}Bi. Whereas the ^{232}Th activity was estimated using 0.911MeV (branching ratio, 27.8%) and 0.583 MeV (branching ratio, 86%) photo peaks emitted by ^{228}Ac and ^{208}Tl, respectively.

4. Estimation of Soil Radiological Parameters

4.1 Calculation of the Activity ($Bq\ Kg^{-}$)

The activity levels of ^{40}K. ^{226}Ra and ^{232}Th are determined using following relation[17] –

$$A_C(Bq\ Kg^{-}) = \frac{\text{Net Count of Specific Peak}}{\text{efficiency} \times \text{time} \times \text{mass}} \text{ ...... (1)}$$

4.2 Radium Equivalent Activity (Ra $_{eq}$)

The external and internal gamma and alpha dose emitted by the Ra and its daughter nuclei is estimated in terms of Radon equivalent (Ra $_{eq}$). it has been evaluated using following relation –

$$Ra_{eq} = A_{Ra} + 1.43A_{T\square} + 0.077A_K \text{ .... (2)}$$

The Ra$_{eq}$ must be below 370 $Bq\ Kg^{-}$ in the building soil to avoid harmful impact. It comes out equivalent to 1mSv/y (for dwelling occupants)[18].

4.3 External hazard index (H_{ext})

H_{ext} (Model I) has been estimated using equation (3)[19]

$$H_{ext} = \frac{A_{Ra}}{370} + \frac{A_{T\square}}{259} + \frac{A_K}{4810} \leq 1 \text{ .... } \quad (3)$$

Model II extended for a room having ventilation in the form of doors and windows and evaluated using the relation (4)[19]

$$H_{ext} = \frac{1}{2}\left(\frac{A_{Ra}}{370} + \frac{A_{T\square}}{259} + \frac{A_K}{4810}\right) \leq 1 \text{ .... } \quad (4)$$

Here in relation (4), all the three isotopic radioactivity terms are reduced to half of their values in relation (3). The inclusion of ventilation in model II will result in some type of airflow in the model room, reducing the exposure of people to radionuclide and all types of dosages.

4.4 Internal Hazard Index (H_{int})

Radionuclides of short life time which release most ionizing particle, i.e. alpha particle affect lungs when inhaled. The internal hazard index is calculated using the relation (5)[20] –

$$H_{int} = \frac{A_{Ra}}{185} + \frac{A_{T\square}}{259} + \frac{A_K}{4810} \leq 1 \text{...... .. } (5)$$

Note : The value of hazard index lower than unity indicate that the material is usable for construction without any risk.

4.5 External Gamma Level Index (ELI_γ)

It is also known as the Characteristic Level Index. It is evaluated using following relation (6)[21]

$$ELI_\gamma = \frac{A_{Ra}}{300} + \frac{A_{T\square}}{200} + \frac{A_K}{3000} \leq 1 \text{ ..... } \quad (6)$$

4.6 Internal Alpha Level Index (ILI_α)

Over contamination because of ^{226}Rn inhalation released from the soil is evaluated using relation (7)[17] –

$$\boldsymbol{ILI_\alpha} = \frac{A_{Ra}}{200} \leq 1 \text{......... } \quad (7)$$

The indoor radon level cannot exceed 200Bq/m^3 due to the absence of Ra concentrations beyond 200 Bq/Kg.

4.7 Activity Utilization Gamma Index (AUI)

The internal Absorbed Dose Rate in houses built of bricks is related to the activity concentration of the natural radioactivity in the soil. The AUI is evaluated using the following relation[21] –

$$AUI = 0.809\frac{A_{Ra}}{50} + 0.4798\frac{A_{T\square}}{50} + 0.4392\frac{A_K}{500} \leq 2 \quad \ldots\ldots\ldots (8)$$

4.8 Exposure Rate (ER)

The following relation (9) is used for evaluation of the ER[22] –

$$ER\ (\mu R\square^{-}) = 1.90A_{Ra} + 2.82A_{T\square} + 0.179A_K \ \ldots\ldots\ldots\ (9)$$

