Terrestrial background radiation studies in South Konkan, Maharashtra, India

S.J. Dhawal[1], G.S. Kulkarni[2], S.H. Pawar[1*]

[1]Center for Interdisciplinary Research, D.Y Patil University, Kolhapur-416004, MS, India
[2]Department of Technology, Shivaji University, Kolhapur- 416004, MS, India

► ***Original article***

**** Corresponding author:***
Dr. S.H. Pawar
Fax: *+91 231 2601595*
E-mail: *vc@dypatilkolhapur.org*

Submitted: Nov. 2012
Accepted: April 2013

Int. J. Radiat. Res., October 2013; 11(4): 263-270

ABSTRACT

***Background*:** The natural radionuclides are always present in soil and care needs to be taken to minimize the radiation dose to humans. These radionuclides are mostly gamma ray emitting radionuclides which contribute to the radiation dose in long term behavior of radionuclides in soil. Health hazards associated with natural radioactivity are of great concern and it is necessary to assess risk due to them. The most common radionuclides found are ^{238}U, ^{232}Th and ^{40}K. ***Materials and Methods*:** The activity concentration of natural radionuclides in the soil samples collected from South Konkan region of Maharashtra, India were analyzed using HPGe based gamma spectrometry. ***Results*:** The activity concentrations from the selected villages are found to be ranging from 24.78 ± 0.14 to 76.38 ± 0.31Bq kg^{-1} for ^{238}U, 30.08 ± 0.14 to 96.18 ± 31Bq kg^{-1} for ^{232}Th and 105.34 ± 0.24Bq kg^{-1} to 432.51 ± 0.48Bq kg^{-1} for ^{40}K. The average absorbed dose rate in air was calculated as 66.89nGy h^{-1}.The annual effective dose rates were varied from 0.27mSv y^{-1} to 0.85mSv y^{-1} with an average of 0.49mSv y^{-1}. The mean radium equivalent activity value for soil samples of South Konkan was 144.84 Bq kg^{-1} which is lower than 370Bqkg^{-1} of world average. ***Conclusion*:** It is observed that the study area is free from hazards of Radium and its progeny nuclides like Radon. The external hazard index for all soil samples from South Konkan was lower than unity denoting that the villages from this study area are safe for human health.

Keywords: *Absorbed dose rate, annual effective dose, radium equivalent activity, terrestrial radioactivity, gamma spectrometry, South Konkan.*

INTRODUCTION

Knowledge of natural radionuclides concentration levels in soil and their distribution in the environment is of great interest in several fields of science [(1)]. Natural radionuclides in soil are responsible for the background radiation exposure to the population. The terrestrial component of the natural background is dependent on the compositions of the soils and rocks which contain natural radionuclides. The natural radionuclides like ^{238}U, ^{232}Th and ^{40}K significantly contribute to total dose from natural sources [(2)]. Natural radioactivity levels depend on geological aspects, mainly on rocks and soil where they are found in varying concentrations [(3,4)]. According to the United Nations Scientific Committee on the Effects of Atomic Radiation, (UNSCEAR) (1993), the world mean dose from natural radiation sources of normal areas is estimated to be 2.4mSv a^{-1}, while that for all man-made sources, including medical exposure, is about 0.8mSv a^{-1} [(3,5)]. Thus 70% of the radiation dose received by human population is from natural radiation sources. Therefore, on the basis of these radiation levels it can certify that the knowledge of primordial radionuclides, such as ^{238}U, ^{232}Th, ^{40}K is an

important prerequisite for evaluation of the rate of exposure and the absorbed dose by the population [3, 6]. This information ensures radiological control, since a predominant part of the environmental radiation is found in the upper soil layer [6].

The aim of present study is to identify and determine the activity level and resulting impact on human due to terrestrial background radiation in Sindhudurg and Ratnagiri district of South Konkan, Maharashtra, India as shown in figure1.

