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Radioactivity and radiation hazard assessment of Cauvery River, Tamilnadu, India

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Background: Natural radiation is constantly present in the environment and is emitted from a variety of natural and artificial sources. It affects human body and environment. ***Materials and Methods:*** The activity concentrations of ^{238}U, ^{232}Th and ^{40}K have been determined by Gamma ray spectrometer with an HPGe detector in sediments of Cauvery River, Tamilnadu, India. ***Results:*** 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 rate and activity concentration index are also calculated. The observed dose rate measurements from ERDM (Environmental Radiation Dosi Meter) at 1m above the ground level at each site of the both rivers are measured and correlated with calculated absorbed dose rate. ***Conclusion:*** From the various parameters and correlation between them, the Cauvery River does not pose a radiological hazard except the site no. 21, 22, 23, 30, 31 and 35. **Iran. J. Radiat. Res., 2011; 8(4): 211-222**

Keywords: *Sediments, radioactivity, absorbed dose rate, hazardous indices, RHP, activity concentration index.*

INTRODUCTION

The knowledge of the natural radioactivity of building materials is important for the determination of population exposure to radiations, as most of the residents spend about 80% of their time in indoor. Building materials contribute to natural radiation exposure in two ways. First, by gamma radiation, from ^{238}U, ^{232}Th and ^{40}K and their decay products to an external whole body dose exposure and secondly by radon exhalation to an internal dose exposure due to deposition of radon decay products in the human respiratory tract. Elevated dose rates in indoor may arise from high activities of natural radionuclides in building materials. In India dwellings are constructed with concrete mixed with nearly 60% sand separated from river sediments, which may contain highly occurred concentrations of natural radionuclides [(1)].

Radiation is present in every environment of the Earth's surface, beneath the Earth and in the atmosphere. According to UNSCEAR [(2)] (1993) about 87% of the radiation dose received by mankind is due to natural radiation sources and the remaining is due to anthropogenic radiation. It is well known that natural radioactivity is present in rocks, soils, sediments, water and fish. Rocks and soil contain small quantities of the radioactive elements of ^{238}U and ^{232}Th with their daughter products. The concentration of these elements varies considerably depending on the rock formation. The major sources of external radiation are ^{238}U, ^{232}Th, ^{40}K and their decay products. The human population is exposed to a natural background radiation level that is contributed by three components viz., cosmic rays, terrestrial radioactivity and internal radioactivity. The contribution from these components varies with location and altitude (Ajayi, 2002). The terrestrial component is due to the radioactivity of uranium (^{238}U), thorium (^{232}Th) and their progeny radio isotopes and potassium-40 (^{40}K) that is present in environmental

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materials like rocks, soils, sediments, buildings, rivers and ground water. Although these materials contain low-level radioactivity (LLR) the accumulated dose can be high. Measurements of the radiation exposure and radiation levels have been developed recently [2, 3].

The aim of this study was to determine the concentrations of natural radioactivity in Cauvery river sediments and to estimate the radium equivalent, hazardous index, volumetric heat production rate and activity concentration index, which is related to the external g-dose rates. The results were compared with the findings of similar studies carried out in other countries. In the present study an attempt has been made to determine the concentration and effects of ^{238}U, ^{232}Th and ^{40}K in sediments collected from Cauvery river.

MATERIALS AND METHODS

Cauvery River, which is located between Karnataka and Tamil Nadu in India covered over 600 km are shown in figure 1. Each site is separated by a distance of 20km approximately. At each site, a sampling area of 1m [2] was considered and totally 6 wet samples were taken from 2 feet depth for analysis. Each sample has about 2 kg. Then the sample was dried in an oven at 100-110˚C for about 24 hours and sieved through a 2-mm mesh to remove stone, pebbles and other macro-impurities. The homogenized 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.

Activity concentration determination involves measurements of either alpha or beta or gamma radiations from the samples. Due to the inherent properties of the gamma rays like high penetrating power and the interaction process with matter, the

