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Radioactive heat production rate and excess lifetime cancer risk of sand from two major rivers in India – A comparative study

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► ***Original article***

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ABSTRACT

Background**:** Rivers are having a major role in crop cultivation, power generation, and sand used for mining and construction. ***Materials and Methods*****:** The gamma ray spectrometer was used to estimate uranium, thorium, and potassium (238U, 232Th, 40K), and its average is tabulated. Related parameters like absorbed dose (D), Annual Effective Dose Equivalent (AE), and also hazard indices (H) to assess radiation exposure. Additional parameters like radium equivalent (R_{eq}), radioactive heat production (RHP), Excess Lifetime Cancer Risk (ELCR), Alpha (I_{α}), and Gamma Index (I_g), Annual Gonadal dose (AGD) are computed and correlated with the related parameters to understand radioactive penetration to the living things. ***Results*****:** This study exhibits the radioactive contaminants in Cauvery are in control by comparing to the world average except for C20. The average radiological risk of the Palar river is slightly higher and site no.6 shows three times the world average. ***Conclusion*****:** This radioactive pollution can cause serious health effects for the people living in and around those two sites (C20 and P7) who are highly exposed to radiation, which leads to harmful effects on living things.

INTRODUCTION

Several kinds of pollutants, in some cases highly harmful to health, can seriously affect the fluvial system and soil [1]. Environmental gamma radiation is the backbone of today's atmospheric pollution. Soil is one of the major components in the life cycle. The mixtures of organic, inorganic materials, and metal compounds from anthropogenic sources become soil. Concrete and plastering in the construction field are made up of high-quality sand. With the increase in construction activities, river sand demand is continuously increased. Our environment is dangerously changed by the continuous excavation of river sand. Which is reflected in river shore sliding, and water table dropdown through soil erosion [2]. The aggregation of rare earth (radioactive), heavy metals, and magnetic minerals through emissions of rapidly expanding industrial areas, disposal of heavy metal wastes, mine tailings, fertilizers and pesticides, sewage and animal outcomes, discharge of petrochemicals, and atmospheric deposition is contaminating river sand [3,4]. Construction sand should have been strong and clean with low content of organic matter, clay, shells, and chloride.

Blending of natural radioactive isotopes with rocks, sand, soils, sediments, and water and artificial nuclear weapons, nuclear medicines like anthropogenic sources produce atmospheric pollution. Atmospheric exposure to radiation occurs at various levels in the Environment, which changes due to geological variations in different regions of the world. The mechanical and chemical processes spread radionuclides into the sand aggregation. The origination of rocks decides the level of terrestrial background radiation. Fossils like sedimentary rocks emit low radiation whereas granites like Igneous rocks containing dark-colored heavy minerals usually emit higher radiation.

Earth crust, other soil, water, and vegetation like earthbound materials are major sources of environmental radiation. This environmental radiation is mainly derived from major isotopes uranium, thorium, potassium, and the daughter product of uranium such as radium, radon, and thorium. The implication of natural radiation is because of exposure and irradiation of body parts from radon and its daughter's inhalation. The radioactive exposure to living things mainly depends on gamma radiation doses from natural sources [5].

Excessive-life time cancer risks due to the concentration of radionuclides and heavy metal concentrations are measured and correlated in the principal and third longest river of Western African river Niger[6]. Ali *et al.* (2021) investigated the radiation hazard indices from sand samples of Ma'rib

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Governorate in Yemen, where the majority of oil and gas facilities are installed [7].

Daulta *et al.* (2019) conducted natural radioactivity study in soil from 30 sampling sites to find human exposure in Sonipat district, Haryana, India using HPGe detectors. The radiation parameters were detected. From that analysis, the safe annual Gonadal equivalent dose (1 Sv/y) and also negligible lifetime cancer risk was obtained. No significant health danger from other radioactive parameters like Gamma index (I), outside (Hex), and interior (Hin) hazard index is observed from the same locations [8].

River sand became a major portion of building construction. This study aims to compare the radioactive parameters especially radioactive heat production rate and excess lifetime cancer risk to make statistics on radiation exposure. The above two radioactive parameters produce serious health problems for the exposed individuals or genetic disorders that may be reflected in their descendants.

