Natural radioactivity and hazardous index of major South Indian river sediments

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Abstract: The activity concentrations of ^{238}U, ^{232}Th and ^{40}K have been determined by gamma ray spectrometry with an NaI(Tl) detector in sediments of Palar River, Tamil Nadu, India. The absorbed dose rate, radium equivalent concentration, external (H_{ex}) and internal (H_{in}) hazardous indices are calculated from criteria formula and compared with the international recommended limits. The Radioactive Heat Production (RHP) rate and Excess Lifetime Cancer Risk (ELCR) are also calculated. The observed dose rate from ERDM (Environmental Radiation Dosimeter) at 1 m above the ground level at each site of the river is measured and correlated with calculated absorbed dose rate. The distribution of quartz, feldspar, magnetic susceptibility and weight of the magnetic minerals is correlated with radioactivity results. From the observations, the weight of the magnetic minerals is an index to identify the sediments of low or high radiological risk.

Keywords: sediments; Palar River; RHP; radioactive heat production rate; ELCR; excess lifetime cancer risk; quartz; magnetic susceptibility.

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1 Introduction

Radiation of natural origin at the earth's surface consists of two components, namely cosmic rays and radiation from the radioactive nuclides in the earth's crust. The latter component, terrestrial radiation, mainly originates from primordial radioactive nuclides that were made in the early stage of the formation of solar system. Uranium, thorium and potassium are, however, the main elements contributing to natural terrestrial radioactivity (UNSCEAR, 2000). Studies of terrestrial natural radiation are of great importance for several reasons (Al-Jundi, 2002).

Animals and human receive natural background radiation doses from cosmic rays, gamma rays arising from rocks and soil, inhalation of radon gas, ingestion of radionuclides with food, water, and soil. Animals often receive higher doses than human because they ingest more soil or sediment with food items, which raises their body burden of radionuclides. In addition, they live outdoors, which increases their exposure to cosmic rays and terrestrial gamma radiation. The radiological implication of the above nuclides is due to radiation exposure of the body by gamma rays and irradiation of lung tissue from inhalation of radon and its daughters. Therefore, the assessment of gamma radiation doses from natural sources is of particular importance as natural radiation is the largest contributor to the external dose of the world population (UNSCEAR, 1988).

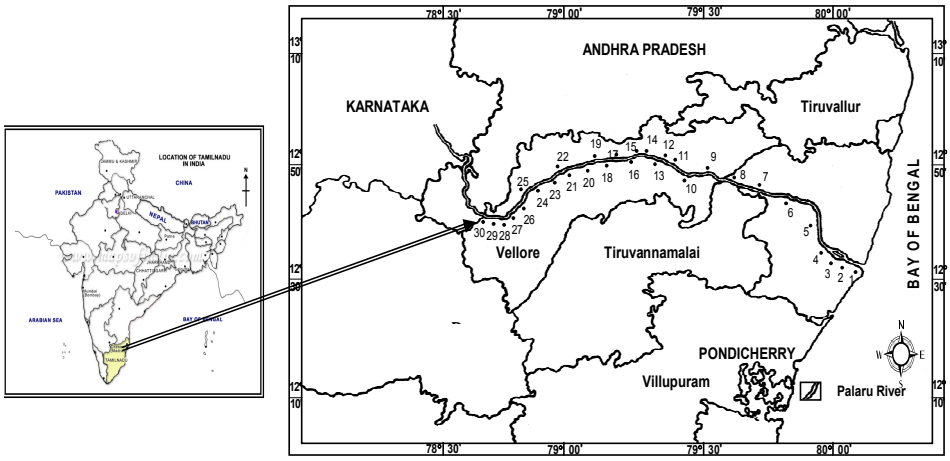
Measurements of activity concentration due to gamma rays from these materials and consequently the determination of dose rate are needed to implement precautionary measures whenever the dose is found to be above the recommended limits. The present investigation is focused on river sediments, as river sediments are normally used as a main material in all types of constructions. Thus, the aim of this study is to determine the activity concentrations, absorbed and observed dose rates, radium equivalent activities (Raeq), hazard indices and Radioactive Heat Production (RHP) rate and Excess Lifetime Cancer Risk (ELCR) in Palar River sediments of Tamil Nadu, India. An attempt has also been made to find out the relation of magnetic susceptibility and weight of the magnetic particles with activity concentration measurements, absorbed dose rate and distribution of quartz and feldspar.

The Palar River starts from Talagavana village in Kolar of Karnataka, which is placed at the height of 900 metres above the sea level. It covers Karnataka, Andhra Pradesh and Tamil Nadu having the total length of 600 km and finally merges with the Bay of Bengal. In the present investigation, the study area covers a distance of 450 km from Sadras to Kanaganachiamman koil.

2 Materials and methods

Figure 1 shows the geographic location of the sampling sites. Each site is separated by a distance of 20 km approximately. At each site, a sampling area of 1 m^2 was considered from upper and lower (2-feet depth) of right, centre and left of the rivers and totally six wet samples were taken for analysis. Each sample weighs about 2 kg. Then the sample was dried in an oven at 100–110°C for about 24 hrs and sieved through a 2-mm mesh to remove stone, pebbles and other macro-impurities. The homogenised sample was placed in a 250 ml airtight PVC container. The inner lid was placed in and closed tightly with outer cap. The container was sealed hermitically and externally using cellophane tape and kept aside for about a month to ensure equilibrium between Ra and its daughter products before being taken for gamma ray spectrometric analysis.

Figure 1 Location of Palar River in Tamil Nadu, India



Activity concentration determination involves measurements of either alpha or beta or gamma radiations from the samples. Owing to the inherent properties of the gamma rays like high penetrating power and the interaction process with matter, the measurement of γ radiation offers useful information than that of α and β radiations. The activity concentrations of primordial radionuclides (^{238}U, ^{232}Th and ^{40}K) in the samples were determined by employing NaI(Tl) gamma ray spectrometer system consisting of coaxial detector (type: 1GC 30; Volume 133cc; PGT make) mounted vertically and coupled to a 4K multichannel analyser (ORTEC MODEL 7450). The detector was housed inside a massive lead shield to reduce the background of the system. It was calibrated using a standard solution of ^{226}Ra in equilibrium with its daughters (obtained from NBS, USA), mixed with simulated soil matrix and counted in the same geometry as that of the soil samples. Three IAEA standard reference materials (a standard soil of known radioactivity-soil-6, a uranium ore sample – RGU1 and a thorium ore sample – RGTh 1) were also used for checking the calibration of the system. The energy resolution of 2.0 keV and relative efficiency of 33% at 1.33 MeV were achieved in the system.