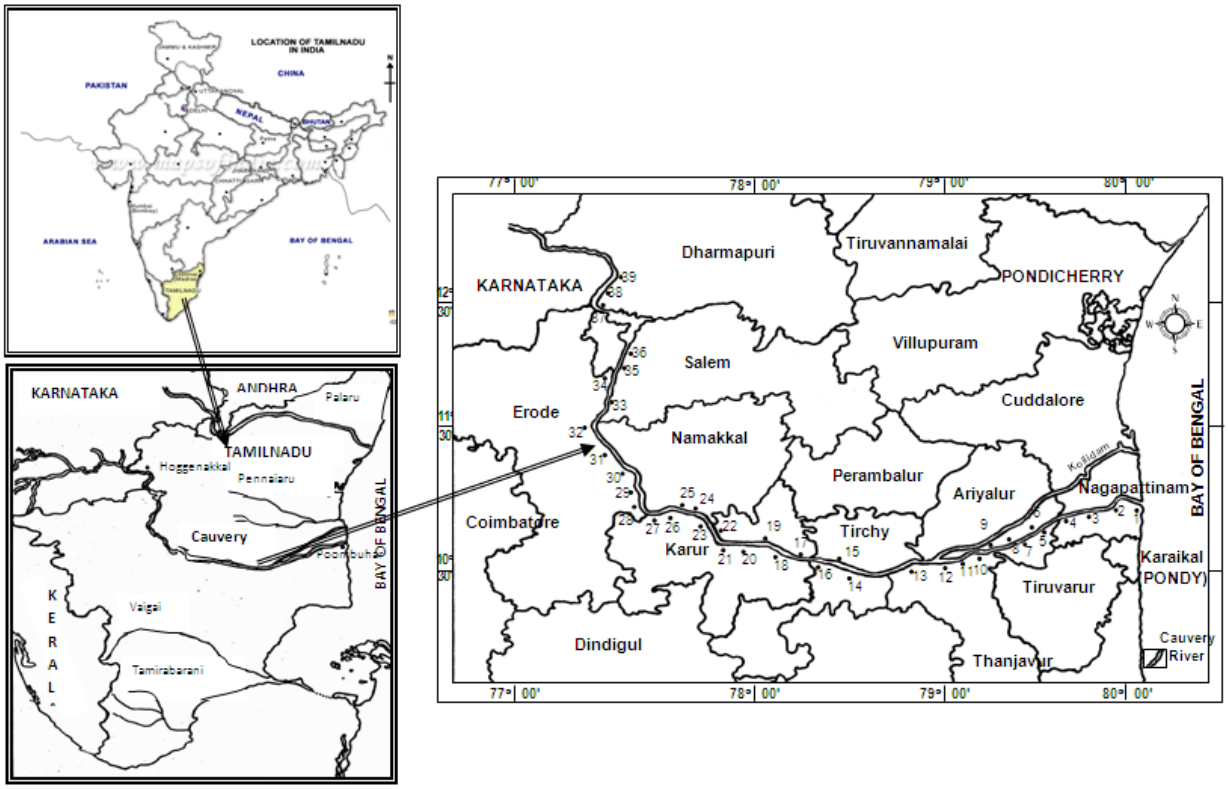

Figure 1. Map of different locations of Cauvery river.

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measurement of gamma radiation offers useful information than that of α and ß radiations.

The activity concentrations of primordial radio nuclides (^{238}U, ^{232}Th and ^{40}K) in the samples were determined by employing a high-resolution hyper pure germanium (HPGe) gamma ray spectrometer system consisting of a p-type intrinsic germanium coaxial detector (type: 1GC 30; Volume 133cc; PGT make) mounted vertically and coupled to a 4K multi channel analyzer (ORTEC MODEL 7 450). 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 2.0KeV and relative efficiency of 33% at 1.33 Mev was achieved in the system.

Each sample, after the equilibrium, is kept on top of the HPGe detector and counted for period of 10000 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, ^{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 radio nuclide 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 - 10000 $nGyh^{-1}$. The ERDM is calibrated regularly before starting the survey using standard sources ^{137}Cs and ^{60}Co. The ERDM readings are recorded at 1m above ground level. Five readings were taken at each site and the average was recorded.

Calculation of radiation hazard parameters

UNSCEAR [2] (1988) has given the dose conversion factors for converting the activity concentrations of ^{238}U, ^{232}Th and ^{40}K into doses ($nGyh^{-1}$ per $Bqkg^{-1}$) as 0.427, 0.662 and 0.043 respectively. Using these factors, the absorbed dose rate is calculated using the equation.

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

Where C_U, C_{Th} and C_K are the activity concentrations ($Bqkg^{-1}$) of uranium, thorium and potassium in sediments respectively.

Normally river sediments are used in building construction; so selection of the materials is also very important. The total activity does not provide as an exact indication of the radiation hazard associated with the materials. As the concentration and distribution of ^{238}U, ^{232}Th and ^{40}K in sediments and soils is not uniform throughout the world so uniformity in respect of exposure to radiation has been defined in terms of the radium equivalent activity given by the equation [4].

$$Ra_{eq} = C_U + A\ C_{Th} + B\ C_K \quad (2)$$

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

The other quantities indicating the radiological hazards are external (H_{ex}) and internal (H_{in}) hazard indices and are defined by the following relations [4].

$$H_{ex} = C_U/370 + C_{Th}/259 + C_K/4810 \le 1$$
$$H_{in} = C_U/185 + C_{Th}/259 + C_K/4810 \le 1 \quad (3)$$

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where C_U , C_{Th} and C_K are the activity concentrations of U, Th and K in Bqkg^{-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.

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 due to its importance in modeling 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, crust of the earth and their heat generating potential.

In the present study, an attempt has been made to find out the radioactivity heat produced in different sites using the relation given by Rybach (1988) [5] .

$$A = 10^{-5}\rho(9.52C_U + 2.56C_{Th} + 3.48C_K)\ \mu Wm^{-3} \quad (4)$$

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

The building materials act as sources of radiation and also as shields against outdoor radiation [2]. In massive houses made of different building materials such as stone, bricks, concrete or granite, the factor that mainly affects the indoor absorbed dose is the activity concentrations of natural radionuclides in those materials, while radiation emitted by sources outdoors is efficiently absorbed by the walls. Consequently, dose rates in air indoors will be elevated accordingly to the concentrations of naturally occurring radionuclides used in construction materials. According to the EC, an activity concentration index (I_{Yr}) is calculated that is given by the following expression [1]:

$$I_{Yr} = A_U/150 + A_{Th}/100 + A_K/1500 \quad (5)$$

where A_{Th}, A_U and A_K are actual values of the activities per unit mass (Bq.Kg^{-1}) of ^{232}Th, ^{238}U, and ^{40}K in the building materials considered.