This area has a significant diversity of natural resources. Soil is also one of the significant natural resource. The soils of South Konkan are mainly of alluvial and residual types. Lateritic soil found in this area is formed in the hilly upland where the rainfall is more than 200 cm, which is rich in Fe, Al and Ti. The South Konkan comes under very high rainfall lateritic (VRL) soil zone. This zone has low to very low organic carbon content but well supplied with potassium. Soils of this zone contain adequate available Mn and Cu but are deficient in the micronutrients like B, Fe and Zn, which is a major problem in rice cultivation in these soils [7]. In South Konkan region of Maharashtra, at Jaitapur, a village belongs to Ratnagiri district, a nuclear power project (JNPP) of 9900MW is proposed to construct. As such the terrestrial radioactivity studies in this region will have some scientific value. Hence, in this study, we report the calculated absorbed dose rate in air, effective dose rate, radium equivalent activity, and external hazard index for the two districts (Ratnagiri and Sindhudurg) of South Konkan.

MATERIALS AND METHODS

Geology of the area

In the genesis of Konkan the evolution of Western Ghat has played a significant role. Due to the tectonic uplifting initiated by the collision of Indian and Eurasian plate during early tertiary has resulted in the formation of Western ghat. Konkan has evolved as the western extension of the uplifted Coenozoic plateau that was submerged under waters of the Arabian Sea. The basaltic flows and intrusive, Intertrapean and laterite cappings are common geological features of Konkan. The Precambrian granites

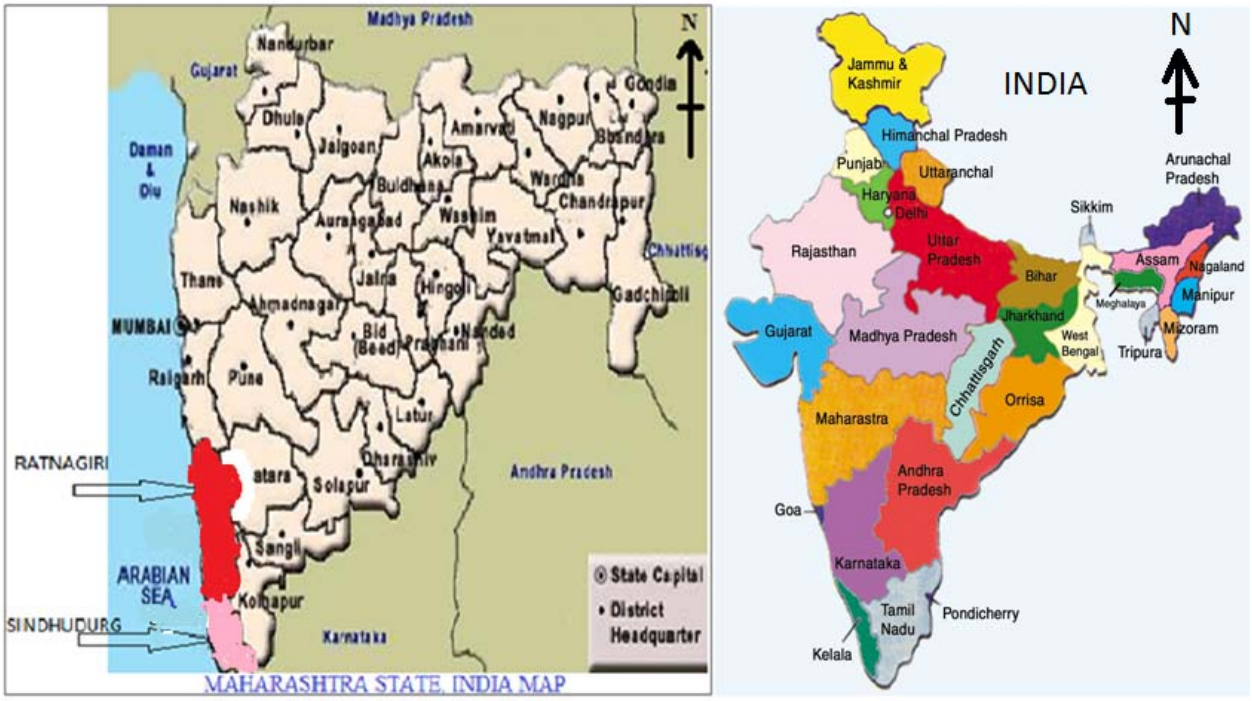

Figure 1. Study area map of South Konkan, Maharashtra, India.

and gneisses, quartzites and amphibolites are exposed in the region around Vengurla in Sindhudurg district that continues upto the Karwar (Karnataka State). The soils of Konkan are of alluvial and residual types. The soil of Konkan is lateritic in south region belongs to Sindhudurg and Ratnagiri districts which is also known as a very high rainfall lateritic soil zone and is well supplied with available potassium [7].