4.9 Relative Dose Rate (DR) to Exposure Rate (ER)

The following relation (10) is used for evaluation of the DR[22]-

$$DR\ (mrem/y) = .0833 \times ER\ (\mu R\square^{-}) \quad \ldots\ldots (10)$$

4.10 Air Absorbed Dose (D_{air})

The external absorbed dose of gamma radiations from the air at about one meter above the surface of the earth is termed as air absorbed dose. It is evaluated using following relation (11)[22] –

$$D_{air}(nGy\square^{-1}) = 0.461 \times A_U + 0.623 \times A_{T\square} + 0.0417 \times A_K \quad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

4.11 Annual Effective Dose Equivalent (AEDE)

The AEDE is evaluated using the following relation (12)[22] –

$$AEDE_{Indoor}(\mu Svy^{-1}) = D_{air}(nGyh^{-1}) \times 8760\square \times 0.8 \times 0.7SvGy^{-1} \times 10^{-3} \ \ldots\ldots\ (12)$$

$$AEDE_{outdoor}(\mu Svy^{-1}) = D_{air}(nGy\square^{-1}) \times 8760\square \times 0.2 \times 0.7SvGy^{-1} \times 10^{-3} \ \ldots\ldots\ldots\ldots\ (13)$$

4.12 Effective Dose Rate (D_{organ}) to Definite Tissues or Body Organ

The effective dose distributed to a definite body part can be estimated using the following relation (14)[23] -

$$D_{organ}(\mu Svy^{-1}) = AEDE \times C.F. \ \ldots\ldots\ (14)$$

4.13 The Gonadal Dose Equivalent Rate (AGDE)

It is generally believed that the bone surface cells, bone marrow and gonads are the utmost crucial organs. AGDE is evaluated using the following relation (15)[17] –

$$\mathrm{AGDE}\ (\mu\mathrm{Svy}^{-1}) = 3.09 \times \mathrm{A_{Ra}} + 4.18 \times \mathrm{A_{Th}} + 0.0314 \times \mathrm{A_K} \ \ldots\ldots\ldots\ (15)$$

4.14 Effective Lifetime Cancer Risk (ELCR)

The ELCR is evaluated using the relation (16)[17,24,25] –

$$ELCR = AEDE \times DL(65yrs) \times RF(ICRP\ 60, 1990\ uses\ 0.05\ Sv^{-1}) \ldots\ldots\ldots\ (16)$$

4.15 Clark Value

The ratio of concentration of Thorium to Uranium indicates whether uranium extraction from the site is economically viable or not.

$$Clark\ Value = \frac{Conc.of\ Th-232}{Conc.of\ U-238} \ \ldots\ldots\ (17)$$

5. Results and Discussion

5.1 NORM's Concentration around NAPS

As the area around NAPS is very fertile, agriculture is the top profession of the rural people. In this situation the health of the soil becomes essential. Periodic verification of the previous studies is necessary.

The observations of the ZONE – I under the study are tabulated in table 1.

Table: 1. Study of Radionuclide Present in Air and Soil around Narora Atomic Power Station (NAPS), Uttar Pradesh, India

Zone - I (0-3 km)

Parameter	Min.	Max.	Mean	Median	SD	Geo. Mean	Variance	Skewness	kurtosis
Ra-226	29.23	43.37	36.78	36.29	4.28	36.5	18.3	0.06	-1.03
Th-232	24.17	36.56	29.38	28.56	4.1	29.12	16.8	0.42	-1.22
K-40	455	531	502	504	26.8	501.7	719.3	-0.18	-0.63
Ra (eq)	123	139	124	137	6.12	132	39	0.29	-1.47

The results indicate that the ^{238}Ra (U-238) range was 29.23 – 43.37 Bq/Kg and the mean values of Uranium in the surface soil samples are calculated equal to 36.78 ± 3.81 Bq/kg. The maximum value of Uranium was determined in Sam – 1.10 (Retuka Nagla-Maharajpur) and the minimum value was found in Sam – 1.4 (Dharkpur). The ^{232}Th range was 24.17 – 36.56 Bq/Kg and the mean values of ^{232}Th in the surface soil samples are calculated equal to 29.38 ± 1.45 Bq/kg. The maximum value of ^{232}Th was determined in Sam – 1.2 (Niwari Banger) and the minimum value was found in Sam – 1.3 (Rampur). The average value of the ^{40}Kwas found to be 502 ± 39 Bq/Kg.

