

Assessment of Natural Radioactivity Levels and Associated Radiological Hazards For Some Environmental Soil and Rock Samples From Outskirts of Aurangabad, Maharashtra –India Using Gamma- ray Spectrometry.

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ABSTRACT:The level of natural radioactivity in some soil and rock samples collected from different locations of Aurangabad, Maharashtra-India were measured. Concentrations of radionuclides in soil and rock samples were determined by gamma-ray spectrometer using HPGe detector (High Purity Germanium) detector based, low background gamma-ray counting system with specially designed shield. The mean activity level of the natural radionuclides ²²⁶Ra, ²³²Th and ⁴⁰K is 5.673 ± 0.325 , 9.163 ± 0.525 and 168.25 ± 5.8 Bq kg⁻¹, respectively. These values are lower than the world average concentrations 35, 30 and 400 Bq kg⁻¹ for ²²⁶Ra, ²³²Th and ⁴⁰K, respectively (UNSCEAR, 2000). From the measured specific radio activities of the above three natural radionuclides, the radium equivalent activity, the absorbed dose rate, the annual effective dose, the external hazard index, the internal hazard index, the gamma index and alpha index were calculated. The mean values obtained are, 31.874Bq kg⁻¹, 15.171nGy h⁻¹, 0.019mSv y⁻¹, 0.086, 0.101, 0.242 and 0.028 for radium equivalent activity (Ra_{eq}), absorbed dose rates (D), annual effective dose rates (E_{ff} Dose), external hazard index (H_{ex}), internal hazard index (H_{in}), gamma index(I_γ) and alpha index (I_α) respectively. All the health hazard indices are well below their recommended limits. This indicated that the study area was radiologically safe for human being. This research work recommends further studies to estimate internal and external doses from other suspected radiological sources to the population in Aurangabad, Maharashtra-India.

KEYWORDS:Activity concentration, Absorbed dose, HPGe Detector, Natural Radioactivity, Gamma Ray, Radiological hazard.

I. INTRODUCTION

The knowledge of radionuclides distribution and radiation levels in the environment is important for assessing the effects of radiation exposure due to both terrestrial and extraterrestrial sources. Natural background radiation is of terrestrial and extraterrestrial origin. Terrestrial radiation is due to radioactive nuclides present in varying amounts in rocks, building materials, water, soils and atmosphere [1]. Natural radionuclides of uranium ²³⁸U, thorium ²³²Th and potassium ⁴⁰K are present in the earth's crust. When these radionuclides and their daughters in the series undergo decays gamma rays, beta and alpha radiations are released to the environment [2]. Therefore, human beings are continuously exposed to ionizing radiation both inside and outside their dwellings. Our world is radioactive since the beginning of the universe. Every day, we ingest and inhale radionuclides through our food, air and water [3]. The gamma ray exposure in room is due to radiation emitted decay products of ²²⁶Ra, ²³²Th series and ⁴⁰K. Human has always been exposed to natural radiation arising from the earth as well as from outside the earth

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Vol. 6, Issue 8, August 2017

[4]. It is well documented fact that excessive doses of ionizing radiation can hurt human tissues. Nevertheless, at low doses of radiation, there is quiet significant uncertainty about the total effects. Natural environmental radioactivity and the related external exposure due to gamma radiation depend mainly on the geological and geographical conditions, and appear at different levels in the soils of each region in the world [5]. Every building construction material contains different quantities of natural radioactive nuclides [6]. Radiation exposure due to building materials can be divided into external and internal exposure [7]. The external exposure is caused by direct gamma radiation whereas internal exposure is caused by the inhalation of radon (^{222}Rn), thoron (^{220}Rn) and their short lived decay products [8]. As, radon is a noble gas, it can transport easily through porous media for instance building materials, while usually only a fraction of that produced in the material reaches the surface and enters the indoor air [9].

II. RELATED WORK

Natural environmental radioactivity arises mainly from primordial radionuclides such as ^{40}K , and the radionuclides from the ^{232}Th and ^{238}U series and their decay products, which occur at trace levels in all ground formations. 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 [10]. Such investigations can be useful for both the assessment of public dose rates and the performance of epidemiological studies, as well as to keep reference data records, to ascertain possible changes in the environmental radioactivity due to nuclear, industrial, and other human activities.

III. MATERIALS AND METHODS

A. Sample Collection and Preparation

The methods include samples collection and preparation of the apparatus used to determine the gamma-ray spectra of the concerned samples and analytical methods. These measurements processes were carried out in center for Advanced Research in Environmental Radioactivity Measurements Laboratory (CARER), physics department, Faculty of Science, University of Mangalore. The Environmental samples (rocks, soils) were collected from different places of Aurangabad Maharashtra-India and prepared for measuring the natural radioactivity due to ^{226}Ra , ^{232}Th and ^{40}K by gamma spectroscopic analysis.