Each sample, after the equilibrium, is kept on top of the NaI(Tl) detector and counted for period of 10,000 s. The activity concentration of ^{238}U was evaluated from the gamma ray 609 keV of ^{214}Bi peak, while 911-keV gamma line of ^{228}Ac peak was used to

determine ^{232}Th, and ^{40}K activity concentration was determined from ^{40}K peak at 1461 keV. The activity concentration of each radionuclide in the sample was determined using the total net counts under the selected photo peaks after subtracting appropriate background counts, and applying appropriate factors for photo peak efficiency, gamma intensity of the radionuclide and weight of the sample. The analysis of the gamma spectra obtained was performed using the dedicated software Microsoft Excel. At each sampling site the ambient gamma radiation level was measured using a digital Environmental Radiation Dosimeter (ERDM) which comprised NaI (1.75" × 2") detector (ECIL brand – SM-141D) with a reading range of 1–10,000 nGy h^{-1}. The ERDM is calibrated regularly before starting the survey using standard sources ^{137}Cs and ^{60}Co. The ERDM readings are recorded at 1 m above ground level. Five readings are taken at each site and the average was recorded.

To record the IR spectra, the samples were ground in acetone to a particle size of 53 μm with small agate balls in an agate vial and kept at 4°C to prevent heating and structural changes. The KBr pressed disc technique is used. The powder is then mixed with KBr in agate mortar with 1:20 ratio. A 35-mg pellet, 13 mm in diameter, is pressed into vacuum disc with up to 5 tonnes/cm^2 of compression. Discs are heated in a furnace at 150°C to minimise the amount of absorbed water. Using Nicolate Avatar, 360 series FTIR spectrophotometer, the IR spectra of all the samples are recorded in the region 4000–400 cm^{-1}. The resolution of the instrument is 2 cm^{-1}.

Magnetic susceptibility measurements were carried out using a magnetic susceptibility meter MS2, Bartington Instruments Ltd, linked to MS2B dual frequency sensor (470 and 4700 Hz). The dried river sediments sampled with paleomagnetic plastic boxes (8 cm^3) were placed in a magnetic field of 100 mT, which is produced by partial ARM device attached to a shielded demagnetiser, Molspin Ltd. The weight of the magnetic minerals was separated from 20 g using an electromagnet to demonstrate its relationship with magnetic susceptibility and radioactivity.

3 Results and discussion

3.1 Activity concentration of primordial radionuclides

The activity concentration of the radionuclides ^{238}U, ^{232}Th and ^{40}K in Bq kg^{-1}, corresponding absorbed dose rates in nGy h^{-1}, and annual effective equivalent dose in μSvy^{-1} are tabulated in Table 1.

As listed in Table 1, the activity concentrations are ranged from 5.64 ± 0.4 to 18.44 ± 0.4 Bq kg^{-1} with a mean value of 9.81 ± 0.3 Bq kg^{-1}, 6.13 ± 1.2 to 254.06 ± 5.6 Bq kg^{-1} with a mean value of 36.49 ± 2.4 Bq kg^{-1} and 483.49 ± 24.3 to 884.78 ± 28.2 Bq kg^{-1} with a mean value of 742.46 ± 26.5 Bq kg^{-1} for ^{238}U, ^{232}Th and ^{40}K, respectively, and are shown in Figure 2. Comparatively similar range of activity concentrations is observed by many authors as listed in Table 2 (Kannan et al., 2002; Vijayan and Behera, 1999; Selvasekarapandian et al., 1999a; Selvasekarapandian et al., 1999b; Selvasekarapandian et al., 2000; Verma et al., 1998; Radhakrishna et al., 1993) in soil with an exception of beach sand samples, where observed values are significantly higher (Kannan et al., 2002; Radhakrishna et al., 1993). In the present study, the activity concentrations are almost lower than in other countries, like China, Greece, France and Bangladesh (Table 3), except site no. 7.

Table 1 The activity concentration, calculated absorbed dose rates, observed dose rates and the annual effective equivalent dose

S. no.	Location	Latitude	Longitude	U Bq kg^{-1}	Th Bq kg^{-1}	K Bq kg^{-1}	Absorbed dose rate nGy h^{-1}	Observed dose rate nGy h^{-1}	Annual effective equivalent dose μSvy^{-1}	
									indoor	outdoor
1	Sadras	12°31′60 N	80°09′60 E	9.06 ± 0.3	11.14 ± 1.4	542.08 ± 24.6	34.12 ± 3.5	75	167.37 ± 4.3	41.84 ± 2.1
2	Paandoor	12°58′60 N	79°58′00 E	9.86 ± 0.4	32.79 ± 2.3	584.52 ± 25.3	49.77 ± 4.4	110	244.17 ± 5.1	61.04 ± 2.6
3	Paalur	12°55′60 N	79°40′00 E	12.45 ± 0.4	53.85 ± 3.2	668.23 ± 26.2	67.60 ± 5.2	150	331.61 ± 5.8	82.90 ± 3.2
4	Maduranthagam	12°46′00 N	79°31′60 E	10.14 ± 0.3	24.36 ± 2.6	697.12 ± 29.1	49.48 ± 4.6	90	242.74 ± 4.8	60.68 ± 2.8
5	Chengalpattu	12°42′60 N	80°01′00 E	8.86 ± 0.2	7.29 ± 1.1	707.13 ± 30.2	38.73 ± 3.9	100	190.12 ± 3.6	47.50 ± 2.4
6	Valajabath	12°55′60 N	79°22′60 E	7.65 ± 0.1	10.38 ± 1.0	824.08 ± 31.3	45.17 ± 4.3	110	221.58 ± 4.5	55.39 ± 2.8
7	Kanchipuram	12°49′60 N	79°43′00 E	17.03 ± 0.3	254.06 ± 5.6	755.31 ± 29.6	198.03 ± 8.6	350	971.45 ± 9.2	242.86 ± 4.8
8	Perumbakkam	12°50′00 N	79°36′00 E	10.05 ± 0.2	21.76 ± 2.1	873.6 ± 28.4	55.41 ± 5.2	120	271.83 ± 4.8	67.96 ± 3.2
9	Kaveripakkam	12°51′00 N	79°30′00 E	9.86 ± 0.1	33.74 ± 2.4	826.31 ± 28.6	60.76 ± 5.4	110	298.07 ± 5.2	74.52 ± 3.4
10	Pudhupadi	12°52′00 N	79°24′60 E	11.21 ± 0.2	44.16 ± 3.1	703.11 ± 26.3	62.53 ± 5.6	120	306.76 ± 4.9	76.69 ± 3.6
11	Walajapet	12°53′60 N	79°21′60 E	11.46 ± 0.2	48.78 ± 3.3	834.28 ± 28.7	71.16 ± 5.8	180	349.07 ± 4.4	87.27 ± 4.2
12	Ranipet	12°55′60 N	79°19′60 E	11.57 ± 0.2	51.98 ± 3.6	852.19 ± 28.8	73.97 ± 5.9	150	362.86 ± 5.2	90.71 ± 4.3
13	Vizharam	12°55′00 N	79°15′60 E	10.12 ± 0.1	25.14 ± 2.4	826.13 ± 29.0	55.51 ± 4.8	125	272.30 ± 2.9	68.07 ± 3.8
14	Rathnagiri	12°52′60 N	79°12′60 E	5.64 ± 0.4	20.59 ± 2.1	654.29 ± 27.3	43.37 ± 4.7	135	212.76 ± 4.6	53.19 ± 2.9
15	Sathuvancheri	12°53′60 N	79°09′00 E	7.06 ± 0.3	42.46 ± 2.8	692.36 ± 27.2	59.24 ± 5.2	105	290.60 ± 4.4	72.65 ± 3.2
16	Vellore	12°55′60 N	79°07′00 E	9.03 ± 0.2	62.52 ± 2.8	731.4 ± 26.3	74.26 ± 3.6	120	364.27 ± 3.7	91.07 ± 4.1