The observations of the ZONE – II under the study are tabulated in table 2.

Table: 2. Study of Radionuclide Present in Air and Soil around Narora Atomic Power Station (NAPS), Uttar Pradesh, India

Zone - II (3-6 km)

Parameter	Min.	Max.	Mean	Median	SD	Geo. Mean	Variance	Skewness	kurtosis
Ra-226	31.21	43.56	36.04	35.95	3.44	35.89	11.8	0.4	-0.39
Th-232	27.56	34.05	29.19	28.57	2.76	29.07	7.6	0.54	-1.05
K-40	465	547	511	517	27.12	510	736	-0.38	-1.09
Ra (eq)	124	147	133	129	9.92	124	41.27	1.12	-1.87

The results in Table (2) indicate that the ^{238}Ra (U-238) range was 31.21 – 43.56 Bq/Kg and the mean values of Uranium in the surface soil samples are calculated equal to 36.04 ± 3.81 Bq/kg. The maximum value of Uranium was determined in Sam – 2.12 (Gokulpur Bangar) and the minimum value was found in Sam – 1.10 (Dhak Nagla). The ^{232}Th range was 27.56 – 34.05 Bq/Kg and the mean values of ^{232}Th in the surface soil samples are calculated equal to 29.19 ± 1.45 Bq/kg. The maximum value of ^{232}Th was determined in Sam – 2.15 (Niwari Banger) and the minimum value was found in

Sam – 2.5 (Bazidpur). The average value of the ^{40}Kwas found to be 511 ± 39 Bq/Kg.

The observations of the ZONE – II under the study are tabulated in table 2.

Table: 3. Study of Radionuclide Present in Air and Soil around Narora Atomic Power Station (NAPS), Uttar Pradesh, India

Zone - III (6-9 km)

Parameter	Min.	Max.	Mean	Median	SD	Geo. Mean	Variance	Skewness	kurtosis
Ra-226	30.14	43.15	36.29	36	4	36.09	16.02	0.21	-1.13
Th-232	23.41	37.44	30.09	29.93	4.5	29.78	20.2	0.19	-0.99
K-40	461	553	512	515	28.41	511.5	807	-0.31	-0.99
Ra (eq)	123	149	137	141	12.62	128.09	111.7	0.46	-2.62

The results in Table (3) indicate that the ^{238}Ra (U-238) range was 30.14 – 43.15 Bq/Kg and the mean values of Uranium in the surface soil samples are calculated equal to 36.29 ± 3.81 Bq/kg. The maximum value of Uranium was determined in Sam – 3.12 (Dadar Alupura) and the minimum value was found in Sam – 3.7 (Rupaspur). The ^{232}Th range was 23.41 – 37.44 Bq/Kg and the mean values of ^{232}Th in the surface soil samples are calculated equal to 30.09 ± 1.45 Bq/kg. The maximum value of ^{232}Th was determined in Sam – 3.12 (Dadar Alupura) and the minimum value was found in Sam – 3.13 (Malahpur). The average value of the ^{40}Kwas found to be 512 ± 39 Bq/Kg.

The overall data obtained from the 52 locations was evaluated and summarized in the following table below -

Table:4. Study of Radionuclide Present in Air and Soil around Narora Atomic Power Station (NAPS), Uttar Pradesh, India

Overall Zone (0 - 9 km)

Parameter	Min.	Max.	Mean	Median	SD	Geo. Mean	Variance	Skewness	kurtosis
Ra-226	29.23	43.56	36.27	36.29	3.82	36.15	14.62	0.24	-0.93
Th-232	23.41	37.44	29.57	28.59	3.75	29.32	14.07	0.39	-0.78
K-40	455	553	508.56	514	27.22	507.93	741.11	-0.29	-1.01
Ra (eq)	97.7	139.7	117.7	116.8	11.28	117.1	91.8	0.78	-1.97

The mean value of the concentrations of ^{40}K, ^{226}Ra and ^{232}Th are found similar to that carried by various researchers in India and other countries as given below (Table 5).