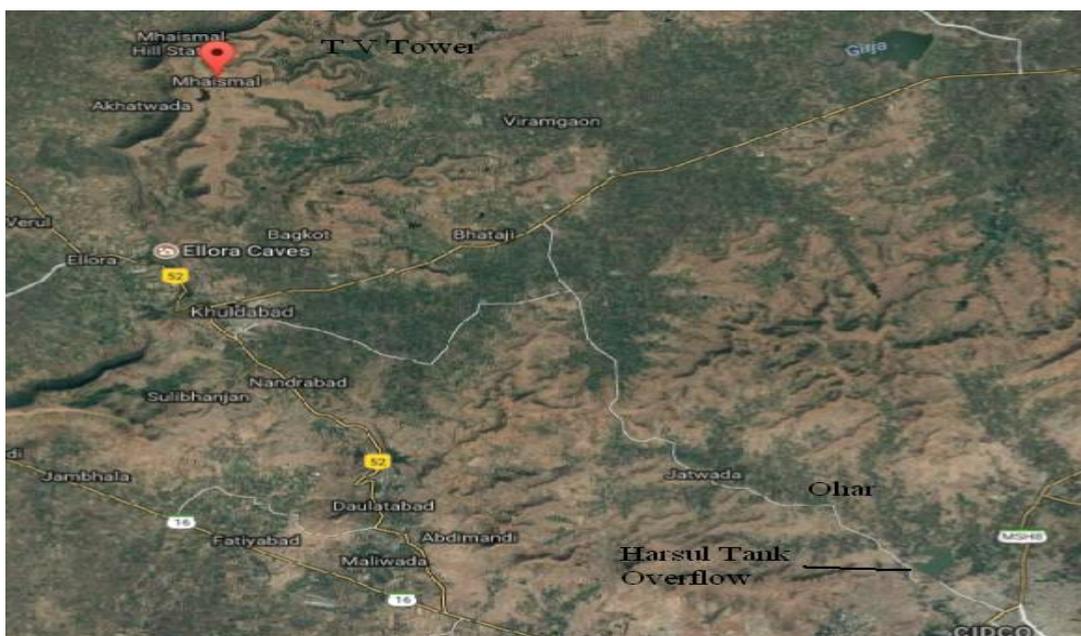


Fig-1: The locations around Aurangabad where from samples are collected.

International Journal of Innovative Research in Science, Engineering and Technology

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Rock samples were crushed to small pieces and grinded to be powder and soil samples were collected with the only constraint that no sampling site should be taken close to a field boundary, a road, a tree or other obstruction. Surface soils were then taken from different places within cleared area from the ground surface up to 2cm and mixed together thoroughly in order to obtain a representative sample of that area. After removing the stones, the samples (rock/soil) were dried in an oven at 105°C, to remove moisture and sieved through a 100 mesh (equivalent 5 mm) which is the optimum size enriched in heavy mineral [11]. The samples were packed in plastic containers dimensions of 60 mm in diameter and 100 mm height. The samples were weighed and stored for a minimum period of one month to allow daughter products to come into radioactive secular equilibrium with their parents ^{226}Ra and ^{232}Th [12] before gamma spectrometric analysis and then were counted for 8h depending on the concentration of the radionuclides.

B. Gamma-ray Spectrometry

Gamma spectrometry offers a convenient, direct, and non-destructive method to measure the activity of different radionuclides in the environmental samples. It also offers high efficiency NaI(Tl) detectors and high resolution (semiconductor detectors) detection. This technique enables the use of large quantities of samples to be counted. It is also possible, in this method, to reduce the extraneous background to very low values using suitable shielding arrangement. These features together with appropriate competent software coldest hat have now become available has made the gamma spectrometry method one of the most accurate technique for determining the activity concentration in the environmental samples. In the present study, HPGe gamma spectrometer was used for the determination of gamma active radionuclide in soil and rock samples. NaI(Tl) scintillator and HPGe semiconductor detector are commonly used for the gamma ray spectrometry. Hyper pure germanium detectors are widely used for gamma ray spectroscopy to determine quantitatively the activities of natural ^{40}K , ^{232}Th , ^{226}Ra in the environmental samples. The HPGe detectors have very high resolution, but the efficiencies are low compared to those of scintillation detectors such as NaI(Tl). The high purity germanium detector can be produced from either n-type or p-type (Germanium) semiconductor material. The block diagram of HPGe gamma ray spectrometer system is shown in fig (2). The spectrum was analysed using a 16 K multichannel analyzer connected to computer using GENIE-2000 software. The sealed sample was placed in the protection unit of gamma ray spectrometry for the counting time of eight hours. The HPGe gamma spectrometry systems present study is p-type closed end co-axial detector (Model GR 4021, Canberra, USA). It has a dimension of 61 mm diameter and 52 mm length. The energy resolution (FWHM) of this detector is 2.01 keV at 1.33 MeV (60CO).

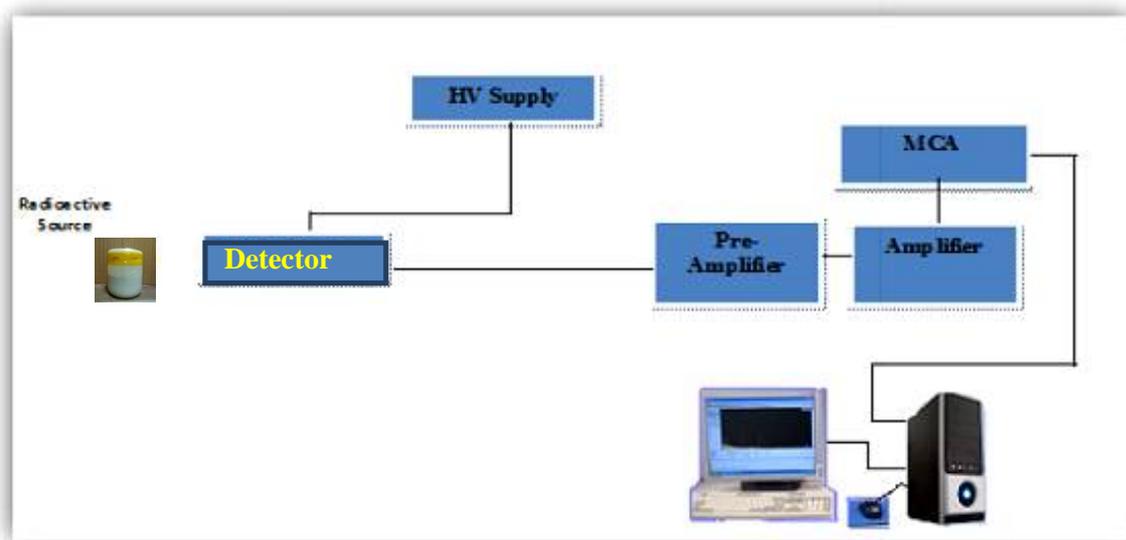


Fig-2: Block diagram of gamma-spectrometer detectors.