Table 1 The activity concentration, calculated absorbed dose rates, observed dose rates and the annual effective equivalent dose (continued)

S. no.	*Location*	*Latitude*	*Longitude*	*U* $Bq\ kg^{-1}$	*Th* $Bq\ kg^{-1}$	*K* $Bq\ kg^{-1}$	*Absorbed dose rate* $nGy\ h^{-1}$	*Observed dose rate* $nGy\ h^{-1}$	*Annual effective equivalent dose* μSvy^{-1}	
									indoor	*outdoor*
17	Melmanavur	12°55′00 N	79°04′60 E	8.52 ± 0.1	46.52 ± 2.3	698.42 ± 26.2	62.65 ± 3.4	130	307.35 ± 3.9	76.84 ± 3.6
18	Virungipuram	12°55′00 N	79°01′00 E	8.91 ± 0.1	21.15 ± 1.6	707.18 ± 28.1	47.39 ± 2.7	120	232.48 ± 2.8	58.12 ± 2.9
19	Kothikuppam	12°55′00 N	78°57′60 E	8.41 ± 0.2	18.63 ± 1.4	743.68 ± 27.8	47.18 ± 2.5	115	231.43 ± 3.4	57.86 ± 3.1
20	Pallikonda	12°55′60 N	78°55′60 E	8.67 ± 0.2	6.13 ± 1.2	756.28 ± 27.3	40.04 ± 2.3	140	196.43 ± 1.9	49.11 ± 2.8
21	Madhanoor	12°53′60 N	78°52′60 E	8.84 ± 0.3	20.89 ± 2.2	884.78 ± 28.2	54.83 ± 3.6	140	269.21 ± 2.6	67.25 ± 3.4
22	Melpatti	12°51′60 N	78°57′00 E	8.62 ± 0.2	24.68 ± 2.4	867.12 ± 27.3	56.34 ± 3.8	110	276.39 ± 3.2	69.10 ± 3.6
23	Vadapudupatti	12°42′00 N	78°48′60 E	8.96 ± 0.4	27.45 ± 2.6	796.15 ± 28.4	55.16 ± 3.2	110	270.60 ± 3.6	67.65 ± 3.5
24	Ambur	12°46′00 N	78°42′00 E	9.03 ± 0.4	33.78 ± 3.1	731.16 ± 26.3	56.34 ± 3.9	180	276.38 ± 3.9	69.10 ± 3.8
25	Jothi Veeraraghavapuram	12°44′60 N	78°40′60 E	8.75 ± 0.3	19.95 ± 2.5	779.8 ± 26.8	49.70 ± 2.7	140	243.79 ± 2.9	60.95 ± 2.9
26	Gollakuppam	12°42′00 N	78°39′60 E	8.58 ± 0.2	24.15 ± 2.3	840.63 ± 27.2	54.86 ± 3.6	125	269.10 ± 3.5	67.28 ± 3.6
27	Vaniambadi	12°40′00 N	78°37′00 E	8.93 ± 0.3	22.79 ± 2.6	821.96 ± 27.8	53.36 ± 3.9	140	261.74 ± 4.1	65.44 ± 3.4
28	Ambalur	12°38′00 N	78°35′60 E	18.44 ± 0.4	52.42 ± 3.1	483.49 ± 24.3	61.32 ± 4.2	140	300.82 ± 5.3	75.20 ± 4.1
29	Avarakuppam	12°39′60 N	78°34′60 E	9.62 ± 0.2	19.66 ± 1.8	532.67 ± 25.2	39.26 ± 3.8	110	192.60 ± 3.2	48.15 ± 2.8
30	Kanaganachiammankoil	12°37′60 N	78°33′60 E	8.83 ± 0.2	11.64 ± 1.6	858.22 ± 30.3	47.93 ± 4.1	120	235.10 ± 4.6	58.78 ± 3.3
Max				18.44 ± 0.4	254.06 ± 5.6	884.78 ± 28.2	198.03 ± 8.6	350	971.45 ± 9.2	242.86 ± 4.8
Min				5.64 ± 0.4	6.13 ± 1.2	483.49 ± 24.3	34.12 ± 3.5	75	167.37 ± 4.3	41.84 ± 2.1
Mean				9.81 ± 0.3	36.49 ± 2.4	742.46 ± 26.5	58.85 ± 4.2	132.33	288.69 ± 3.7	72.17 ± 3.4

Table 2 The mean activity concentrations (Bq kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K for different states of India

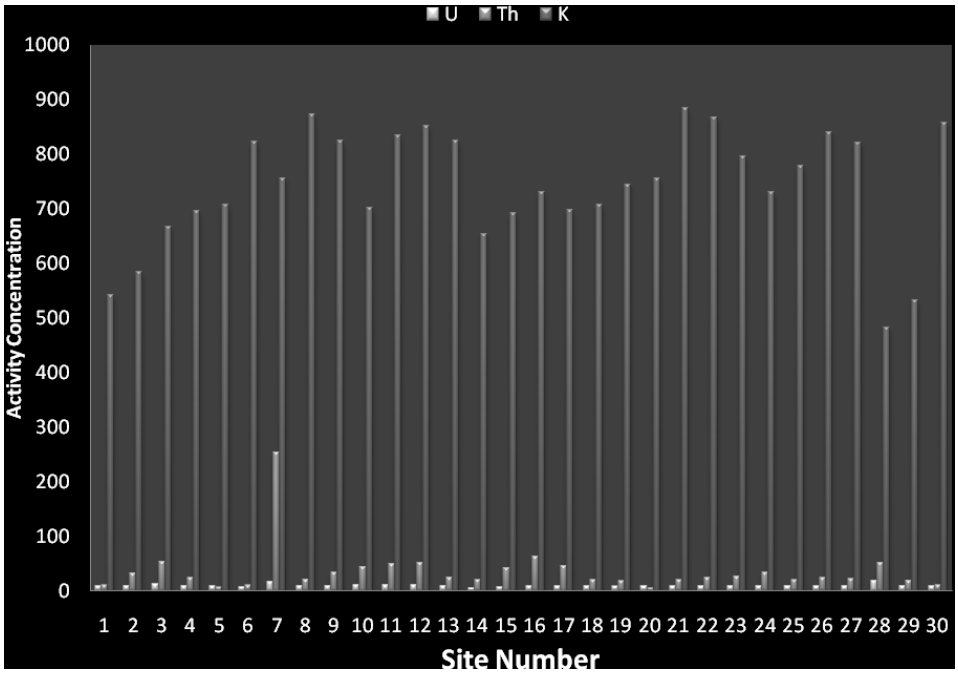
S. no.	Location	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	References
			Soil		
1	Kalpakkam, Tamil Nadu	5–71	15–776	200–854	Kannan et al. (2002)
2	Bhubaneswar, Orissa	18–30	33–80	213–247	Vijayan and Behera (1999)
3	Coonoor, Tamil Nadu	BDL-49	4–224	14–731	Selvasekarapandian et al. (1999a)
4	Gudalore, Tamil Nadu	17–62	19–272	78–596	Selvasekarapandian et al. (2000)
5	Narora, Uttar Pradesh	32–65	46–90	469–756	Verma et al. (1998)
6	Rawatbhata, Rajasthan	17–40	27–67	127–49	Verma et al. (1998)
7	Udhagamandalam, Tamil Nadu	0–88	26–226	96–444	Selvasekarapandian et al. (1999b)
8	Ullal, Karnataka	546	2971	268	Radhakrishna et al. (1993)
9	Uttar Pradesh	12–25	20–25	538–1018	Mishra and Sadasivan (1971)
			Beach sand		
10	Kalpakkam, Tamil Nadu	36–258	352–3872	324–05	Kannan et al. (2002)
11	Ullal, Karnataka	374	158	158	Radhakrishna et al. (1993)
	River sediment				
12	Cauvery river, Tamil Nadu	10.31	27.83	416.73	Murugesan et al. (2011)
13	Bharathappuzha, Kerala	41.86 (^{226}Ra)	54.86	477.75	Krishnamoorthy et al. (2014)
14	Palar River, Tamil Nadu	10.48	38.28	727.51	Present study