Table: 5 Global Concentration of Natural Radioactivity (Bq/Kg) and radium equivalent (Bq/Kg) in soil samples

Area/Country	^{226}Ra	^{232}Th	^{40}K	Ra_{eq}
Garwal, India[26]	76	106	980	303
Aravali Hills[27]	12.15	45.17	639.24	125.96
Kalpakam, India[28]	23	93	434	189

Fatehabad & Hisar, Haryana[17]	31.60	23.30	402	114
Egypt[29]	17	18	320	67
USA[18]	40	35	370	118
Iran[30]	28	22	640	109
Bangladesh[18]	29	52	292	127
Saudi Arabia[31]	15	11	225	48
Turkey[18]	86	51	772	218
Japan[18]	33	28	310	97
World Average[18]	35	30	400	-

For almost all samples of the soil, the order of the activities is found as ^{40}K > ^{238}U > ^{232}Th. The average value of the ^{40}K in all three zones is found above average. It indicates over use of fertilizer. The overall observations highlight a variable activity concentration of the radionuclide in the soil samples within the region and the importance of conducting regular monitoring to ensure public health and environment safety. A comparatively variable value of ^{226}Ra, ^{232}Th and ^{40}K indicates deviation from a normal distribution.

5.2 Dose Rates due to Radioactivity in the Soil

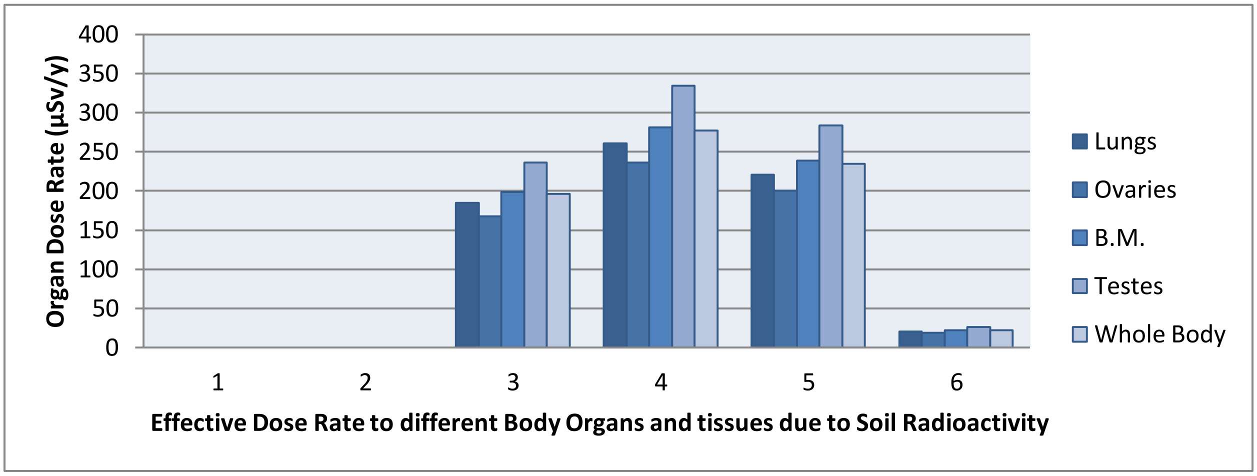
Various dose rates due to radioactivity in the soil are tabulated in the following table (6).

Table: Range and Average Values of different Doses due to Natural Radioactivity in Soil

	E.R μRh^{-1}	DR mrem/y	AAD nGy/y	AEDE μSvy^{-1}			GDER μSvy^{-1}	Lungs μSvy^{-1}	Ovaries μSvy^{-1}	B.M. μSvy^{-1}	Testes μSvy^{-1}	Whole Body μSvy^{-1}
				Out	In	Total						
Min.	202.9	16.9	47.03	57.67	230.71	288.38	331.04	184.56	167.3	199	236.5	196
Max	287.3	23.4	66.47	81.52	326.08	407.60	464.74	260.86	236.4	281.2	334.2	277
Mean	243.3	20.3	56.35	69.12	276.43	345.55	395.36	221.15	200.4	238.4	283.4	235
SD	22.7	18.9	5.23	6.41	25.66	32.07	36.02	20.52	18.6	22.1	26.3	22

Abbreviations: E.R. – Exposure Rate, D.R. – Relative Dose Rate, AAD – Air Absorbed Dose, AEDE – Annual Effective Dose Equivalent, GDER – Gonadal Dose Equivalent Rate, B.M. – Bone Marrow.