RESULTS AND DISCUSSION

Activity concentration of primordial radionuclides

The activity concentration of the radio nuclides ^{238}U, ^{232}Th and ^{40}K in Bqkg^{-1}, corresponding absorbed dose rates in nGyh^{-1} and annual effective equivalent dose in μSvy^{-1} of the sediment samples collected from Cauvery River are listed in table 1.

As listed in table 1, the activity concentrations obtained in this study ranged from 1.29±0.1 to 21.49±0.8 Bqkg^{-1} with a mean of 5.31±0.4 Bqkg^{-1}, 6.33±0.6 to 224.79±2.6 Bq kg^{-1} with a mean value of 34.04±1.4 Bqkg^{-1} and 178.18±18.6 to 1698.48±30.1 Bqkg^{-1} with a mean value of 401.11±24.3 Bqkg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively and are shown in figure 2. Comparatively similar range of concentrations of ^{238}U, ^{232}Th and ^{40}K are observed by many authors [6-9] (table 2) in soil with an exception of beach sand samples, where observed values are significantly higher [6,10]. In the present study, activity concentrations are almost lower than the other countries like China, Greece, France and Bangladesh (table 3) except site no. 30 and 31.

The mean activity concentration of ^{238}U is 0.15 times of the international recommended limit [3] (35 Bqkg^{-1}) and 0.36 times of the all India average value [11] (14.8 Bqkg^{-1}), whereas the mean ^{232}Th activity concentration is 1.13 and 1.86 times of the international recommended limit (30 Bqkg^{-1}) and all India average value (18.3 Bqkg^{-1}). The mean concentration of ^{40}K is 1.01 times of the international recommended limit (400 Bqkg^{-1}). This shows that the ^{40}K activity concentration dominates over ^{238}U and ^{232}Th isotope activities like what normally happens in soil. The low concentration of ^{40}K may be attributed to leaching, because of the heavy rainfall near Cauvery river area [12] (table 4).

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Table 1. The Activity concentration, calculated absorbed dose rates, observed dose rates and the annual effective equivalent dose of Cauvery river sediments.