Table 3 The mean activity concentrations (Bq kg^{-1}) of ^{238}U, ^{232}Th, and ^{40}K for different countries in the world

S. no.	Country	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	References
1	China	62	90	524	Ziquiang et al. (1988)
2	USA	34	36	472	Delune et al. (1986)
3	Republic of Ireland	37	26	350	McAulay and Moran (1988)
4	Greece	214	43	1130	Travidon et al. (1996)
5	France	37	38	599	Lambrechts et al. (1992)
6	Bangladesh	38	66	272	Mantazul et al. (1999)
7	Taiwan	18	28	479	Chu et al. (1992)
8	Egypt	17	18	316	Ibrahiem et al. (1993)
9	Kuwait	36	6	227	Saad and Al-Azmi (2002)
10	Nigeria	16	24	35	Arogunjo et al. (2004)
11	World	35	30	400	UNSCEAR (2000)

The mean activity concentration of ^{238}U is 0.28 times lower than the international recommended limit (UNSCEAR, 2000) and 0.66 times lower than the all India average value (Mishra and Sadasivan, 1971), whereas the mean of ^{232}Th is 1.22 times and 1.99 times higher. The mean concentration of ^{40}K is 1.85 times higher than the international recommended limit. This shows that the ^{40}K dominates over ^{238}U and ^{232}Th, which is what normally happens in soil.

Figure 2 Graph of activity concentration for different locations



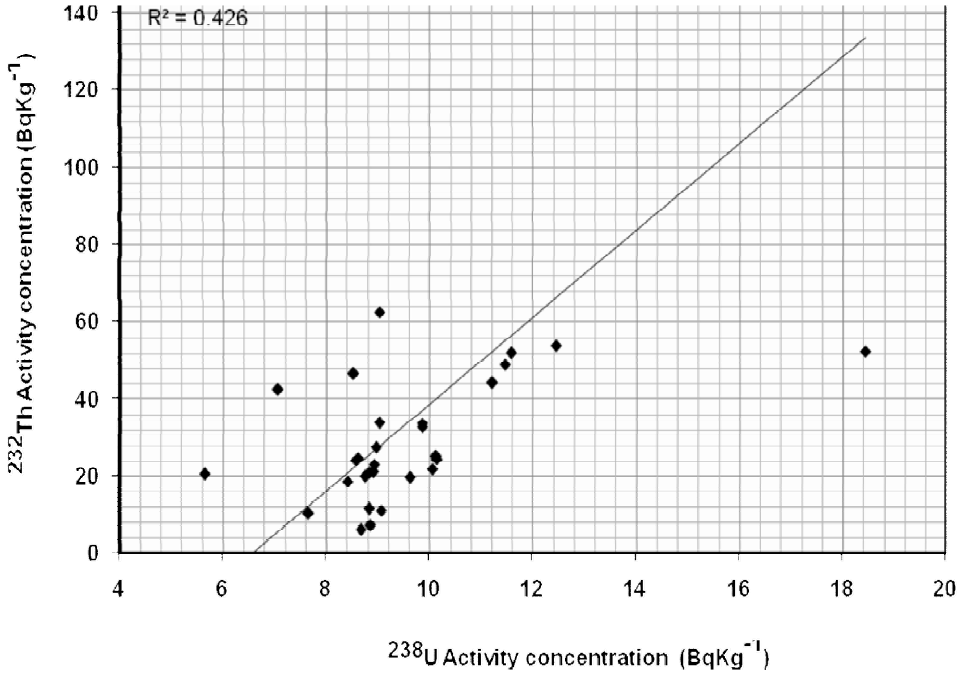
3.2 Correlation between activity concentrations

The correlation between ^{238}U and ^{232}Th is found to be weak ($R^2 = 0.426$) which indicates that the presence of monazite mineral is less likely (Figure 3). The values are almost less than unity, because ^{232}Th activities are usually greater than ^{238}U activities in the crust, which is the origin of the river. This implies that relative mobility of uranium (largely dissolved) and thorium (largely particulated) depends upon prevailing hydrological region. The adsorption of uranium by clay minerals, insoluble oxides, oxihydroxides and organic matters may be due to leaching of sediments from weathering, erosion and transport in the surfacial environments. Uranium is quite soluble in oxidising natural waters, whereas thorium is much less soluble.

According to Abdelhady et al. (1994), the $^{40}K/^{232}Th$ ratio has a special significance and varies with clay mineral type, because the concentrations of ^{40}K and ^{232}Th depend upon the relative amounts of the feldspars, mica and clay minerals. During the weathering process, ^{232}Th and ^{40}K react differently. ^{40}K is more soluble and is easily carried away in water, whereas ^{232}Th tends to remain. Ratios of $^{40}K/^{232}Th$ vary considerably from feldspar (low) to kaolinite (high). In the present study, higher values

(site nos. 5, 6 and 20) of $^{40}K/^{232}Th$ may indicate the presence of feldspars or clay or combination of both as maximum. These results are confirmed by FTIR analysis. The activity ratio of $^{40}K/^{238}U$ and $^{40}K/^{232}Th$ gives no obvious trend with poor correlation.

Figure 3 Correlation between ^{238}U and ^{232}Th



3.3 Dose calculation

UNSCEAR (1988) has given the dose conversion factors for converting the activity concentrations of ^{238}U, ^{232}Th and ^{40}K into doses (nGy h^{-1} per Bq kg^{-1}) as 0.427, 0.662 and 0.043, respectively. Using these factors, the absorbed dose rate is calculated using the equation.