Sampling methodology

In order to measure terrestrial radioactivity in soil, 10 surface soil samples were collected from undisturbed sites of selected locations. These locations with GPS co-ordinates are given in table 1.

Around 1 kg soil sample was collected from each sample site and stones, organic matter were removed. The samples were then dried by placing them in an oven at 110ºC for 24 hours then crushed to pass through 70 mesh sieve to be homogenized in size. The homogenized soil samples were sealed in plastic containers and left for at least one month, before gamma spectrometric analysis, to attain secular equilibrium between radon and its decay products [8-10].

Measurement of radioactivity

The natural radioactivity of soil depends upon soil formation as well as transport processes that were involved since soil formation; chemical and biochemical interactions influence the distribution patterns of uranium, thorium and their decay products [11]. Gamma ray spectrometry analysis of the soil samples for natural radioactivity was carried out by using a coaxial high purity germanium (HPGe) detector. The concentration of natural radionuclide in these samples was determined from the peaks at 238 keV (^{212}Pb) and 911 keV (^{228}Ac) for ^{232}Th, the peaks at 351 keV (^{214}Pb) and 609 keV (^{214}Bi) for the ^{238}U and the peak at 1460 keV for ^{40}K [2]. The activity of ^{238}U, ^{232}Th and ^{40}K was calculated using following relation:

$$Q(Bqkg^{-1}) = CPS \times \frac{100}{E} \times \frac{100}{A} \qquad (1)$$

Q = Activity due to radionuclide
CPS = Area Counts/Time under photo peak after subtracting the background.
A= % gamma abundance of radionuclide.
E= Counting efficiency in % .
W= Weight of the sample in kg.

Table 1. Name and GPS Co-ordinates of the selected villages of Ratnagiri and Sindhudurg District, South Konkan, Maharashtra, India.

Location No.	Location Name	GPS Co-ordinates
1	Thakurwadi	N 16^{0}30.553’ Eo73^{0}22.315’
2	Dale	N 16^{0}37.119’ Eo73^{0}22.459
3	Devgarh	N 16^{0}23.054’ Eo73^{0}23.758’
4	Hurshi	N 16^{0}28.689’ Eo 73^{0}21.592
5	Bhalawali	N 16^{0}43.404’ Eo73^{0}24.397’
6	Kuveshi	N16^{0}36.140’ Eo73^{0}21.517’
7	Mithgawane	N 16^{0}35.076’ Eo73^{0}22.390’
8	Rajapur	N 16^{0}39.025’ Eo73^{0}30.676’
9	Jaitapur	N 16^{0}37.601’ Eo73^{0}22.000’
10	Nadan	N 16^{0}26.519’ Eo73^{0}24.892’

RESULTS AND DISCUSSION

Table 2 shows the activity concentrations of the main natural radionuclides of the U series, Th series and ^{40}K in the soil samples and total contribution of these radionuclides to the exposure rate at 1m above the ground in selected 10 villages of South Konkan.

From the table 2, it is observed that, for the ^{238}U series activity concentration, the results ranged from 24.78±0.14 to 76.38±0.31 Bq kg^{-1} with an average of 44.76±0.20 Bq kg^{-1}. For the ^{232}Th series results ranged from30.08±0.14 to 96.18±0.31 Bq kg^{-1} having average of 59.42±0.21 Bq kg^{-1} and ^{40}K activity concentration values ranged from 105.34±0.24 to 432.51±0.48 Bqkg^{-1}. Average activity concentrations of present study area, activity for ^{238}U and ^{232}Th are higher than world average value of 40Bqkg^{-1} for ^{238}U and ^{232}Th while average of ^{40}K concentration occurs low when compared with world average of 370 Bq kg^{-1} [12], but shows higher activity than the world average in Hurshi village of Sindhudurg district. The highest activity concentration for all these three natural nuclides was found in Hurshi village. The Hurshi village belongs to Sindhudurg District. The soils of this district are mainly of alluvial, lateritic and quartzite type and it also contains Precambrian granites and gneisses. External exposure to gamma radiation for outdoors mainly caused due to occurrence of terrestrial radionuclides at trace levels in all ground formations. Therefore, the natural environmental radiation mainly depends on the geological and geographical conditions of corresponding locations [13]. Higher level of radiation is associated with igneous rocks, such as granite, and lower level with sedimentary rock. However some shales and phosphate rocks show relatively high content of radionuclides [12]. Granite occurs in great batholiths which are the most abundant plutonic rocks of mountain belts and continental shield areas. They may occupy thousands of kilometers and are usually associated with quartz monzonite, granodiorite, diorite and gabbro and mainly consist of coarse grains of quartz, potassium feldspar and sodium feldspar. Granites also contain some common minerals like mica and hornblende. Granites are chemically composed of 75% silica, 12% aluminium, less than 5% soda, as well as lime, iron, magnesia and titania in smaller quantities [14]. The Granites show natural radioactivity and exhibit an enhanced elemental concentration of Uranium (U) and Thorium (Th) compared to the very low abundance of these elements observed in the course of partial melting and fractional crystallization of magma, which enables U and Th to be concentrated in the liquid phase and become incorporated into the more silica-rich products. Because of this reason, igneous rocks of granitic composition are strongly enriched in U and Th (on an average 5 ppm of U and 15 ppm of Th, compared to rocks of basaltic or ultramafic composition (< 1 ppm of U) [15-17]. As Sindhudurg districts soil contains granites and gneisses the Hurshi village shows such a highest radioactivity.