C. Calibration of Gamma-ray Spectrometer System

The calibration of the spectrometer system for energy measurements is necessary to know the approximate energies of the radiation source being analyzed. The aim of calibration is to identify the radionuclide and activity concentrations present in an environmental sample. Energy calibration is carried out to ensure linear relationship between energy and the number of channels corresponding to that energy, and to determine the energy of each channel in a spectrum. The spectrum is acquired for a reasonable time so that the photo peaks have sufficient counts for analysis. The regions of interest and centroid peak channel numbers are identified. Then the slope of the straight line plotted between the channel numbers versus energy represents the energy calibration factor. Fig (3) shows the energy calibration curve for HPGe detectors.

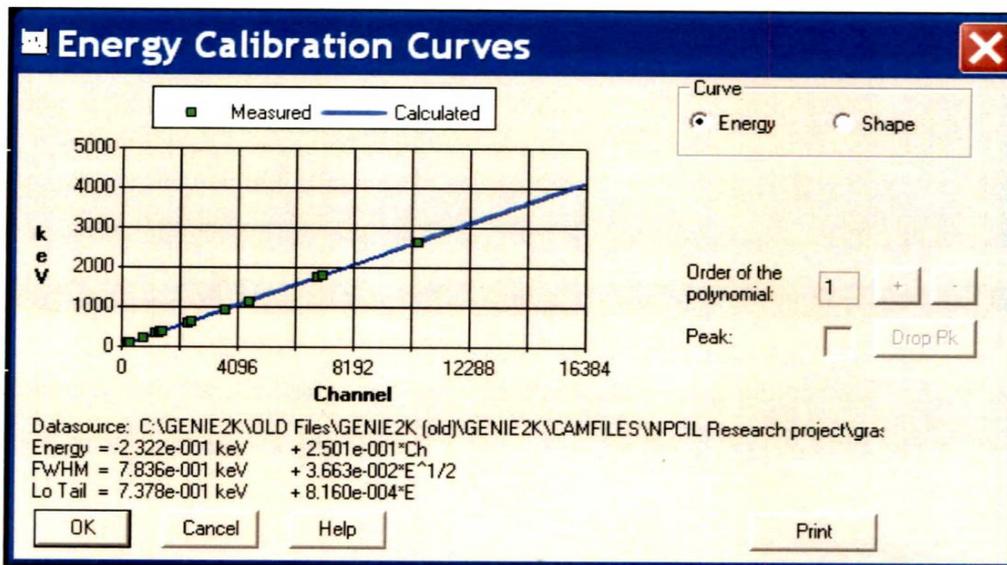


Fig-3: Energy calibration curve for the p-type HPGe detector generated by the GENIE-2000 software.

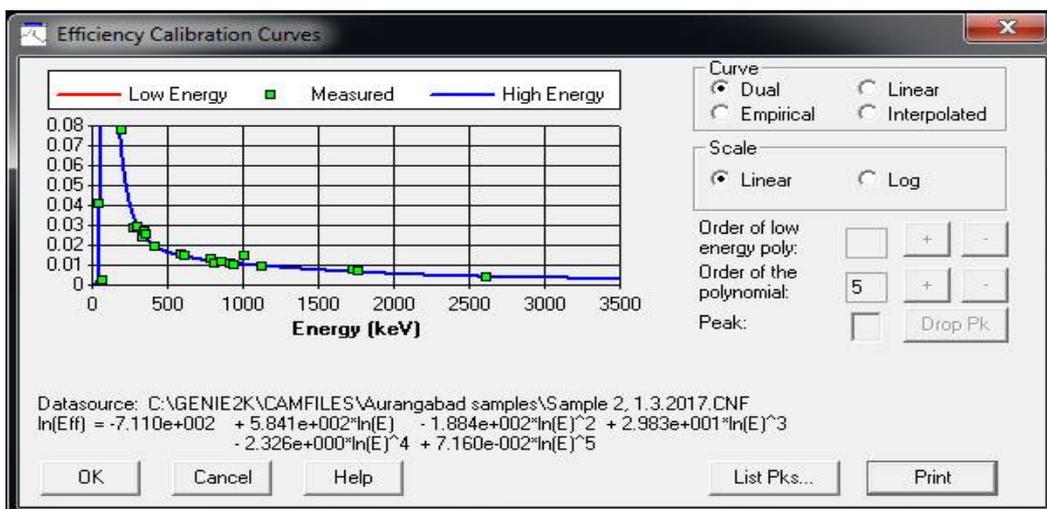


Fig-4: Efficiency calibration curve for the p-type HPGe gamma spectrometer system (as generated using GENIE-2000 gamma spectrum analyses software).

The energy of any channel can be determined with the straight-line equation: $E = (m \times \text{channel number}) + c$

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Where, E is the Energy, c is the intercept, and m is the slope of the straight line. In the present work, the detector efficiency calibration was performed using IAEA quality assurance reference materials: RGU-238, RGTh-232, RGK-1, and SOIL-6. These standard reference materials were taken in 300 ml plastic containers (similar to the containers used for filling the soil samples for gamma spectrometric determination). The standard materials and samples were taken in containers of the same size and type so that the geometry remained the same. The samples were counted long enough (30,000 s) to reduce the counting error. The variation of efficiency of the detector with energy for different gamma lines of various radionuclides for the p-type HPGe gamma ray spectrometer system used in the present study is shown in fig(4).