S. No.	Location	Lattitude	Longitude	U $BqKg^{-1}$	Th $BqKg^{-1}$	K $BqKg^{-1}$	Absorbed dose rate $nGyh^{-1}$	Observed dose rate $nGyh^{-1}$	Annual effective equivalent dose $mSvy^{-1}$
1	Poombhuhar	11˚09´00N	80˚12´60E	6.15±0.7	13.23±0.9	398.91±21.4	28.02±1.4	90	0.17
2	N.N. Chavady	11˚07´60N	80˚05´00E	3.52±0.4	14.38±1.2	428.62±24.1	28.89±1.6	95	0.18
3	Mayiladuthurai	11˚05´60N	79˚40´00E	5.21±0.5	16.92±1.3	448.62±26.1	32.05±1.8	100	0.20
4	kuttalam	11˚03´60N	79˚34´00E	2.63±0.3	15.32±1.5	432.62±27.4	29.27±1.9	85	0.18
5	Aduthurai	11˚01´60N	79˚28´60E	1.32±0.2	16.94±1.4	442.6±22.3	30.15±2.1	90	0.18
6	Thirubhuvanam	10˚59´00N	79˚25´60E	2.62±0.3	18.78±0.9	429.63±21.4	31.29±2.4	80	0.19
7	Kumbakonam	10˚58´00N	79˚22´60E	3.13±0.4	22.87±1.2	416.47±24.3	33.49±2.0	70	0.20
8	Swamimalai	10˚57´60N	79˚18´60E	3.78±0.4	26.73±1.4	380.24±25.6	34.62±2.4	65	0.21
9	Pappanasam	10˚55´60N	79˚16´00E	4.32±0.5	34.79±1.6	401.15±26.2	40.77±2.6	60	0.25
10	Kabisthalam	10˚54´60N	79˚10´00E	4.63±0.5	28.72±1.5	385.36±21.4	36.44±2.5	64	0.22
11	Tiruvaiyar	10˚52´60N	79˚05´00E	5.61±0.6	22.72±1.3	373.93±23.2	32.63±2.3	68	0.20
12	Thirukkattupalli	10˚50´60N	78˚58´00E	1.98±0.2	13.44±0.8	377.27±22.6	25.44±1.9	63	0.16
13	Kallanai	10˚51´00N	78˚47´60E	4.32±0.5	33.20±1.4	410.94±24.7	40.20±2.4	72	0.25
14	Trichy	10˚51´60N	78˚43´60E	3.38±0.4	21.73±1.1	398.48±21.5	32.12±1.8	85	0.20
15	Srirangam	10˚52´00N	78˚40´60E	2.56±0.3	10.85±0.8	385.05±20.4	24.41±2.2	97	0.15
16	Mukkombur	10˚53´60N	78˚32´60E	1.64±0.2	19.32±1.3	383.42±26.2	29.22±2.6	56	0.18
17	Gunaseelam	10˚54´60N	78˚28´60E	2.32±0.3	14.62±1.1	368.42±24.3	25.94±2.3	60	0.16
18	Kulithalai	10˚55´60N	78˚25´00E	2.67±0.3	12.49±1.6	353.25±25.8	24.11±2.1	64	0.15
19	Thottiyam	10˚55´00N	78˚20´60E	2.16±0.3	26.32±1.8	385.76±24.2	33.91±2.4	68	0.21
20	Krishnarayapuram	10˚55´00N	78˚16´60E	1.88±0.2	38.75±1.7	402.22±22.1	42.24±2.8	72	0.26
21	Mayanoor	10˚55´60N	78˚13´60E	3.01±0.4	82.93±2.1	307.61±20.3	66.18±2.4	220	0.40
22	Kattuputhur	10˚47´60N	78˚06´60E	4.03±0.6	73.47±1.8	438.60±24.2	66.35±2.6	190	0.41
23	Puliyur	10˚37´60N	78˚02´60E	6.96±0.5	67.40±1.6	548.20±26.4	68.53±2.5	230	0.42
24	Vangal	10˚45´60N	77˚58´60E	3.90±0.2	25.53±0.8	304.98±20.1	30.68±1.6	63	0.19
25	Velayutham-	10˚48´60N	77˚56´00E	1.89±0.3	14.44±0.6	304.73±21.2	22.91±1.4	58	0.14
26	palayam	10˚52´60N	77˚55´60E	1.46±0.2	14.16±0.6	278.63±20.0	21.43±1.8	50	0.13
27	Pothanoor	11˚04´60N	77˚54´60E	1.29±0.1	15.98±0.7	256.71±19.8	21.54±1.7	47	0.13
28	Noyyal	11˚09´60N	77˚52´60E	4.95±0.5	20.50±1.2	294.62±21.2	27.55±1.9	70	0.17
29	Kodumudi	11˚20´60N	77˚48´00E	8.88±0.6	28.93±1.4	256.38±23.6	32.84±2.7	69	0.20
30	Solasiranmani	11˚26´60N	77˚46´60E	17.62±0.8	152.63±2.2	420.86±27.8	120.71±1.8	240	0.74
31	Valajapettai	11˚20´60N	77˚43´60E	21.49±0.8	224.79±2.6	529.44±28.6	171.99±2.4	350	1.05
32	Erode	11˚26´60N	77˚40´60E	8.88±0.3	12.61±0.8	321.71±21.8	25.48±1.6	48	0.16
33	Bavani	11˚32´60N	77˚42´60E	2.94±0.2	8.35±0.6	488.91±24.3	27.48±1.8	66	0.17
34	Kalvadangam	11˚37´60N	77˚45´00E	11.87±0.2	18.71±0.9	178.18±18.6	24.39±2.1	59	0.15
35	Ammapettai	11˚42´00N	77˚46´60E	12.97±0.3	24.03±1.2	1698.48±30.1	93.54±2.4	170	0.57
36	Thekkanoor	11˚48´00N	77˚47´60E	3.91±0.4	6.33±0.6	197.58±15.4	14.11±1.6	61	0.09
37	Mettur	11˚56´60N	77˚52´60E	4.67±0.5	20.41±1.2	210.62±18.2	23.77±1.6	72	0.15
38	Kulathur	11˚56´60N	77˚53´00E	8.65±0.5	43.71±1.8	250.40±20.3	41.69±1.8	81	0.25
39	Kaveripuram	12˚34´00N	77˚58´00E	12.16±0.6	50.85±2.1	353.66±23.2	52.08±2.4	93	0.32
Max	Hoggenakal			21.49±0.8	224.79±2.6	1698.48±30.1	171.99±2.4	350	1.05
Min				1.29±0.1	6.33±0.6	178.18±18.6	14.11±1.6	47	0.09
Mean				5.31±0.4	34.04±1.4	401.11±24.3	40.73±1.8	96.10	0.25

Table 1 shows the calculated absorbed dose rate due to the presence of ^{238}U, ^{232}Th and ^{40}K in sediments. The mean absorbed dose rate is 0.79 times of international recommended limit (51 $nGyh^{-1}$). The contribution by each of the radio nuclides ^{238}U, ^{232}Th and ^{40}K in $nGyh^{-1}$ to the absorbed dose rate is 5.5% (2.26 $nGyh^{-1}$), 55.34% (22.54 $nGyh^{-1}$) and 42.33% (17. 24 $nGyh^{-1}$) respectively.

In situ gamma dose rate at 1m above the ground has also been measured using the ERDM in each location and the values are tabulated in table 1. The observed dose rates is positively correlated with calculated absorbed dose rate with strong correlation coefficient (R=0.92) as shown in figure 3. The ERDM dose rates (observed) are nearly two times higher than the absorbed dose rate values. This difference may be due to

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background contribution from cosmic rays high energy beta particles and X rays. In determining the annual effective equivalent dose at each location, the living style 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 8hrs of the day in an office (or) classroom or laboratory, 12 hrs indoors and the remaining 4hrs outdoors. This applies to the greater part of the population in a location who are either office workers or pupils/students. Hence 20/24 or 0.83 was adopted as the outdoor occupancy factor (80%) with the conversion factor of 0.70SvGy^{-1} to convert absorbed dose rate in air (nGyh^{-1}) to indoor annual effective equivalent dose (mSvy^{-1}) for this study. The mean indoor annual effective equivalent dose is 0.74 times with that of the international recommended limit 0.34 mSvy^{-1}. But the site no. 21, 22, 23, 30, 31 and 35 shows higher values, which is higher than the international recommended limit [3, 13].