Table 2. Activity Concentrations of natural nuclides for soil sample.

Sr. No.	Name	Activity of Uranium (U-238) Bq/kg	Actvity of Thorium (Th-232) Bq/kg	Activity of Potassium (K-40) Bq/kg
1	Thakurwadi	40.75±0.18	64.54±0.20	128.34±0.26
2	Dale	24.78±0.14	30.08±0.14	159.23±0.27
3	Devgarh	48.75±0.25	66.21±0.26	191.15±0.38
4	Hurshi	76.38±0.31	96.18±0.31	432.51±0.48
5	Bhalawali	39.61±0.17	55.55±0.19	134.15±0.25
6	Kuveshi	49.56±0.19	62.33±0.19	205.52±0.28
7	Mithgawane	57.3±0.23	65.12±0.22	269.88±0.34
8	Rajapur	28.47±0.16	37.63±0.17	146.48±0.29
9	Jaitapur	39.69±0.16	56.75±0.18	105.34±0.24
10	Nadan	42.34±0.17	59.78±0.19	190.47±0.27
	MEAN	44.76±0.20	59.42±0.21	196.31±0.31

Radiation hazard indices

Table 3 shows the calculated absorbed dose rate in air, annual effective dose, radium equivalent activity and external hazard index for soil samples collected from selected ten villages of Sindhudurg and Ratnagiri district of South Konkan, India.

Absorbed dose rate in air (D)

It has been found that the contribution of natural radionuclide to the absorbed dose rate in air depends on the concentration of the radionuclide in soil. It is also observed that greatest part of the gamma radiation comes from terrestrial radionuclide. Terrestrial gamma radiation is directly connected with radionuclide concentrations in soil. If a radionuclide activity concentration in soil is known then its exposure dose rate in air can be found. The conversion factors for ^{238}U, ^{232}Th and ^{40}K are 0.427, 0.662 and 0.043nGy h^{-1} per Bq kg^{-1}, respectively. The absorbed dose rate in air due to terrestrial gamma radiation can be calculated using the following formula:

$$D\ (nGy\ h^{-1}) = 0.427C_U + 0.662C_{Th} + 0.043C_K \quad (2)$$

Where D denotes the dose rate at 1m above the ground, C_U, C_{Th} and C_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively, in the soil sample[2, 18]. Table 2 shows the lowest absorbed dose rate in air was 37.34nGy h^{-1} depicted by the Dale village belongs to Ratnagiri district and the highest was 114.88nGy h^{-1} depicted by Hurshi village belongs to Sindhudurg District. The maximum value shown by Hurshi village was compared with world average of 57nGy h^{-1} [12] and this value found to be higher than the worldwide value whereas minimum value shown by the Dale village is within limit.

Radium equivalent activity (Ra_{eq})

Radium Equivalent Activity was calculated to assess the hazards associated with materials that contain ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg [19, 20]. this was calculated using following equation 3:

$$Ra_{eq} = (Q_K \times 0.077) + (Q_U) + (Q_{Th} \times 1.43) \quad (3)$$

According to the world average, maximal admissible value for Ra_{eq} is 370Bq kg^{-1}[12]. From the present study, it is observed that all the villages show lower Ra_{eq} than the world average.