MATERIALS AND METHODS

Sample preparation

The sand samples are collected from 26 and 21 locations of the Cauvery and Palar rivers respectively as shown in figure 1. The length and breadth of the rivers are dry during summer. The sampling area of 1m2 (surface and 2 feet depth) is selected from the right, left, and center of the sites, and 2kg of the sample were collected and dried at 100-110˚C in an oven for about 30 hours, pebbles and stones can be removed through sieves the homogenized sample is filled in a 250ml silicon and polythene tape sealed airtight PVC container and maintain for a minimum of 30 days before being taken for gamma-ray spectrometric analysis.

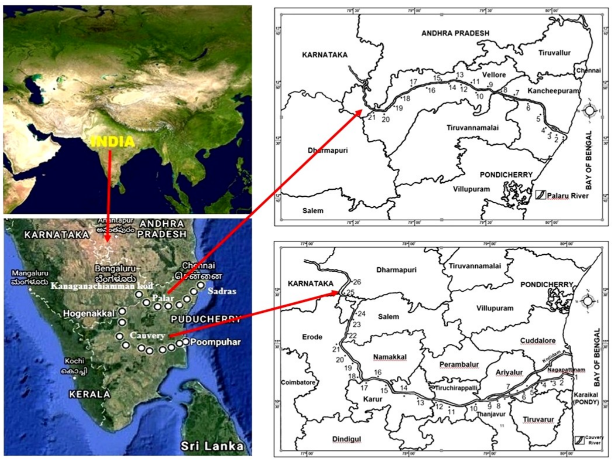

Figure 1. Map of Cauvery and Palar river in Tamilnadu, India.

Gamma ray spectrometry

Gamma spectrometer includes a 3×3 inches NaI (Tl) detector employed with adequate lead shielding which reduced the background by a factor of about 95%. Samples are exposed to gamma spectral analysis with a counting time of 10,000 s. With the help of count spectra, the concentration of radionuclides is determined in Bq/kg. The content of radioactivity is measured in soil samples by calibrating the efficiency of the instruments for various energies with the known sample geometry. The gamma energies 1460 keV for40K, 1764 keV for uranium from daughter product 214Bi, and 2613 keV for thorium are selected. The minimum detectable values of the above-said detector system for uranium, thorium, and potassium isotopes are 2.21, 2.11, and 8.5 $Bqkg^{-1}$ respectively for a counting time of 10,000s.

Radiological dose parameters

There is no proper statistical evidence for cancer, the average lifetime of the people, typical health diseases, etc. in the study area. For assessing the penetration of radiation to understand health risk, the maximum radioactivity is to be considered instead of average radioactivity [9]. The Radiological dose parameters such as Indoor (D_{in}) and Outdoor (D_{out}) Absorbed dose, Internal (AE_{in}) and External (AE_{ex}) Annual Effective Dose Equivalent (AED), and Annual Gonadal dose equivalent (AGD) is also useful in predicting the health risk, which are calculated and correlated (Table3). This survey may be utilized to limit radiation exposure to living things while river sand is used as building materials.

Indoor (D_{in}) and outdoor (D_{out}) absorbed dose

The equation is given below[10] is used to evaluate D_{in} and D_{out} with the conversion factors of ^{238}U, ^{232}Th, and ^{40}K into doses (nGy/h per Bq/kg).

$$D_{in}=(0.92C_U+1.1C_{Th}+0.081C_K) \quad (1)$$

$$D_{out}=(0.427C_U+0.662C_{Th}+ 0.043C_K) \quad (2)$$

Where 0.92 and 0.427, 1.1 and 0.662, 0.081and 0.043 are conversion factors of the elemental activities CU, CTh, and CK in Bq/kg respectively.