D. Calculation Activity Concentrations

Since radioactive nuclei emit a discrete spectrum of photons, peaks in the spectrum occur at these photon energies due to interactions leading to full absorption of the photon energy within the sensitive volume. Only quantities describing the intensity of peaks in the spectra are the subject of this work. After the measurement has been completed (8 hours counting time approximately), the peak areas in the spectrum are calculated and corrected for counting losses (Background count) to obtain net count rate. Following the spectrum analysis, count rates for each detected photo peak and activity per mass unit (radiological concentration) for each of the detected nuclides are calculated. The specific activity in (Bq kg⁻¹), A_{Ei}, of a nuclide i and for a peak at energy E, is given by [14]:

$$A_{E,i} = \frac{N_P}{t_c \cdot I_\gamma(E_\gamma) \cdot \epsilon(E_\gamma) \cdot M} \quad (1)$$

Where: N_P is the number of counts in a given peak area corrected for background peaks of a peak at energy E_γ, t_c is the counting life time, I_γ(E_γ) the number of gammas per disintegration of this nuclide for a transition at energy E_γ, ε (E_γ) The detection efficiency at energy E_γ and M the mass in kg of the measured sample. The activity concentration of ²²⁶Ra were measured using the photo peaks of ²¹⁴Pb (295.22 , 351.93 KeV) , ²¹⁴Bi (609.31 and 1120 KeV) and ²²⁶Ra (186.1 KeV). And the activity concentration of ²³²Th series concentration was an average of three values obtained from the photo peaks of the ²²⁸Ac (911.2, 209.25, 338.32keV) and ²⁰⁸Tl (2614, 583.19, 860.56keV). The 1461 keV gamma of ⁴⁰K was used to determine the concentration of ⁴⁰K in different samples. The main radionuclides and specifications are listed in table (1).

Table- 1: Natural Radionuclides found in samples and background [15].

Nuclide to be determined		Nuclide measured	Energy in keV	Probability in %	Half-life time
Ra-226		Ra-226	186.1	3.51	1600 y
		Pb-214	295.22	18.15	26.8 m
		Pb-214	351.93	35.1	
		Bi-214	609.31	44.6	19.9 m
Bi-214	1120.29	14.7			
Th-232	Th-228	Ac-228	209.25	3.89	6.13 h
		Ac-228	338.32	11.27	
		Ac-228	911.2	25.8	
	Ra-228	Tl-208	583.19	30.4	3.07 m
		Tl-208	860.56	4.47	
		Tl-208	2614.53	35.64	
K-40		K-40	1460.83	10.67	1.28×10 ⁹ y

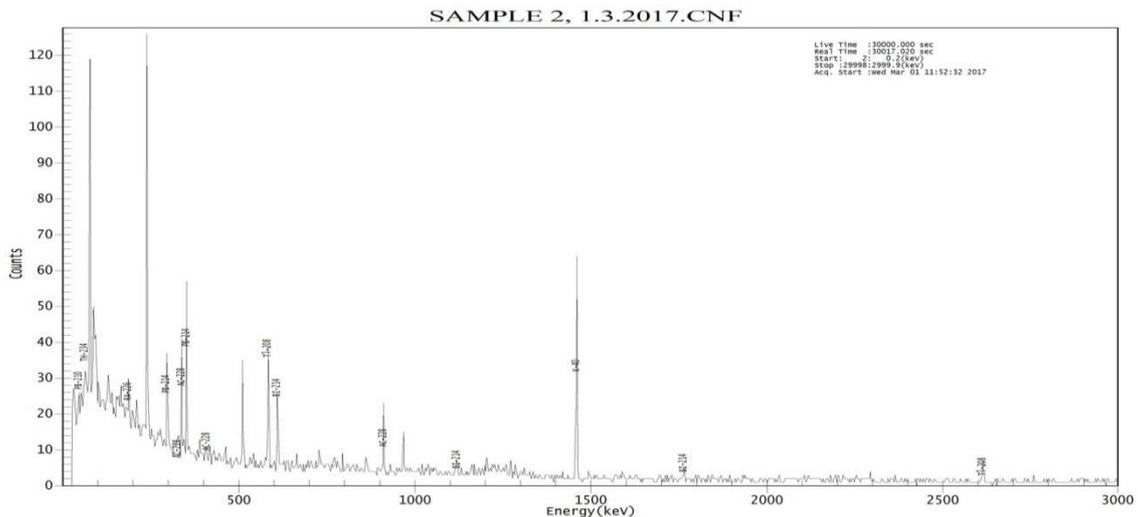


Fig-5: Gamma-ray spectrum obtained for soil sample.

E. Computation of Radiological Effects

Radium equivalent activity:

The distribution of ^{226}Ra , ^{232}Th and ^{40}K in soil and rock samples is not uniform. Uniformity with respect to exposure to radiation has been defined in terms of Ra_{eq} . The radium equivalent activity (Ra_{eq}) was calculated by using the following relation [16, 17, 18]:

$$\text{Ra}_{\text{eq}} = A_{\text{Ra}} + 1.43 A_{\text{Th}} + 0.077 A_{\text{K}} \quad (2)$$

Where A_{Ra} , A_{Th} and A_{K} are the activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K , respectively in Bq kg^{-1} . In estimating this index, it has been assumed that 370 Bq kg^{-1} of ^{226}Ra , 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K produce the same gamma doses [19].