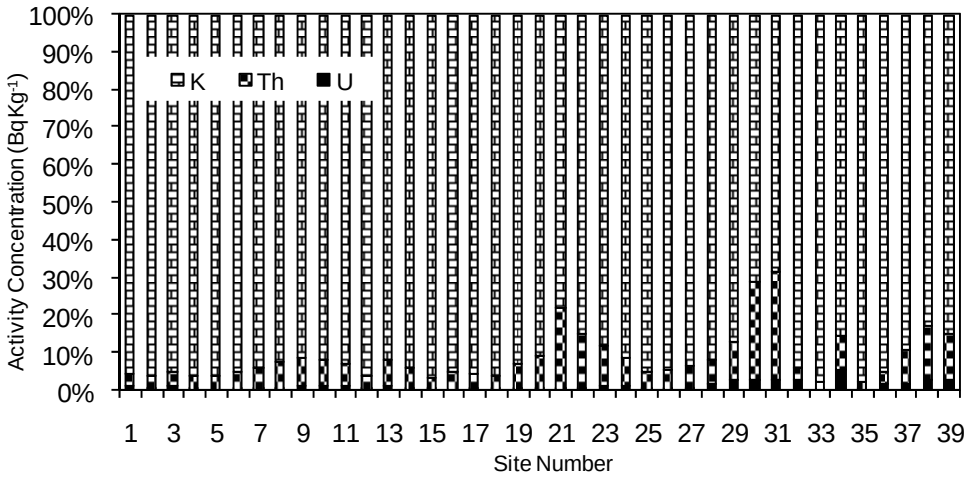

Figure 2. Graph of activity concentration in different locations of Cauvery River.

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

Sl. No.	Location	^{238}U BqKg^{-1}	^{232}Th BqKg^{-1}	^{40}K BqKg^{-1}	Reference
	Soil				
1	Kalpakkam, T.N	5-71	15-776	200-854	Kannan *et al.* (2002)[6]
2	Bhuvaneswar, Orissa	18-30	33-80	213-247	Vijayan and Behera (1999)[7]
3	Coonoor(Ooaty), T.N.	BDL-49	4-224	14-731	Selvasekarapandian *et al.* (1999a)[8]
4	Gudalore, T.N.	17-62	19-272	78-596	Selvasekarapandian *et al.* (2000)[21]
5	Narora, U.P.	32-65	46-90	469-756	Verma *et al.* (1998)[9]
6	Rawatbhata, Rajasthan	17-40	27-67	127-49	Verma *et al.* (1998)[9]
7	Udagamandalam, (Ooty taluk), T.N.	0-88	26-226	96-444	Selvasekarapandian *et al.*(1999b)[22]
8	Ullal, Karnataka	546	2971	268	Radhakrishna *et al.* (1993)[10]
9	Uttarpradesh	12-25	20-25	538-1018	Mishra and Sadasivam (1971)[11]
	Beach Sand				
10	Kalpakkam, T.N	36-258	352-3872	324-405	Kannan *et al.* (2002)[6]
11	Ullal, Karnataka	374	158	158	Radhakrishna *et al.* (1993)[10]
	River sediment				
12	Cauvery river, T.N.	5.31	34.04	401.11	Present study

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

Sl. No.	Country	^{238}U BqKg^{-1}	^{232}Th BqKg^{-1}	^{40}K BqKg^{-1}	Reference
1	China	62	90	524	Zigiang *et al.* (1998)[23]
2	USA	34	36	472	Delune *et al.* (1986)[24]
3	Republic of Ireland	37	26	350	Mc Aulay and Moran (1988)[25]
4	Greece	214	43	1130	Travidan *et al.* (1996)[26]
5	France	37	38	599	Lambrechts *et al.* (1992)[27]
6	Bangladesh	38	66	272	Mantazul *et al.* (1999)[28]
7	Taiwan	18	28	479	Chu *et al.* (1992)[29]
8	Egypt	17	18	316	Ibrahiem *et al.* (1993)[30]
9	Kuwait	36	6	227	Saad *et al.* (2002)[31]
10	Nigeria	16	24	35	Arogunjo *et al.* (2004)[32]
11	World	35	30	400	UNSCEAR (2000)[3]

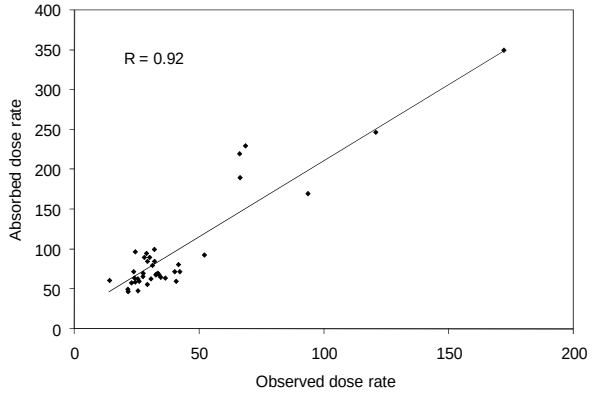

Figure 3. Correlation between absorbed dose rate and observed dose rate.