External hazard index (H_{ex})

External Hazard Index was calculated for an evaluation of the hazard of the natural gamma radiation. It was calculated using equation 4:

$$H_{ex} = Q_U/370 + Q_{Th}/259 + Q_K/4810 \leq 1 \quad (4)$$

All ten villages show external hazard index of soil samples below unity which denotes that these villages are safe for human health [21].

Table 3. Absorbed dose rate in air, annual effective dose, radium equivalent activity and external hazard index for soil samples.

Sr. No.	Name	Absorbed dose rate in air nGy/h	Annual Effective Dose Rate mSv/y	Radium equivalent activity Bq/kg	External Hazard Index
1	Thakurwadi	65.64	0.40	142.92	0.39
2	Dale	37.34	0.23	80.06	0.22
3	Devgarh	72.87	0.45	158.15	0.43
4	Hurshi	114.88	0.70	247.22	0.67
5	Bhalawali	59.46	0.36	129.38	0.35
6	Kuveshi	71.26	0.44	154.52	0.42
7	Mithgawane	79.18	0.49	171.20	0.46
8	Rajapur	43.37	0.27	93.56	0.25
9	Jaitapur	59.05	0.36	128.95	0.35
10	Nadan	65.84	0.40	142.49	0.38
	MEAN	66.89	0.41	144.84	0.39

Annual effective dose rate (E)

In order to estimate the annual effective dose rate, account must be taken of (a) the conversion coefficient from absorbed dose in air to effective dose and (b) the outdoor occupancy factor. Using the absorbed dose rate in air data obtained from the concentration values of natural radionuclide in soil, and adopting the conversion factor from the absorbed dose rate in air to the effective dose (0.7 Sv Gy^{-1}) proposed by UNSCEAR [12], the annual effective dose rate was calculated from the following formula [1, 12, 21]:

$$E_{air} = TQD_{air} \times 10^{-6} \qquad (5)$$

where D_{air} is the absorbed dose rate in air, Q the conversion coefficient and T the time in hours for 1 y, i.e. 8760 h. The results are presented in table 3. From this table it was found that the maximum annual effective dose rate as 0.70 mSv y^{-1} and minimum of 0.23mSv y^{-1}. The average of annual effective dose rate was found to be 0.49mSv y^{-1}. From all these readings it was oberved that the annual effective dose for Hurshi village was found to be higher than the worlwide value i.e. 0.46 mSv y-1 while the average of annual effective dose for all the villages and the minimum value shown by the Dale village was found to be lower than the world average value [12]. The annual effective dose values of present study are compared with previous studies carried out in other countries and in India. Table 4 depicts the comparison of present study annual effective dose rate values with other studies conducted world-wide.

The figure 2 shows the correlation between ^{238}U and ^{232}Th specific activity in soils of selected locations from South Konkan, India. The correlation between ^{238}U and ^{232}Th specific activity is weak with correlation coefficient of 0.95.

CONCLUSION

The present study has presented the results of measuring the activity concentrations of terrestrial gamma emitter for radionuclides for

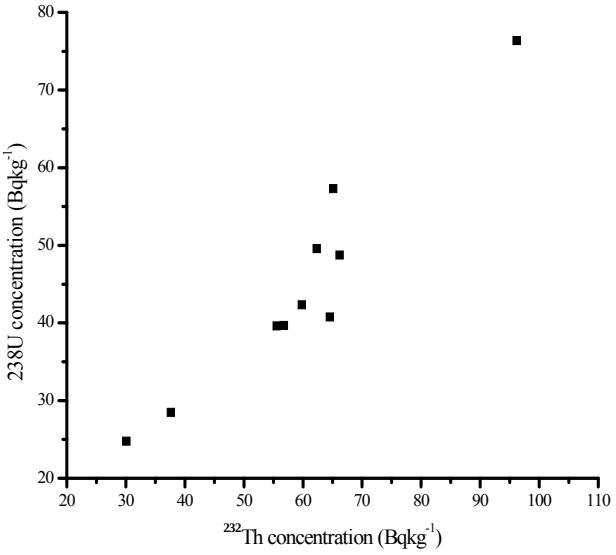

Figure 2. Correlation between ^{238}U and ^{232}Th specific activity in soils of selected locations.