Calculation of air absorbed dose rate:

The measured activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K are converted into doses (nGy h^{-1} per Bq kg^{-1}) by applying the factors 0.462, 0.604 and 0.042 for Radium, thorium and potassium, respectively (UNSCEAR, 2000). These factors are used to calculate the total absorbed gamma dose rate in air at one meter above the ground level using the following equation [20]:

$$D_{\text{ab}} = 0.462 A_{\text{Ra}} + 0.604 A_{\text{Th}} + 0.0417 A_{\text{K}} \quad (3)$$

Where A_{Ra} , A_{Th} and A_{K} are in Bq kg^{-1} .

Effective dose rates:

To measure the annual effective doses, both indoors and outdoors, considerations must be made for the conversion coefficient from absorbed dose in air to effective dose and the indoor and outdoor occupancy factors respectively. The conversion coefficient, 0.7 SvGy^{-1} was recommended by UNSCEAR (UNSCEAR, 2000). The adults spend about 80% of their time indoors, while the remaining 20% time is spent outdoors. Therefore, the indoor and outdoor occupancy factors were given as 0.8 and 0.2, respectively (UNSCEAR, 2000). Hence, the annual indoor and outdoor effective doses (mSv) are given as follows:

$$H_{\text{E (indoor)}} = D_{\text{ab}} \times 8760 \text{ h} \times 0.8 \times 0.7 \text{ SvGy}^{-1} \times 10^{-6} \quad (4)$$

$$H_{\text{E (outdoor)}} = D_{\text{ab}} \times 8760 \text{ h} \times 0.2 \times 0.7 \text{ SvGy}^{-1} \times 10^{-6} \quad (5)$$

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External and Internal Hazard Index:

For the measurement of gamma radiation dose expected to be delivered externally from building materials, the external hazard index is given as follows [21]:

$$Hex = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_k}{4810} \quad (6)$$

The radiation risk is negligible when the maximum value of the external hazard index is less than unity ($H_{ex} \leq 1$), which is equivalent to a maximum value of the Raeq activity $< 370 \text{ Bq kg}^{-1}$. Internal exposure arises from the inhalation of radon (^{222}Rn) gas and its progeny products or ingestion of other radionuclides. Since radon is carcinogenic, it is present in all building materials. Hence for the measurement of radon exposure, the internal hazard index is given as follows [21]:

$$Hin = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_k}{4810} \quad (7)$$

Gamma index (I_γ):

Gamma index (I_γ) proposed by the European Commission has been calculated from the activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in soil samples [6]. This index is given as follows:

$$I_\gamma = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_k}{1500} \quad (8)$$

For materials that are used in bulk quantities (Such as clay bricks and concrete etc.), the value of $I_\gamma \leq 0.5$ corresponds to a dose rate criterion of 0.3 mSv yr^{-1} whereas $0.5 < I_\gamma \leq 1$ corresponds to a criterion of 1 mSv yr^{-1} [22].

Alpha index (I_α):

As radon progeny decay, they emit radioactive alpha particles and attach to aerosols, dust and other particles in the air. As we inhale, radon progeny are deposited on the cells lining the airways where the alpha particles can damage DNA and potentially cause lung cancer. The excess alpha radiation due to radon inhalation originating from building materials is estimated through the alpha index (I_α), which is defined as follows [23]:

$$I_\alpha = \left(\frac{A_{Ra}}{200} \right) \quad (9)$$

The recommended upper limit concentration of ^{226}Ra is 200 Bq kg^{-1} which gives $I_\alpha = 1$.

IV. RESULTS AND DISCUSSION

The Activity concentrations of ^{226}Ra , ^{232}Th , ^{40}K , radium equivalent activity, absorbed dose rate, annual effective doses, hazard index, gamma index and alpha index in soil and rock samples collected from Aurangabad Maharashtra-India were measured and presented in table (2,3,4) with the standard deviation (\pm SD).

Table -2: The Activity concentration of ^{226}Ra , ^{232}Th and ^{40}K in samples collected from Aurangabad city of India (Bq Kg^{-1}).

Sample. No	Location	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})
1	Harsul Tank overflow	3.6 ± 0.3	7.98 ± 0.5	190.3 ± 6.2
2	Ohar	5.39 ± 0.3	7.97 ± 0.5	156.7 ± 5.5
3	Mhaismal Lake	7.1 ± 0.4	10.7 ± 0.6	169.0 ± 5.8
4	Mhaismal TV Tower	6.6 ± 0.3	10.0 ± 0.5	157.0 ± 5.7
	Minimum	3.6 ± 0.3	7.97 ± 0.5	156.7 ± 5.5
	Maximum	7.1 ± 0.4	10.7 ± 0.6	190.3 ± 6.2
	Mean	5.673 ± 0.325	9.163 ± 0.525	168.25 ± 5.8
	SD	1.557	1.401	15.777

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From table (2) the activity concentration of ^{226}Ra have been measured and ranges from 3.6 ± 0.3 to $7.1 \pm 0.4 \text{ Bq kg}^{-1}$ with a mean value of $5.673 \pm 0.325 \text{ Bq kg}^{-1}$. The values of ^{232}Th ranges from 7.97 ± 0.5 to $10.7 \pm 0.6 \text{ Bq kg}^{-1}$ with a mean value of $9.163 \pm 0.525 \text{ Bq kg}^{-1}$. The values of ^{40}K ranges from 156.7 ± 5.5 to $190.3 \pm 6.2 \text{ Bq kg}^{-1}$ with a mean value of $168.25 \pm 5.8 \text{ Bq kg}^{-1}$. It was observed that the activity of ^{232}Th is found higher than ^{226}Ra in all the samples. The world average concentrations are 35, 30 and 400 Bq kg^{-1} for ^{226}Ra , ^{232}Th and ^{40}K , respectively (UNSCEAR, 2000). The obtained mean activity concentration of ^{40}K is $168.36 \text{ Bq kg}^{-1}$, which is indeed lower than the worldwide average 400 Bq kg^{-1} . The activity concentration of ^{40}K is found higher than the activity of ^{226}Ra and ^{232}Th in all samples. The results shown in table (2) also indicate that the mean value of $^{40}\text{K} > ^{232}\text{Th} > ^{226}\text{Ra}$. However, the activity concentration of ^{226}Ra , ^{232}Th and ^{40}K in all soil and rock samples of these areas are lower than the world reported values (UNSCEAR, 2000).