Radiological hazards

The calculated Ra_{eq} values from equation (2) are presented in table 5. It is observed that the site no. 31 shows maximum of 383.71±6.3 Bqkg^{-1} and minimum of 28.18±4.2 Bqkg^{-1} in site no.36. For the estimation of radiological consequences instead of comparing the average values, maximum value is taken into account. The maximum Ra_{eq} value of Cauvery (383.71±6.3 Bqkg^{-1}) river is slightly higher than the international recommended limit [6] (370 Bqkg^{-1}). Rizzo *et al.* [14] reported the Ra_{eq} value of sedimentary silicic sand varies from 10 to 53 Bqkg^{-1} with a mean of 34±14 Bqkg^{-1} for 6 samples. The mean value of silicic sand is two times lower than the present study and ten times lower than the international recommended value (370 Bqkg^{-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.

From table 4, the maximum values of H_{ex} and H_{in} are observed in site no. 31 (1.036±0.53, 1.094±0.48). The hazard indices are to be higher than unity, which may cause harm to people living in this region.

Radioactive heat production (RHP)

In the present study, the heat production rate ranges from 0.1858±0.07 μWm^{-3} (site no.36) to 3.0389±0.75 μWm^{-3} (site no.31) with a mean value of 0.5568± 0.06 μWm^{-3}. This shows that the low RHP rate (below 1μWm^{-3}) except site no. 21, 22, 23, 30, 31 and 35 are observed. The overall heat generation mainly depends on ^{232}Th amount (71.41%). However, an increase in the concentrations of ^{238}U, ^{232}Th and ^{40}K reflects the integrated effect of heat production rate [5, 15].

Activity concentration index

According to the European Union [16], building materials should be exempted from all restrictions concerning their radioactivity. The excessive gamma radiation due to those materials causes the increase of the annual effective dose received by an individual by a maximum value of 0.3 mSvy^{-1}. Effective doses exceeding the dose criterion of 1 mSvy^{-1} should be taken into account in terms of radiation protection. The estimated activity concentration index is calculated

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and listed in table 3. Values of index I ≤1 correspond to 0.3 $mSvy^{-1}$, while I ≤3 correspond to 1 mSv/y. Thus, the activity concentration index should be used only as a screening tool for identifying materials which might be of concern to be used as covering material [1]. In the present study, the calculated gamma activity concentration index ranges from 0.28 (site no. 36) to 3.82 (site no. 31). The entire measured samples exhibit I<1 except site nos. 21, 22, 23, 30, 31 and 35, which corresponding to a recommended annual effective dose criterion of 0.3 $mSvy^{-1}$. This indicates that the Cauvery River sediments can be safely used as building materials except site nos. 21, 22, 23, 30, 31 and 35.

Correlation between activity concentrations

Correlation between the activity concentrations of the three elements (^{238}U, ^{232}Th

Table 4. Hazard indices, radium equivalent, radioactive heat production rate, Activity utilization index of Cauvery river sediments.

Site No.	H_{ex}	H_{in}	Ra_{eq} $BqKg^{-1}$	RHP μWm^{-3}	Activity concentration index
1	0.1506±0.01	0.1673±0.03	55.78±5.2	0.3166±0.05	0.58
2	0.1541±0.02	0.1637±0.04	57.09±5.6	0.2846±0.07	0.64
3	0.1727±0.04	0.1867±0.06	63.94±6.5	0.3263±0.06	0.66
4	0.1562±0.06	0.1633±0.02	57.85±5.4	0.2765±0.03	0.65
5	0.1610±0.07	0.1646±0.03	59.62±5.2	0.2861±0.08	0.68
6	0.1689±0.03	0.1760±0.01	62.56±5.8	0.3237±0.05	0.65
7	0.1833±0.04	0.1918±0.04	67.90±6.1	0.3780±0.04	0.64
8	0.1925±0.02	0.2027±0.05	71.28±7.3	0.4265±0.08	0.62
9	0.2294±0.05	0.2411±0.06	84.96±6.5	0.5416±0.09	0.71
10	0.2035±0.06	0.2160±0.03	75.37±5.6	0.4698±0.04	0.64
11	0.1806±0.03	0.1958±0.07	66.89±6.3	0.4152±0.06	0.57
12	0.1357±0.04	0.1410±0.09	50.25±5.2	0.2711±0.03	0.57
13	0.2253±0.07	0.2370±0.03	83.44±4.8	0.5276±0.06	0.71
14	0.1759±0.06	0.1850±0.02	65.14±5.3	0.3719±0.05	0.61
15	0.1289±0.02	0.1358±0.06	47.72±6.8	0.2358±0.07	0.58
16	0.1587±0.04	0.1632±0.04	58.79±5.9	0.3155±0.09	0.59
17	0.1393±0.06	0.1456±0.03	51.59±5.2	0.2744±0.02	0.55
18	0.1289±0.07	0.1361±0.05	47.73±4.8	0.2591±0.04	0.53
19	0.1877±0.09	0.1935±0.02	69.50±6.5	0.4245±0.05	0.63
20	0.2383±0.08	0.2434±0.03	88.26±7.1	0.5790±0.06	0.77
21	0.3923±0.02	0.4004±0.05	145.29±4.2	1.1539±0.56	1.42
22	0.3857±0.02	0.3966±0.04	142.86±4.3	1.0316±0.42	1.27
23	0.3930±0.04	0.4118±0.05	145.55±4.6	1.0180±0.48	1.21
24	0.1725±0.01	0.1831±0.02	63.89±3.8	0.4107±0.03	0.53
25	0.1242±0.03	0.1293±0.02	46.00±3.9	0.2603±0.06	0.46
26	0.1165±0.02	0.1205±0.03	43.16±4.1	0.2285±0.08	0.43
27	0.1186±0.02	0.1220±0.04	43.91±4.2	0.2773±0.09	0.41
28	0.1538±0.04	0.1672±0.05	56.95±4.6	0.3741±0.05	0.47
29	0.1890±0.05	0.2130±0.01	69.99±4.7	0.5242±0.07	0.51
30	0.7244±0.08	0.7720±0.02	268.29±5.8	2.0820±0.62	2.55
31	1.0361±0.53	1.0941±0.48	383.71±6.3	3.0389±0.75	3.82
32	0.1396±0.03	0.1636±0.03	51.68±3.8	0.3834±0.06	0.45
33	0.1418±0.04	0.1498±0.02	52.53±4.2	0.2552±0.07	0.78
34	0.1414±0.07	0.1734±0.04	52.35±4.3	0.4509±0.02	0.34
35	0.4809±0.09	0.5160±0.06	178.12±6.4	0.8380±0.05	2.74
36	0.0761±0.06	0.0867±0.01	28.18±4.2	0.1858±0.07	0.28
37	0.1352±0.08	0.1478±0.09	50.07±4.8	0.3493±0.09	0.39
38	0.2442±0.03	0.2676±0.08	90.44±6.5	0.6473±0.04	0.72
39	0.3027±0.05	0.3356±0.07	112.11±7.2	0.9009±0.06	0.85
Max	1.0361±0.53	1.0941±0.48	383.71±6.3	3.0389±0.75	3.82
Min	0.0761±0.06	0.0867±0.01	28.18±4.2	0.1858±0.07	0.28
Mean	0.2292±0.04	0.2436±0.05	84.89±5.6	0.5568±0.06	0.89