Table 4. Comparison of annual effective dose rate (uSv/y) obtained in the present study with those from other studies conducted world-wide.

Sr.No.	Region	Annual Effective dose rate (uSv/y)	Reference
1	South Konkan(India)	230-700	Present study
2	AANH(Jordan)	40-151	J. Al – jundi *et al.* (2003) [22]
3	Nigeria	32-284	Jibiri (2001) [23]
4	Russiafa City (Jordan)	50-290	Al-Jundi(2002) [24]
5	Rio Grande do Norte (Brazil)	117-1361	Malanca *et al.*(1996)[25]
6	Nile Delta (Egypt)	9-117	Ibrahim *et al.* (1993)[10]
7	Istanbul(Turkey)	Average 80	Karahan and Bayulken (2000)[2]
8	Namibia	110-220	Steinhausler and Lettner(1992)[26]
9	Kalpakkam (India)	29-681	Kannan *et al.*(2002)[6]
10	Taif governorate(Saudi Arabia)	30-50	A. El- Aydarous(2007)[1]

soil samples of selected villages from South Konkan, India. The results obtained from the study area have activity concentrations ranging from 24.78±0.14 to 76.38±0.31 Bq kg^{-1} for ^{238}U, 30.08±0.14 to 96.18±31 Bq kg^{-1} for ^{232}Th and 105.34±0.24 Bq kg^{-1} to 432.51±0.48 Bq kg^{-1} for ^{40}K. The values of absorbed dose rates in air of soil samples range from 37.34 to 114.88nGy h^{-1} with a mean value of 66.89 nGy h^{-1}. The annual effective dose rates varied from 0.27mSv y^{-1} to 0.85mSv y^{-1} with an average of 0.49mSv y^{-1}. This baseline level of 0.49mSv y^{-1} is below recommended limit of 1mSvy^{-1} by International commission on radiological protection (ICRP) for the public and this value indicates the South Konkan area of India has a normal value of terrestrial background radiation. The radium equivalent activity values for soil samples of South Konkan varied from 80.06-247.22 Bq kg^{-1} with a mean value of 144.84 Bq kg^{-1} which is lower than 370 Bq kg^{-1} of world average UNSCEAR 2000 [12], indicates that this study area is free from hazards of Radium and its progeny nuclides like Radon. The external hazard index for all soil samples from South Konkan is lower than unity denotes that the villages from South Konkan, India are safe for human health.

ACKNOWLEDGEMENT

The authors are very much thankful to DAE-BRNS for financial assistance and to Dr M. P. Chougaonkar, RP &AD division, BARC, for his valuable scientific guidance. The authors are also grateful to Dr D. Rao from BARC, for his technical help. They are also thankful to research fellows from Center for Interdisciplinary Research, for their co-operation.