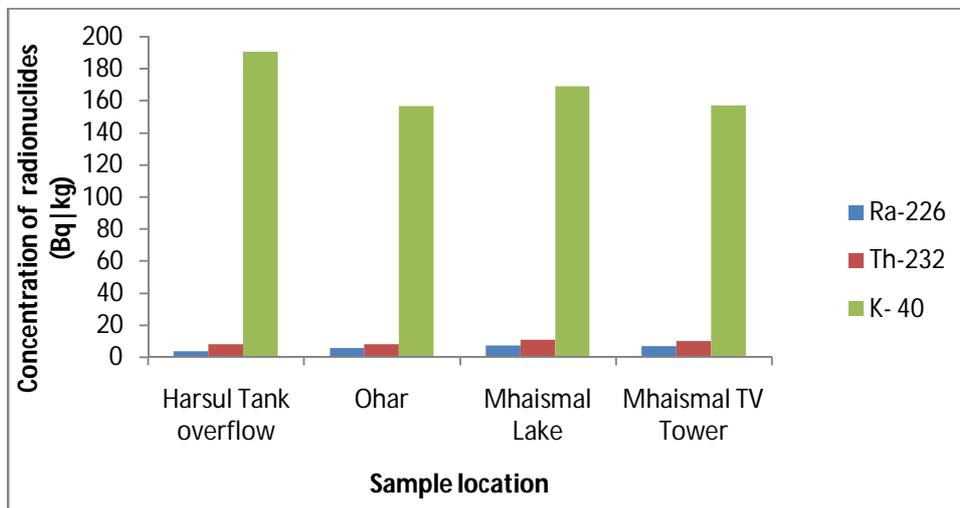


Fig-6: Variation of activity concentration ^{226}Ra , ^{232}Th and ^{40}K in different samples.

Table-3: Radium equivalent activity, Absorbed dose and Annual Effective dose for the samples collected from the study area.

Sample No	Radium equivalent (Bqkg ⁻¹)	Absorbed dose (nGyh ⁻¹)	Annual Effective dose Indoor (mSv y ⁻¹)	Annual Effective dose Outdoor (mSv y ⁻¹)
1	29.665	14.419	0.071	0.018
2	28.853	13.839	0.068	0.017
3	35.414	16.790	0.082	0.021
4	32.989	15.636	0.077	0.019
Minimum	28.853	13.839	0.068	0.017
Maximum	35.414	16.790	0.082	0.021
Mean	31.874	15.171	0.074	0.019
S D	3.039	1.314	0.007	0.002

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Table-4: Radiological Hazard parameters for the samples collected from the study area.

Sample. No	External Hazard index (H_{ex})	Internal Hazard index (H_{in})	Gamma index (I_γ)	Alpha index (I_α)
1	0.080	0.090	0.231	0.018
2	0.078	0.093	0.220	0.027
3	0.096	0.115	0.267	0.036
4	0.089	0.107	0.249	0.033
Minimum	0.078	0.090	0.220	0.018
Maximum	0.096	0.115	0.267	0.036
Mean	0.086	0.101	0.242	0.028
S.D	0.008	0.012	0.021	0.008

Table(3) shows The value of radium equivalent activity (Ra_{eq}) in samples varies from 28.853 to 35.414 Bq kg⁻¹ with a mean value of 31.874 Bq kg⁻¹ and a standard deviation of 3.039. The radium equivalent activity in soil samples lower than the 370 Bq kg⁻¹ limits set by OECD (OECD, 1979). The value of absorbed dose rate varies from 13.839 to 16.790 nGy h⁻¹ with mean value of 15.171 nGy h⁻¹. The global average absorbed dose level is 86 nGy h⁻¹ and Indian average absorbed dose level is 90 nGy h⁻¹. It has been observed that the calculated values of absorbed dose is found less of Indian and global average values. The absorbed dose rate values calculated for each sample is shown in table (3). All values of absorbed dose rate are lower than the world average value i.e., 55 nGy h⁻¹ (UNSCEAR, 1993). The values of the annual effective dose indoors are found to vary from 0.068 to 0.082 mSv yr⁻¹ with a mean value 0.074 mSv y⁻¹ whereas outdoors is found to vary from 0.017 to 0.021 mSv y⁻¹.