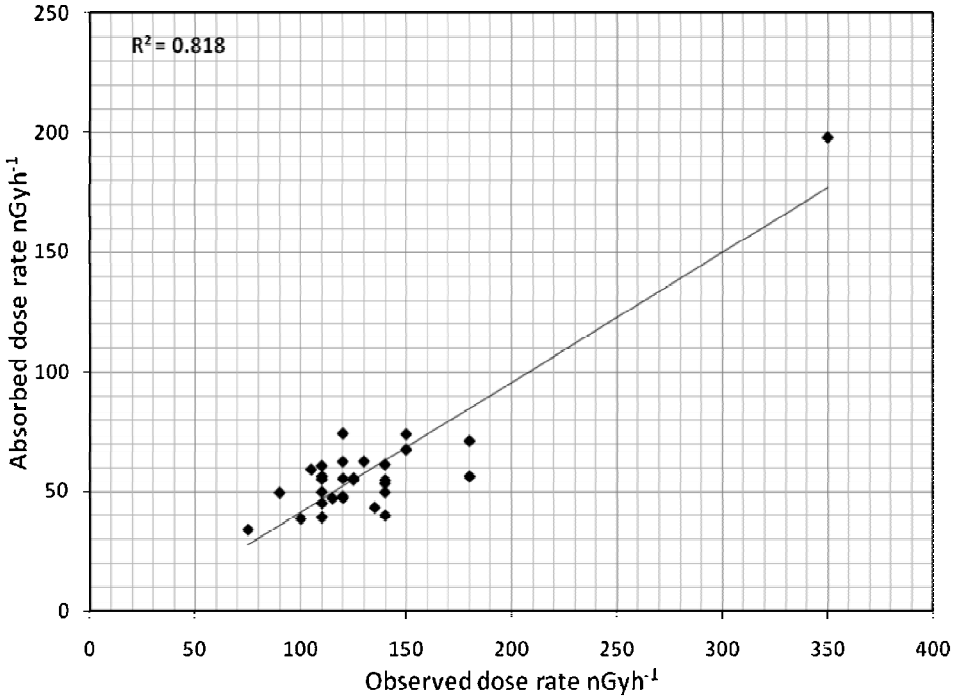
$$D = (0.427\ C_U + 0.662\ C_{Th} + 0.043\ C_K)\ \text{nGy h}^{-1},$$

where C_U, C_{Th} and C_K are the activity concentrations (Bq kg^{-1}) of uranium, thorium and potassium in sediments, respectively. The mean absorbed dose rate (58.85 ± 4.2 nGy h^{-1}) is found to be about 1.15 times higher than the international recommended limit. The contribution of the radionuclides ^{238}U, ^{232}Th and ^{40}K in nGy h^{-1} to the mean absorbed dose rate is 7.1% (4.18 nGy h^{-1}), 41.04% (24.15 nGy h^{-1}) and 54.26% (31.93 nGy h^{-1}).

In situ gamma dose rate at 1 m above the ground has also been measured using the ERDM in each location of the river and the values are tabulated in Table 1. The observed dose rates are positively correlated with calculated absorbed dose rates with strong correlation coefficient (R = 0.90) as shown in Figure 4. The ERDM dose rates (observed) are nearby two times higher than the absorbed dose rate values. This difference may be due to background contribution from cosmic rays. It is also responsible for high energy beta particles and X-rays.

In determining the annual effective equivalent dose at each location, the lifestyle of the people or outdoor occupancy factor of a location was considered. A typical resident in a location, both male and female, would spend about 8 hrs of the day in an office (or) classroom or laboratory, 12 hrs indoors and the remaining 4 hrs outdoors. This applies to the greater part of the population in a location who are either office workers or pupils/students. Hence 4/24 or 0.17 was adopted as the outdoor occupancy factor (20%) with the conversion factor of 0.70 $SvGy^{-1}$ to convert absorbed dose rate in air (nGy h^{-1}) to annual effective equivalent dose (μSvy^{-1}) for this study (Ajayi, 2002). The annual effective equivalent dose varies between 41.84 ± 2.1 μSvy^{-1} (site no. 1) and 242.86 ± 4.8 μSvy^{-1} (site no. 7) with a mean of 72.17 ± 3.4 μSvy^{-1}, which is 1.03 times higher than the international recommended limit 70 μSvy^{-1}.

Figure 4 Correlation between absorbed dose rate and observed dose rate



3.4 Radioactive hazards

3.4.1 Radium equivalent

Normally river sediments are used in building construction; so the radioactive nature of the materials is also very important. The total activity does not provide an exact indication of the radiation hazard associated with the materials. A common index is defined in terms of radium equivalent activity (Ra_{eq}) as given by the equation (Beretka and Mathew, 1985).

$$Ra_{eq} = C_U + A\ C_{Th} + B\ C_K,$$

where C_u, C_{Th} and C_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K (Bq kg^{-1}), respectively, and, A and B are constants. For the safe utilisation of materials, the annual limit on the external gamma ray dose (1.5 mSv), this corresponds to the value of 370 Bq kg^{-1} for radium equivalent.

From Table 4, it is observed that site no. 7 shows the maximum of 438.49 ± 9.2 Bq kg^{-1} and the minimum of 66.73 ± 5.6 Bq kg^{-1}(site no. 1). For the estimation of radiological consequences instead of comparing the average values, maximum value is taken into account. The maximum Ra_{eq} is slightly higher than the international recommended limit (370 Bq kg^{-1}). Rizzo et al. (2001) reported the Ra_{eq} value of sedimentary silicic sand varies from 10 to 53 Bq kg^{-1} with a mean of 34 ± 14 Bq kg^{-1}. The mean value of silicic sand is two times lower than the present study and ten times lower than the international recommended value (370 Bq kg^{-1}). In the present study, the low concentration of Ra_{eq} value may be related to the transportation of radioactive materials by weathering, sedimentation and maximum water flow due to heavy rainfall in its origin.

3.4.2 Correlation between ^{232}Th and Ra_{eq}

The linear correlation between Ra_{eq} and ^{232}Th as shown in Figure 5 may indicate that the river mouth from laterite origin. Similar findings have also been reported in literature for lateritic soil samples of Karnataka (Narayana et al., 2001; Yu-Ming et al., 1987). The Karnataka state is the origin of Palar River.

3.4.3 Hazard indices

The other quantities indicating the radiological hazards are external (H_{ex}) and internal (H_{in}) hazard indices and are defined by the following relations (Mishra and Sadasivan, S., 1971).

$$H_{ex} = C_U/370 + C_{Th}/259 + C_K/4810 \leq 1,$$

$$H_{in} = C_U/185 + C_{Th}/259 + C_K/4810 < 1,$$

where C_U, C_{Th} and C_K are the activity concentrations of U, Th and K in Bq kg^{-1}. The internal exposure to radon (^{222}Rn) and its decay products is controlled by internal hazard index (H_{in}) and for safe use, this index must be less than unity. From Table 4, the maximum values of H_{ex} and H_{in} are observed in site no. 7 (1.184 ± 0.31, 1.230 ± 0.52). The hazard indices are to be higher than unity, which may cause harm to people living in this region.

3.4.4 Radioactive heat production (RHP) rate

During the last few decades, the assessment of the amount of radioactive elements, the major internal heat source of the earth, was the subject of several studies owing to its importance in modelling the thermal evaluation of the lithosphere. The radioactive isotopes ^{238}U, ^{232}Th and ^{40}K contribute most of the terrestrial heat flow. These elements are fundamental for understanding the nature of the mantle, and crust of the earth and their heat generating potential.