REFERENCES

1. El-Aydarous A (2007) Gamma Radioactivity levels and Their Corresponding External Exposure of Some Soil Samples from taif Governorate, Saudi Arabia. *Global journal of Environmental Research,**1-2:**49-53.*
2. Karahan G and Bayulken A (2000) Assessment of gamma dose rates around Istanbul (Turkey). *Journal of Environmental Radioactivity, 47213-221.*
3. Jose Araujo dos Santos Junior, Jorge Joao Ricardo Ferreira Cardoso, Cleomacio, Miguel da Silva, Sueldo Vita Silveira and Romilton dos Santos Amaral (2005) Analysis of the 40K levels in Soil using Gamma Spectrometry. *Brazilian Archives of Biology and technology, 48221-228.*
4. Tzortzis M and Tsertos H (2004) Determination of thorium, uranium and potassium elemental concentrations in surface soils in Cyprus. *Journal of Environmental Radioactivity, **27:** 325-338.*
5. Ghiassi-Nejad M, Beitollahi MM, Fallahian N, Amidi J, Ramezani H (2001) Concentrations of natural radionuclides in imported mineral substances. *Environment International, **26:** 557-560.*
6. Kannan V, Rajan MP, Iyengar MAR, Ramesh R (2002) Distribution of natural and antropogenia radionuclides in soil and beach sand samples of Kalpakkam(India) using hyper pure germanium (HPGe) gamma ray spectrometry. *Applied Radiation and Isotopes, 57: 109-119.*
7. Mahesh Shindikar (2006) Ecological studies on Mangoves of Maharashtra coast. *An unpublished dissertation submitted to University of Pune, 189 p.*
8. Ramli AT (2009) Assessment of Radiation Dose Rates in the High terrestrial Gamma Radiation Area of Selama District, Perak, Malaysia. *Applied Physics Research, **1:** 45-52.*
9. Mollah S, rahman NM, Kodlus MA, Husain SR (1987) Measurement of high natural background radiation level by TLd at Cox and Bazar coastal areas in Bangaladesh. *Journal of radiation Protection Dosimetry, 1839-41.*
10. Ibrahim NM, Abd El Ghani, AH, Shawky EM, Ashraf EM, Farouk MA (1993) Measurement of radioactivity levels in soils in the Nile delta and middle Egypt. *Journal of Health physics, **64:** 620-627.*
11. Myrick TE, Berven BA, Haywood FF (1983) Determination of concentrations of selected radionuclides in surface soil in the US. *Health Physics, **45/3:** 631-642.*
12. United Nations Scientific Committee on the Effects of Atomic Radiation (2000) Annex B. Exposures from natural radiation sources (New York: USA)
13. Florou H and Kritidis P (1992) Gamma Radiation Measurements and Dose Rate in the Coastal Areas of a Volcanic Island, Aegean Sea, Greece. *Radiat Prot Dosimetry, **45(1-4):** 277-279.*
14. Snelling A and Woodmorappe J (1998) Rapid Rocks – Granites… they didn't need millions of years of cooling. *Creation Ex Nihilo, **21:** 37-39.*
15. Faure G (1986) Principles of Isotope Geology. John Wiley & Sons; 2nd edition. ISBN: 0471864129.
16. Mınager MT, Heath MJ, Ivanovich M, Montjotin C, Barillon CR, Camp J, Hasler SE (1993) Migration of uranium from uranium-mineralized fractures into the rock matrix in granite: implications for radionuclide transport around a radioactivewaste repository. 4th International Conference of Chemistry and Migration Behaviourof Actinides and Fission Products in the Geosphere (Migration 1993), Charleston,

USA, 12-17 December 1993. *Radiochimica Acta, 66/67 47-83.*

17. Tzortzis Michalis and Tsertos Haralabos (2003) Gamma radiation measurements and dose rates in commercially used natural tiling rocks (granites), UCY-PHY-02/03, Physics/0212104.
18. Beck HL (1972) The physics of environmental radiation fields. Natural radiation environment II, CONF-720805P2. *Proceedings of the Second International Symposium on the Natural Radiation Environment.*
19. Al-Sulaiti HA, Regan PH, Bradley DA, Matthews M, Santawamaitre T, Malain D (2008) Preliminary Determination of Natural Radioactivity levels of the state of Qatar using High- Resolution Gamma ray Spectrometry. *IX Radiation Physics and Protection Conference, 15-19* Nasr City- Cairo, Egypt.
20. Bereka J and Mathew PJ (1985) Natural radioactivity of Australian building materials, industrial wastes and by-products. *Health Phys,* ***48:*** *87-95.*
21. Jabbar A, Arshed W, Arshad SB, Syed SA, Muhammad D (2010) Measurement of soil radioactivity levels and radiation hazard assessment in mid Rechana interfluvial region, *Pakistan J Radioanal Nucl Chem,* ***283:*** *371-378.*
22. Al-Jundi J (2003) Natural radioactivity concentrations in soil samples along the Amman Aqaba Highway. *Jordan Radiat Meas,* ***36:*** *555-560.*
23. Jibiri NN (2001) Assessment of health risk levels associated with terrestrial gamma radiation dose rates in Nigeria. *Environ int,* ***27:*** *21-26.*
24. Al- Jundi J (2002) Population doses from terrestrial gamma exposure in areas near to old phosphate mine, Russiafa, *Jordan Radiat Meas,* ***35:*** *23-28.*
25. Malanca A, Gaidolfi L, Pessina V, Dallara G (1996) Distribution of ^{226}Ra, ^{232}Th, and ^{40}K of Rio Grande do Norte (Brazil). *J Environ Radioact,* ***30:*** *55-67.*
26. Steinhausler F and Lettner H (1992) Radiometric survey in Namibia. *Radiat Protect Dosim,* ***45(1/4):*** *553-555.*