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and ^{40}K) is shown in figures 4 to 6. The correlation between ^{238}U and ^{232}Th is found to be weak (R = 0.73) which indicates that the presence of monazite mineral in sediments is less likely. The ^{232}Th values are almost less than unity, because ^{232}Th activities are usually greater than ^{238}U activities in the crust of origin of the rivers. 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 oxidizing natural waters, whereas thorium is much less soluble. This indicates that the water flow of Cauvery river is maximum [17].

According to Abdel Hady *et al.* [18], the $^{40}K/^{232}Th$ ratio has a special significance and varies with clay mineral type. Because, the concentration of ^{40}K and ^{232}Th depends 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 value (site nos. 33 and 35) of $^{40}K/^{232}Th$ may indicate the presence of feldspars or clay or combination of both as maximum. These results were confirmed by FTIR analysis [19]. The activity ratio of $^{40}K/^{238}U$ and $^{40}K/^{232}Th$ give no obvious trend with poor correlation.

Table 5. Comparison of present results with the corresponding world average values.

Radiological parameters	Present results (Average)	World average	Ratio of the Present average/world average
^{238}U Bqkg^{-1}	5.31	33	0.16
^{232} Th Bqkg^{-1}	34.04	45	0.75
^{40}K Bqkg^{-1}	401.11	420	0.96
Absorbed dose rate	40.73	51	0.79
Indoor Annual effective dose equivalent mSvy^{-1}	0.25	3.4	0.71
Internal hazard index, Bqkg^{-1}	0.23	0.5	0.46
External hazard index, Bqkg^{-1}	0.24	0.5	0.48
Radium equivalent activity Bqkg^{-1}	84.89	129.7	0.65
Radiation heat production rate µWm^{-3}	0.5568	1	0.55
Activity concentration index	0.89	1	0.89

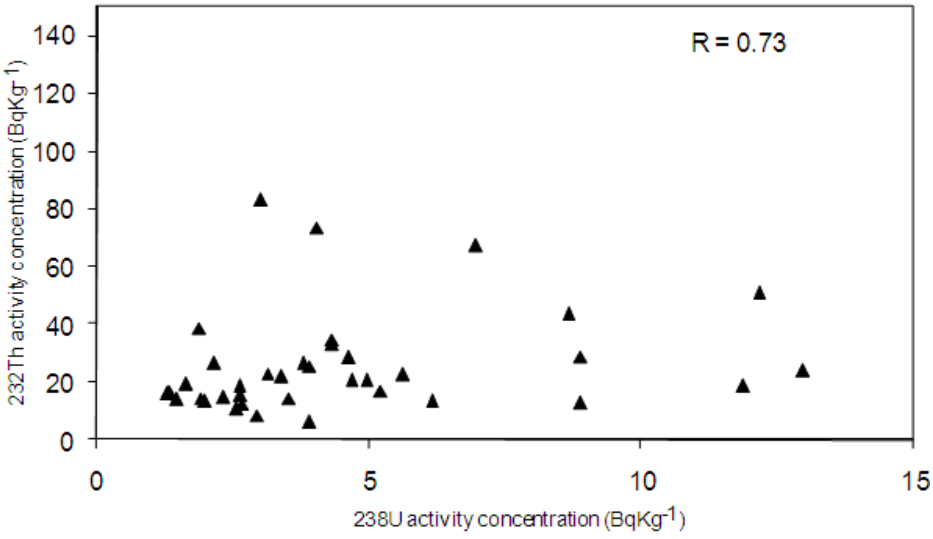

Figure 4. Correlation between ^{238}U and ^{232}Th.