The range of ER at one meter above the surface level, the relative dose rate, the air absorbed dose, the annual effective dose equivalent and the annual gonadal dose equivalent were found 203 – 287 μR□$^{-1}$, 16.9 – 23.4 $mrem/y$, 47.03 – 66.47 nGy/y, 288.38 – 407.6 $\mu Sv/y$ and 331.04 – 464.74 $\mu Sv/y$ respectively.

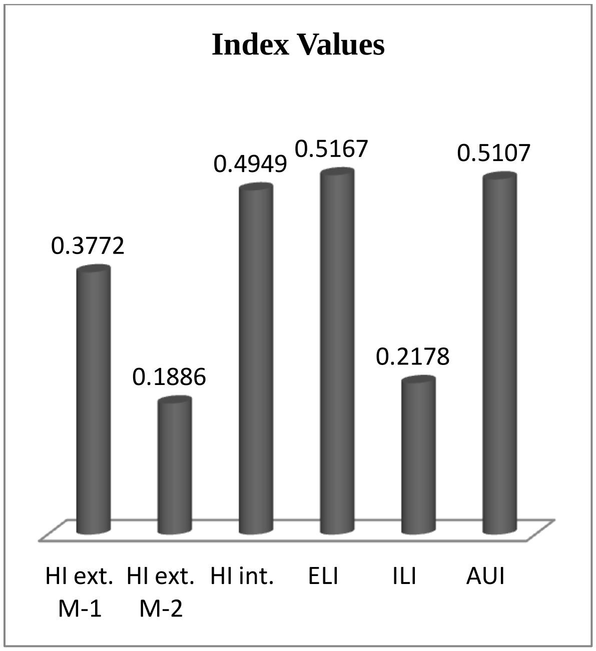


The authors have used different conversion factor (C.F.) to convert air dose to organ dose. The Excess Lifetime Cancer Risk (ELCR) was found within safe limits. The table clearly indicates that testes has maximum and ovaries have least exposure to the radiations. The AEDE (indoor + outdoor) is found below $1 mSv/y$. UNSCEAR has set a baseline value for AGED to be 300 mSv/y.

The observation relating to Index values are tabulated in Table (6) given below -

Sr. No.	Index	Index Value	Optimum Value
1.	Hazard Ind. (Ext.) M-1	0.3772	≤ 1
2.	Hazard Ind. (Ext.) M-2	0.1886	≤ 1
3.	Hazard Ind. (Int.)	0.4949	≤ 1
4.	Gamma level Ind. (Ext) – ELI	0.5167	≤ 1
5.	Alpha Level Ind. (Int.) – ILI	0.2178	≤ 1
6.	Activity Utilisation Gamma Index (AUI)	0.5107	≤ 2

Histogram representations of the Index values are shown below:



Risk Analysis

To check the potential threat due to radioactivity in the soil, relevant index values like hazard index (both internal and external), level indices - activity utilization index (alpha utilization index) internal gamma level index were evaluated by considering only the maximum values of parameters to count the maximum extent of hazard. All indices were found less than one. It reflects that there is no potential threat due to the use of the soil for construction of bricks and related materials.

Conclusion

The data obtained from the soil samples was compared to the UNSCEAR suggested reference levels. The index values are found below the reference line, i.e for unity. The data can be used in future for temporal and spatial variations. From the experiments on the soil samples of the study area around NAPS and computational work on the data obtained following conclusions can be drawn –

1. The soil samples collected from the study area are found to have radionuclide in varying range.

2. Maximum activity is shown for ^{40}K. it is due to over-use of the phosphate fertilizer in agriculture field.

3. Ra$_{eq}$ is found below the permissible level.

4. Testes are exposed maximum and ovaries minimum due to radiation in the air.

5. All the three indices – hazard, level and activity utilization – fall below the internationally recognized standard.

6. The Clark Value is close to one. It suggested that the area under study is economically improper site for uranium extraction.

Acknowledgement

The authors are thankful to the all people who cooperated in making the study of the area scientifically meaningful.

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