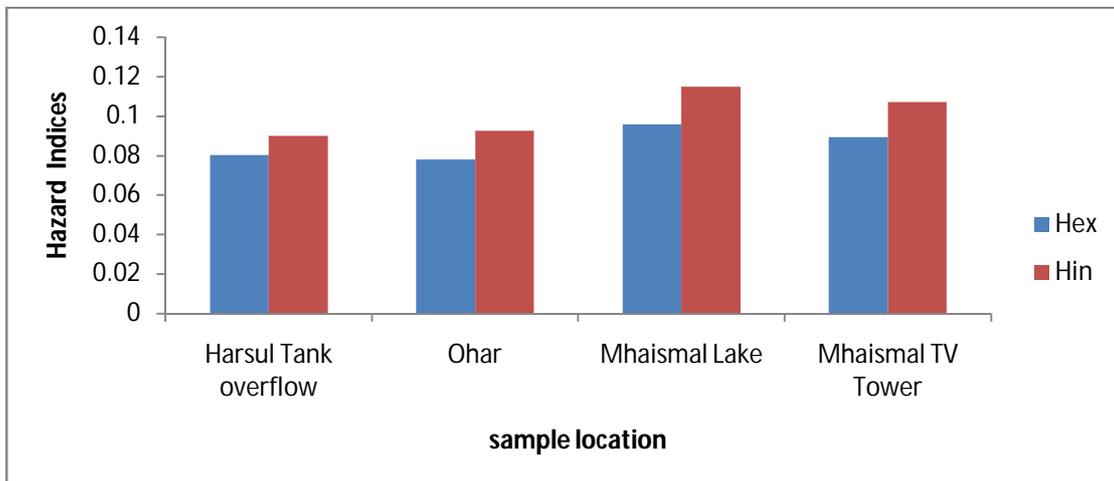


Fig -7: Comparison of external (H_{ex}) and internal (H_{in}) radiation hazard indices.

The annual effective dose is found marginally below the international recommended value 1 mSv y⁻¹ for the general public (UNSCEAR, 2000). The range of external hazard index vary from 0.078 to 0.096 with a mean value of 0.086, while the values of internal hazard indices in soil samples vary from 0.090 to 0.115 with an average of 0.101. It is seen that the average value of external and internal hazard index is less than unity. A comparison of measured values of internal and external radiation hazard indices for each sampling site is shown in figure (7), which indicates that internal radiation hazard index is greater than external radiation hazard index at every sampling site; which shows that the use of a material in the construction of dwellings is considered safe. The values of external

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and internal hazard indices in the present study is less than unity, indicating that the soil from this city is safe and can be used as a construction material without posing any significant harmful effects to the inhabitants.

The calculated values of gamma index I_γ for the soil samples are given in table (4). It is observed that the values are quite lower the limit of 0.5 [24]. The values of I_α calculated from the concentrations of ^{226}Ra are presented in table (4). However, the alpha index in samples has been found to vary from 0.018 to 0.036 with an average value of 0.028 and a standard deviation of 0.008. It is observed that all values of I_α are below the maximum permissible value of $I_\alpha=1$. The obtained results are comparable to the worldwide average concentration table (5). A comparison of measured activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in soil with that of reported values from other areas is given in table (5), which indicates that measured mean activity concentrations of these radionuclides in the present study are comparable with the reported data.

Table- 5: Comparison of activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in soil samples in different areas of the India.

Sample. No	Location	Mean activity concentration (Bq kg ⁻¹)			References
		^{226}Ra	^{232}Th	^{40}K	
1	World average	35	30	400	[25]
2	All India	14.8	18.3	-	[26]
3	Rajasthan, India	93.5	54.0	74.5	[27]
4	Hamirpur district, India	44.2	174.5	93.1	[28]
5	Mysore City	37.5	75.5	550.4	[29]
6	Aurangabad city	5.67	9.16	168.25	Present study, 2017

Table-6: Comparison of natural radioactivity with other studies of worldwide.

Sample. No	^{226}Ra (Bq kg ⁻¹)	^{232}Th (Bq kg ⁻¹)	^{40}K (Bq kg ⁻¹)	References
1	92.53	66.04	502.43	[30]
2	49.97	57.17	89.82	[31]
3	28.2	31.8	840.7	[32]
4	12.16	6.3	432.84	[33]
5	15.93	45.73	188.3	[34]
6	35	30	400	[35]
7	5.67	9.16	168.25	Present study, 2017

Correlation study:

Correlation analyses were performed to reveal the possible relationship between concentrations of different radionuclides in the samples. The Pearson product-moment correlation matrixes for the correlation coefficient values (r) between the radionuclides activity concentrations were calculated. The correlation between ^{226}Ra & ^{232}Th , ^{226}Ra & ^{40}K and Radium and absorbed dose in air of soil samples is computed from the concentrations of these radionuclides and shown in figs.8 to 10 respectively. There is a strong correlation between ^{226}Ra and ^{232}Th , for the samples (with positive correlation coefficients $r = 0.88$) in all sampling locations. And there is negative correlation between ^{226}Ra & ^{40}K [Correlation coefficient $r = -0.70$] in samples. The value of correlation between ^{226}Ra and ^{232}Th was significantly higher

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when compared to that between ^{226}Ra and ^{40}K this significant positive correlation suggests that their content in the soil is mostly influenced and controlled by similar origin of sources [36].

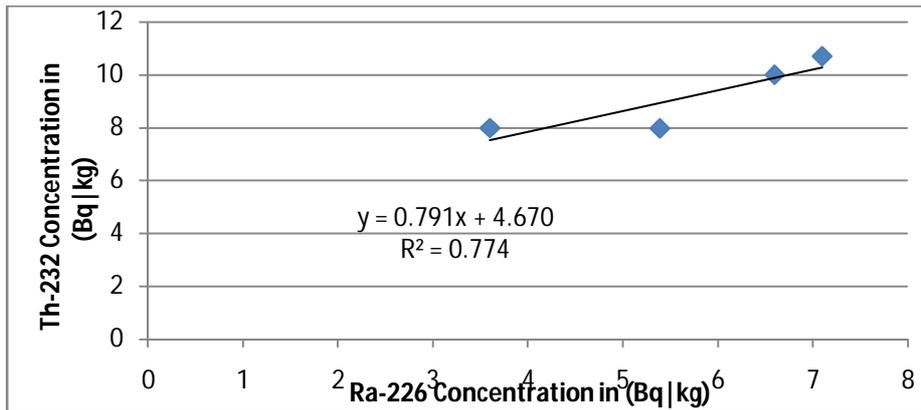


Fig-8: Correlation between Radium and Thorium concentration in Soil samples.