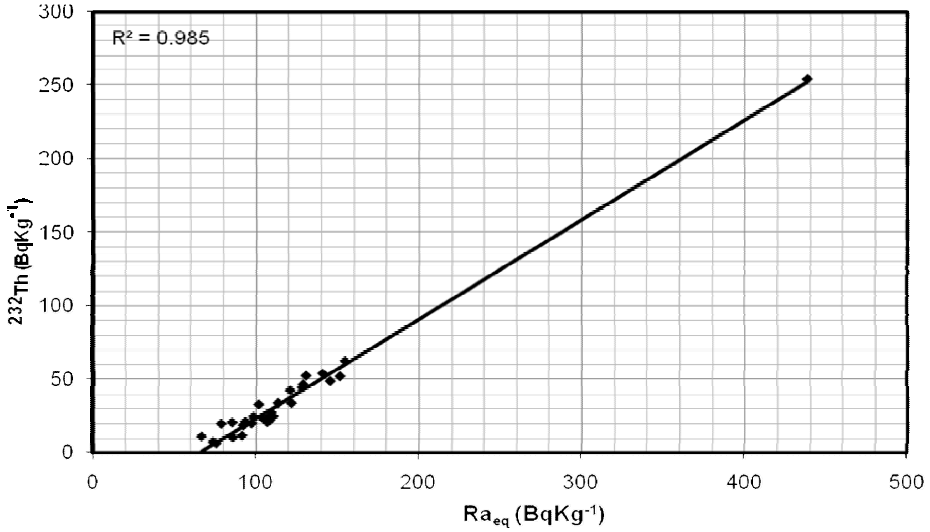
Table 4 Hazard indices, radium equivalent, radioactive heat production rate, magnetic susceptibility and weight of the magnetic minerals

Site no.	H_{ex}	H_{in}	$Raeq$ *Bq kg*$^{-1}$	*RHP* μWm^{-3}	*ELCR*		$\chi \times 10^{-8}$ $m^3 kg^{-1}$	*Weight of magnetic minerals in mg*	*Extinction coefficient* cm^2/mg		*Quartz + feldspar*
					indoor	*outdoor*			*Quartz*	*Feldspar*	
1	0.1802 ± 0.02	0.2047 ± 0.04	66.73 ± 5.6	0.3618 ± 0.04	0.59 ± 0.02	0.15 ± 0.02	16.1	235	329.03	42.76	371.79
2	0.2748 ± 0.04	0.3014 ± 0.06	101.76 ± 6.3	0.5771 ± 0.06	0.85 ± 0.06	0.21 ± 0.03	38.8	247	217.42	30.85	248.27
3	0.3805 ± 0.06	0.4141 ± 0.07	140.91 ± 6.8	0.8770 ± 0.09	1.16 ± 0.09	0.29 ± 0.03	28.4	320	391.76	61.86	453.62
4	0.2664 ± 0.05	0.2938 ± 0.03	98.65 ± 5.8	0.5366 ± 0.06	0.85 ± 0.06	0.21 ± 0.01	26.3	254	256.17	54.21	310.38
5	0.1991 ± 0.03	0.2231 ± 0.02	73.73 ± 5.4	0.3389 ± 0.04	0.67 ± 0.03	0.17 ± 0.01	28.4	187	162.22	32.59	194.81
6	0.2321 ± 0.04	0.2528 ± 0.05	85.95 ± 5.7	0.3928 ± 0.05	0.78 ± 0.04	0.19 ± 0.01	17.4	210	570.78	161.8	732.58
7	1.1840 ± 0.31	1.2300 ± 0.52	438.49 ± 9.2	3.3128 ± 0.45	3.40 ± 0.2	0.85 ± 0.04	279.7	620	301.34	30.81	332.15
8	0.2928 ± 0.03	0.3200 ± 0.06	108.43 ± 4.3	0.5697 ± 0.07	0.95 ± 0.04	0.24 ± 0.01	26.2	249	295.2	72.68	367.88
9	0.3287 ± 0.07	0.3554 ± 0.07	121.73 ± 5.3	0.7050 ± 0.09	1.04 ± 0.07	0.26 ± 0.01	61.8	250	234.67	82.63	317.3
10	0.3470 ± 0.08	0.3773 ± 0.05	128.50 ± 5.4	0.7977 ± 0.08	1.07 ± 0.08	0.27 ± 0.02	279.7	245	173.94	111.22	285.16
11	0.3928 ± 0.05	0.4237 ± 0.08	145.45 ± 5.8	0.8878 ± 0.07	1.22 ± 0.07	0.31 ± 0.02	55.2	328	168.23	76.54	244.77
12	0.4091 ± 0.04	0.4404 ± 0.07	151.52 ± 5.7	0.9111 ± 0.05	1.27 ± 0.08	0.32 ± 0.03	16.7	290	162.61	41.71	204.32
13	0.2962 ± 0.06	0.3235 ± 0.05	109.68 ± 5.3	0.6265 ± 0.07	0.95 ± 0.05	0.24 ± 0.01	9.1	280	210.66	61.082	271.74
14	0.2308 ± 0.02	0.2460 ± 0.01	85.46 ± 4.9	0.4597 ± 0.05	0.74 ± 0.03	0.19 ± 0.01	57.9	236	296.76	87.47	384.23
15	0.3270 ± 0.04	0.3460 ± 0.04	121.09 ± 5.6	0.7269 ± 0.08	1.02 ± 0.09	0.25 ± 0.02	52.1	340	252.31	56.78	309.09
16	0.4179 ± 0.08	0.4423 ± 0.03	154.75 ± 7.3	1.0391 ± 0.21	1.27 ± 0.09	0.32 ± 0.04	44.6	380	187.38	49.53	236.91
17	0.3478 ± 0.06	0.3709 ± 0.04	128.82 ± 6.8	0.8110 ± 0.07	1.08 ± 0.08	0.27 ± 0.02	51.3	320	171.34	49.65	220.99

Table 4 Hazard indices, radium equivalent, radioactive heat production rate, magnetic susceptibility and weight of the magnetic minerals (continued)