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The linear correlation between Ra_{eq} and ^{232}Th activity as shown in figure 7 may indicate the river starting from laterite origin. Similar findings have also been reported in literature for lateritic soil samples of Karnataka [10] and Taiwan [20]. The Karnataka state is the origin of Cauvery River.

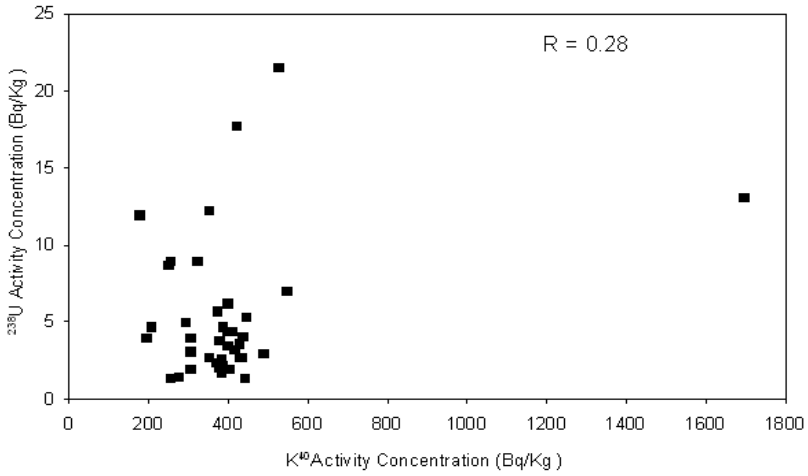

Figure 5. Correlation between ^{40}K and ^{238}U.

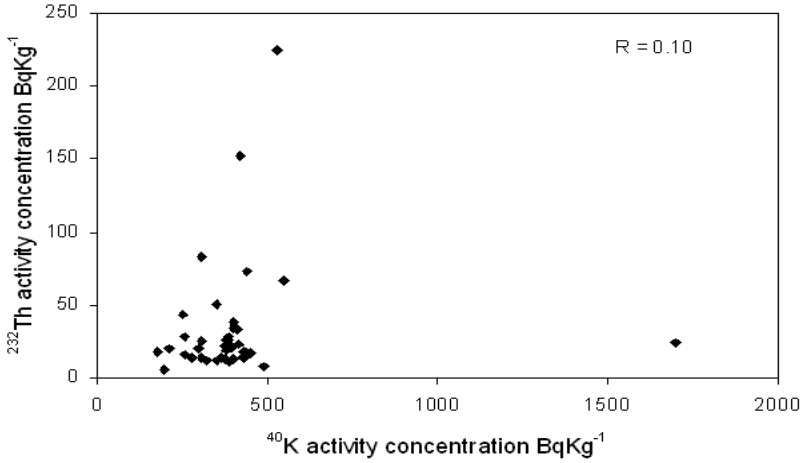

Figure 6. Correlation between ^{40}K and ^{232}Th.

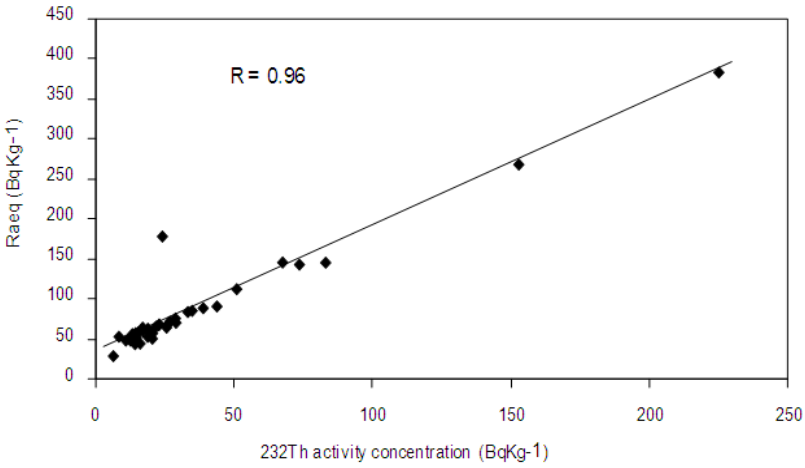

Figure 7. Correlation between Ra_{eq} and ^{232}Th.

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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 concentration of ^{238}U, ^{232}Th and ^{40}K for Cauvery river is lower than the international recommended limit. The mean annual effective equivalent dose is 0.71 times with that of international recommended limit ($70\mu Svy^{-1}$). In the present study, the mean value of Ra_{eq}, H_{ex} and H_{in} found are lesser than the international recommended limit of 370 $Bqkg^{-1}$, 1 and 1 respectively and the mean value of activity concentration index and RHP rate is also lesser than the international recommended limit. Therefore Cauvery river sediments do not pose source of radiation hazard when used as building materials. Among all the sites, the site no. 21, 22, 23, 30, 31 and 35 show the higher values of absorbed, observed, annual effective equivalent dose, radium equivalent, hazard indices, activity concentration index and RHP rate. This implies that inhabitance of those areas are subjected to increase radiation exposure, which is harmful to human health. So those sites can be avoided for building construction.

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