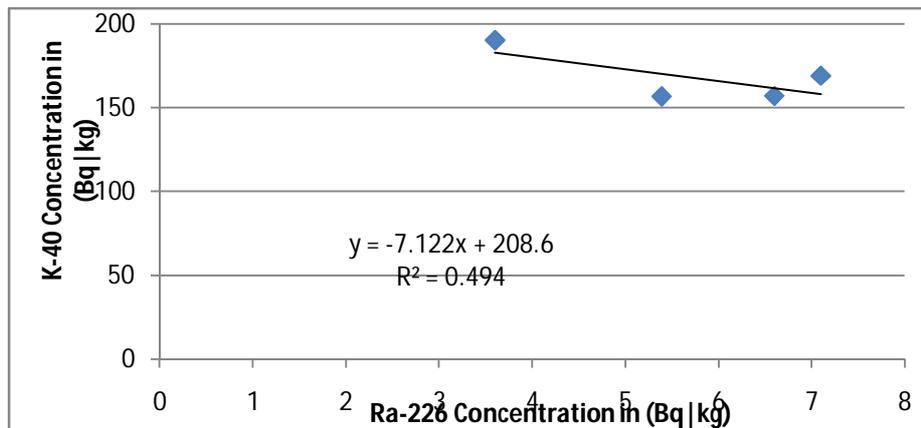


Fig-9: Correlation between Radium and Potassium concentration in Soil samples

Fig. (10) Shows the correlation between ^{226}Ra and the absorbed dose in air. There exists a good correlation between ^{226}Ra and the absorbed dose in air. The value of correlation coefficient is ($r = 0.76$).

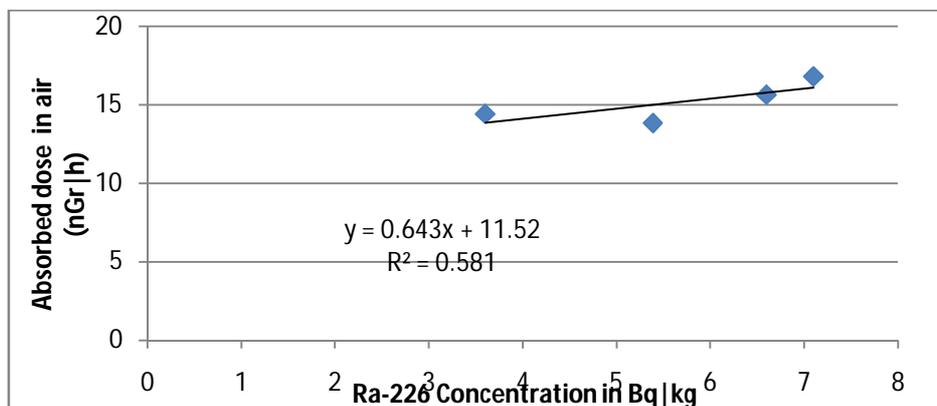


Fig-10: correlation between Ra-226 and absorbed dose in air

International Journal of Innovative Research in Science, Engineering and Technology

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V. CONCLUSION

The activity concentration of ^{226}Ra , ^{232}Th and ^{40}K has been measured for some soil and rock samples from different locations of Aurangabad Maharashtra, India by using gamma-ray spectrometry (HPGe) detector. The activity of ^{226}Ra , ^{232}Th and ^{40}K in samples are found to range from 3.6 ± 0.3 to $7.1 \pm 0.4 \text{ Bq kg}^{-1}$, 7.97 ± 0.5 to $10.7 \pm 0.6 \text{ Bq kg}^{-1}$ and 156.7 ± 5.5 to $190.3 \pm 6.2 \text{ Bq kg}^{-1}$, respectively, while world average concentrations are 35, 30 and 400 Bq kg^{-1} for ^{226}Ra , ^{232}Th and ^{40}K , respectively (UNSCEAR, 2000). The average and ranges of activity concentration of ^{226}Ra , ^{232}Th and ^{40}K in soil of these areas are quite lower than the world average reported values (UNSCEAR, 2000). The Average value of radium equivalent activity is $31.874 \text{ Bq kg}^{-1}$ which is below the recommended value of 370 Bq kg^{-1} . The values of absorbed dose rates due to ^{226}Ra , ^{232}Th and ^{40}K in soil samples vary from 13.8345 to $16.790 \text{ nGy h}^{-1}$ with an average value of $15.171 \text{ nGy h}^{-1}$. The calculated values of absorbed dose have been found lower than Indian and global average value. The values of annual effective dose rates in indoor has been found to vary from 0.068 to 0.084 mSv y^{-1} with an average value of 0.074 mSv y^{-1} furthermore annual effective dose rates in outdoor is found to vary from 0.017 to 0.021 mSv y^{-1} with an average value of 0.019 mSv y^{-1} . It is observed from the table that the indoor annual effective dose is higher than the outdoor annual effective dose. This is below the limit of 1 mSv y^{-1} for general population (UNSCEAR, 2000). The calculated values of external hazard H_{ex} are vary from 0.078 to 0.096 with an average value of 0.086 whereas internal hazard index H_{in} are vary from 0.090 to 0.115 with an average value of 0.101 . All values of H_{ex} and H_{in} are less than unity. However, the value of gamma index I_{γ} is found to vary from 0.220 to 0.267 with an average value of 0.242 and values of I_{γ} were also found lower than one. All the values of Alpha index I_{α} were found below the maximum permissible value i.e.1. Therefore, the soil samples used in the present study is exempted from all the restrictions concerning radioactivity, also these soil samples are safe to be used in building construction. The mean value of gamma index is obtained below the limit of 1. On the basis of our results, we concluded that the soil of the study area does not pose any radiological health hazard to the public.

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