Site no.	H_{ex}	H_{in}	$Raeq$ $Bq\ kg^{-1}$	RHP μWm^{-3}	$ELCR$		$\chi \times 10^{-8}$ $m^3\ kg^{-1}$	$Weight\ of\ magnetic\ minerals\ in\ mg$	$Extinction\ coefficient\ cm^2/mg$		$Quartz + feldspar$
					indoor	*outdoor*			*Quartz*	*Feldspar*	
18	0.2528 ± 0.04	0.2768 ± 0.01	93.61 ± 5.6	0.5568 ± 0.04	0.81 ± 0.04	0.20 ± 0.07	52.6	267	168.43	50.21	218.64
19	0.2493 ± 0.04	0.2720 ± 0.04	92.31 ± 5.7	0.5129 ± 0.06	0.81 ± 0.06	0.20 ± 0.04	33.69	281	246.71	61.34	308.05
20	0.2043 ± 0.05	0.2278 ± 0.03	75.67 ± 6.1	0.3566 ± 0.04	0.69 ± 0.04	0.17 ± 0.02	22.6	267	279.51	66.3	345.81
21	0.2885 ± 0.07	0.3124 ± 0.04	106.84 ± 7.4	0.5438 ± 0.06	0.94 ± 0.09	0.24 ± 0.04	31.3	320	459.12	132.05	591.17
22	0.2989 ± 0.08	0.3222 ± 0.06	110.68 ± 7.6	0.5923 ± 0.07	0.97 ± 0.05	0.24 ± 0.08	33.7	296	446.15	125.63	571.78
23	0.2957 ± 0.09	0.3199 ± 0.05	109.52 ± 7.5	0.6257 ± 0.08	0.95 ± 0.03	0.24 ± 0.04	37.1	289	411.27	86.27	497.54
24	0.3068 ± 0.06	0.3312 ± 0.07	113.63 ± 7.3	0.6785 ± 0.05	0.97 ± 0.07	0.24 ± 0.01	39.8	273	373.19	76.41	449.6
25	0.2628 ± 0.07	0.2864 ± 0.03	97.32 ± 6.4	0.5565 ± 0.03	0.85 ± 0.06	0.21 ± 0.06	27.6	268	306.21	69.61	375.82
26	0.2912 ± 0.08	0.3144 ± 0.01	107.84 ± 7.5	0.6038 ± 0.04	0.94 ± 0.05	0.24 ± 0.09	25.3	295	251.63	67.12	318.75
27	0.2830 ± 0.09	0.3071 ± 0.06	104.81 ± 8.1	0.5676 ± 0.05	0.92 ± 0.07	0.23 ± 0.05	24.5	245	177.11	65.82	242.93
28	0.3527 ± 0.06	0.4026 ± 0.07	130.63 ± 8.2	0.9877 ± 0.06	1.05 ± 0.10	0.26 ± 0.02	136.7	362	88.39	22.26	110.65
29	0.2126 ± 0.04	0.2386 ± 0.03	78.75 ± 6.3	0.4753 ± 0.08	0.67 ± 0.03	0.17 ± 0.03	20.12	278	481.77	117.83	599.6
30	0.2472 ± 0.05	0.2711 ± 0.04	91.56 ± 7.2	0.4944 ± 0.09	0.82 ± 0.05	0.21 ± 0.08	19.31	229	365.16	117.61	482.77
Max	1.1840 ± 0.31	1.2300 ± 0.52	438.49 ± 9.2	3.3128 ± 0.45	3.40 ± 0.2	0.85 ± 0.04	279.7	620	570.78	161.8	732.58
Min	0.1802 ± 0.02	0.2047 ± 0.04	66.73 ± 5.6	0.3389 ± 0.04	0.59 ± 0.02	0.15 ± 0.02	9.1	210	88.39	22.26	110.65
Mean	0.3200 ± 0.06	0.3500 ± 0.06	119.16 ± 7.3	0.7200 ± 0.08	1.01 ± 0.7	0.25 ± 0.04	53.12	288.7	281.22	72.09	353.3

Figure 5 Correlation between Ra_{eq} and ^{232}Th



In the present study, an attempt has been made to find out the RHP rate at different sites using the relation given by Rybach (1988).

$$A = 10^{-5}\,\rho\,(9.52\,C_U + 2.56\,C_{Th} + 3.48\,C_K),$$

where A is RHP rate expressed in μWm^{-3}, ρ is the sample density in kg m^{-3}, C_U and C_{Th} are the uranium and thorium concentration in ppm and C_K is the total potassium concentration in %.

In the present study, the heat production rate varies between 0.3389 ± 0.04 μWm^{-3} (site no. 5) and 3.3128 ± 0.45 μWm^{-3} (site no. 7) with a mean value of 0.7200 ± 0.08 μWm^{-3}. The river shows the low RHP rate (below 1 μWm^{-3}) except site nos. 7 and 16. Here, the overall heat generation mainly depends on ^{232}Th amount and its contributions to RHP are 59.19%. However, an increase in the concentrations of ^{238}U, ^{232}Th and ^{40}K reflects the integrated effect of heat production rate.

3.4.5 Excess lifetime cancer risk (ELCR)

ELCR is calculated using the following equation.

$$ELCR = AEDE \times DL \times RF,$$

where AEDE, DL and RF are the annual effective dose equivalent, duration of life (70 years) and risk factor (Sv^{-1}), fatal cancer risk per sievert. For stochastic effects, ICRP60 uses values of 0.05 for the public (Taskin, 2009). The average value of outdoor ELCR is slightly lesser than the world average (UNSCEAR, 2000) but the average value of indoor ELCR 3.48 times greater.

3.5 Distribution of quartz and feldspar

FTIR spectra are recorded for all the sampling sites, and comparing the observed frequencies with available literature (Madejova, 2003; Russell, 1987; Ramasamy et al.,

2004a; Ramasamy et al., 2003), the minerals such as quartz, feldspar, kaolinite in different composition, nacrite, montmorillonite, illite, chlorite, gibbsite, carbonates, sepiolite and magnesium oxalate are identified. The observed IR absorption frequencies and its corresponding minerals are tabulated in Table 5. The relative distribution of quartz and feldspar among the various sites of the present study (Ramasamy et al., 2004b) is determined using extinction coefficient of the characteristic peaks at 778 cm^{-1} and 640 cm^{-1}, respectively, which is shown in Table 4 and these values are correlated with radioactivity measurements.

Rizzo et al. (2001) suggest that Si is good safety index to select the materials of low radiological impact in geological areas of prevalent magmatic origin. But in the present study, the distribution of quartz and feldspar gives no obvious trend with individual activities (^{238}U, ^{232}Th and ^{40}K) and absorbed dose rate. This suggests Si is not an index to select low radiological area.

Table 5 Observed absorption frequencies (cm^{-1}) from FTIR spectra of the samples

S. no.	*Mineral name*	*Observed frequency cm^{-1}*	*Site number*
1	Chlorite	440	1, 14 and 15
2	Sepiolite	450	16, 23
3	Quartz	458-462	1–30
4	Sepiolite	470	16, 23
5	Orthoclase	530-535	1–30
6	Microcline	580-585	1–30
7	Orthoclase	629-650	1–30
8	Gibbsite	665-675	2, 4, 6, 7, 2, 8-21, 24, 27 and 28
9	Quartz	690-694	1–30
10	Albite	729-732	1–30
11	Quartz	777	1–30
12	Montmorillonite	890-895	18, 19, 21, 26, 30
13	Kaolinite	912-915	9, 18, 19, 22, 25 and 29
14	Kaolinite	1004-1006	9, 18, 19, 22, 25 and 29
15	Kaolinite	1030-1032	9, 18, 19, 22, 25 and 29
16	Albite	1038-1045	1-8, 10-17, 20, 21, 26 and 28
17	Quartz	1080-1083	1-18, 20, 21, 23, 24 and 27
18	Kaolinite	1100-1110	9, 18, 19, 22, 25 and 29
19	Albite	1135-1150	1–30
20	Magnesium Oxalate	1375-1377	9, 18, 19 and 23
21	Cerussite	1384-1388	11, 18, 26 and 28
22	Calcite	1400-1440	9, 11, 13, 18-21, 24 and 27
23	Gibbsite	3527	2, 4, 6, 7, 12, 18-21, 24, 27 and 28
24	Kaolinite	3620, 3654 and 3697	1–30

3.6 Magnetic susceptibility

With the help of Nagamalleswara Rao (1995), the magnetite is responsible for magnetic susceptibility and the monazite is responsible for radioactivity. When comparing magnetic susceptibility with absorbed dose rate of the sediment samples, some of the following results were obtained:

1 High radiation level and low magnetic susceptibility may indicate sediments with low magnetite and high concentration of monazite as in site no. 12.

2 Low radiation level and high magnetic susceptibility may indicate sediments with abundant magnetite and low/negligible monazite content as in site no. 14.

3 Intermediate levels of radiation and magnetic susceptibility may indicate sediments with equal abundance of magnetite and monazite as in site no. 10.

4 High magnetic susceptibility and high radioactivity may indicate abundant magnetite and monazite as in site no. 7.

From the above observations, the correlation between magnetic susceptibility and absorbed dose rate (R = 0.68) is found to be weak as shown in Figure 6, because the resultant magnetic susceptibility is obtained from the resultant effect of dia, para, ferri, and antiferromagnetic materials. Quartz is most popular diamagnetic material. It has very minimum and negative susceptibility values. In the present study, quartz is dominant mineral. So the resultant susceptibility may be slightly varied by different magnetic properties of the sediments like diamagnetism. But the weight of the magnetic minerals gives good correlation with absorbed dose rate (R = 0.91) as shown in Figure 7. To confirm this result, site no. 7 has been selected and the activity concentration values are measured after separating the magnetic mineral content using electromagnet. This result shows that the activity concentration and absorbed dose rate of the respective sample are decreased, i.e. these values are very low when compared to before separation and international recommended limit. It is observed that weight of the magnetic minerals is an index to select the sediments of low or high radiological impact of Palar River.

Figure 6 Correlation between absorbed dose rate and magnetic susceptibility

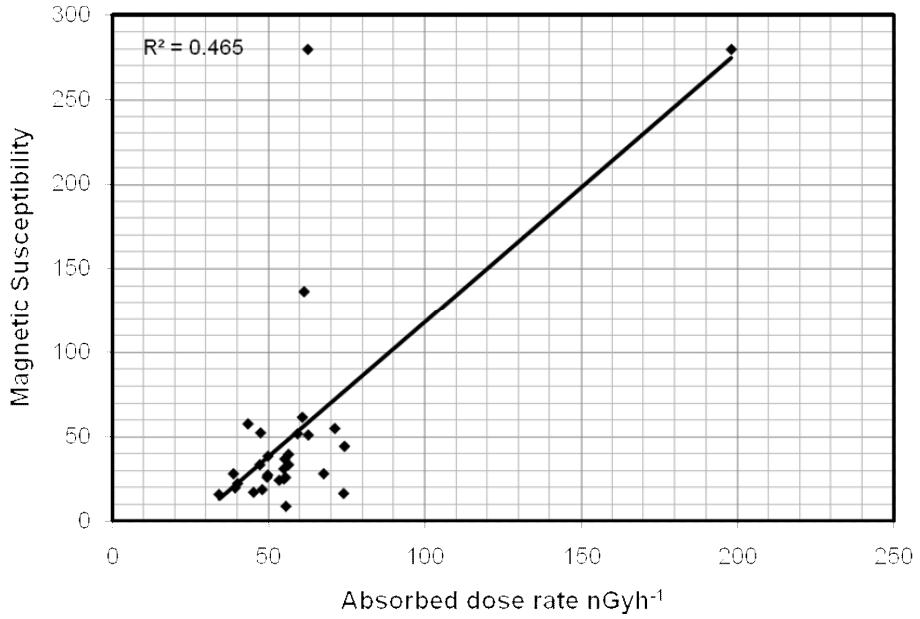
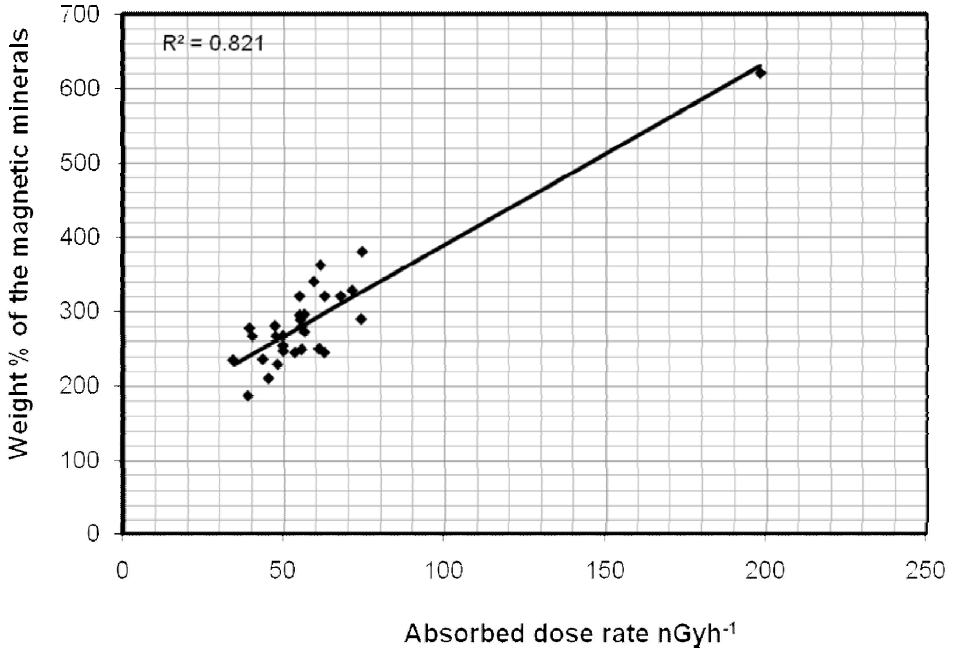


Figure 7 Correlation between absorbed dose rate and weight of the magnetic minerals



4 Conclusion

It is clear from the data of the gamma ray spectroscopic analysis in the present study of sediment samples that the levels of mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K are lower than the international recommended limits. The mean absorbed dose rate is also lower than the international recommended limit. The mean annual effective equivalent dose is 1.03 times that of the international recommended limit (70 μSvy^{-1}). The mean values of Ra_{eq}, H_{ex} and H_{in} found in the present study are less than the international recommended limits of 370 Bq kg^{-1}, 1 and 1, respectively. Therefore, these sediments do not pose a radiation hazard when used as building materials. Among all the sites, site nos. 3,7,9 to 12, 15, 16, 17 and 28 show the highest values of absorbed, observed, annual effective equivalent dose, radium equivalent hazard indices and RHP rate. This implies that inhabitants of those areas are subjected to increased radiation exposure. So these sites are harmful to human health. Though the magnetic susceptibility cannot give any correlation with absorbed dose rate, the weight of the magnetic minerals gives positive correlation with absorbed dose rate, Ra_{eq} and RHP. Thus, the weight of the magnetic minerals is also an index to select low radiological impact of the Palar River sediments.

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