Internal (AE_{in}) and external (AE_{ex}) annual effective dose equivalent

Since the sand is mainly used as building materials, the determination of AE_{in} & AE_{out} of river sand becomes more essential. In determining AE_{in} & AE_{out}, outdoor and indoor occupancy factor is to be considered based on the living style of the people. The residents (male and female) near the rivers would spend about 8 hrs outside the home but somewhat larger indoors (office, classroom, or laboratory), 12 hrs in small indoors (home), and the remaining 4hrs outdoors (beach, road like). The majority population adopted the above classification lifestyle in and around the location, they are either office workers, laborers or students. Therefore 4/24 or 0.17 (17%) and 20/24 or 0.73 (73%) are adopted as indoor and outdoor occupancy factors respectively with the conversion factor of 0.70Sv/Gy to convert

Din and Dout (nGy/h) to AEin & AEout (μSv/y) for this study[11].

$$AE_{in}(\mu Svy^{-1})=D_{in}\ nGyy^{-1}\times 8760\ h\times 0.7\ SvGy^{-1}\times 0.2\times 10^{-3} \quad (3)$$

$$AE_{out}(\mu Svy^{-1})=D_{out}\ nGyy^{-1}\times 8760\ h\times 0.7\ SvGy^{-1}\times 0.8\times 10^{-3} \quad (4)$$

Annual gonadal dose equivalent (AGD)

AGD is a measure of the genetic significance of the yearly exposure of the population's reproductive organs (gonads). The gonads (bone marrow, bone surface cells, etc.,) are usually radiosensitive. A single dose of 0.3Gy to the testes may result in temporary sterility among men; for women, a 3-Gy dose to the ovaries may lead to temporary sterility. Therefore, the Annual Gonadal dose equivalent is calculated using the equation below [12].

$$AGD=(3.09C_U+4.18C_{Th}+0.314C_K)/1000 \quad (5)$$

Where 3.09, 4.18, and 0.314 are conversion factors of Cu, C_{Th}, and C_K in $Bqkg^{-1}$ respectively.

Radiological hazardous parameters

Radiological hazardous indices such as H_{in}, H_{out}, Alpha Index (Iα), Gamma Index (Ig), Activity Utilization Index (AUI), and Annual Gonadal Dose Equivalent (AGD) are calculated and correlated (table 4).

Internal (H_{in}) and external (H_{ex}) hazard index

Radon, a gaseous radionuclide, and its short life daughters are hazardous to the breathing system of the human body. The direct gamma radiation exposure to living things becomes external exposure whereas the inhalation of radon (^{222}Rn), thoron (^{220}Rn), and their short-living decay products produce internal exposure. Internal and external Hazardous indices are given by the following equation [13].

$$H_{in} = \left(\frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810}\right) \leq 1 \quad (6)$$

$$H_{ex} = \left(\frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810}\right) \leq 1 \quad (7)$$

Radium equivalent (R_{eq})

The total activity does not provide an exact indication of the radiation hazard associated with the materials [14, 15]. Radium equivalent activity yields gamma index gives from the combination of ^{226}Ra or ^{238}U ^{232}Th and ^{40}k in the sample [16].

$$R_{eq}=(C_U+AC_{Th}+BC_K \quad (8)$$

Where A (1.43), B (0.077) are exposure constants.

For the safer utilization of materials, the annual limit on the gamma ray dose (external) is to be a maximum of 0.3 mSv, this corresponds to the value of 370Bq/kg.

Internal ($ELCR_{in}$) and external ($ELCR_{out}$) excess lifetime cancer risk

Cancer is a life-threatening disease and the percentage of this disease increases all over the world due to various reasons. One of the reasons is the radiation effect on the biological cell. Excess lifetime cancer risk (ELCR) is computed using the below equation [17, 18].

$$ELCR_{in}=E_{in}\times DL\times RF \quad (9)$$

$$ELCR_{out}=E_{out}\times DL\times RF \quad (10)$$

where E_{in} and E_{out}, DL, and RF are the indoor and outdoor annual effective dose equivalent, the average duration of life (70years) and risk factor (Sv^{-1}) or fatal cancer risk per Sievert respectively. For stochastic effects, ICRP 60 uses values of 0.05 for the public [19].

Alpha (I_α) and gamma activity concentration index (I_g)

The alpha or internal hazard indices were proposed to evaluate the exposure level due to radon inhalation emanated from building materials. The alpha index is estimated by the following formula [20].

$$I_\alpha = \frac{C_u}{200Bqkg^{-1}} \quad (11)$$

To check out whether the safety requirements for building materials are being fulfilled, an activity concentration index or external hazard, *Iγ is* calculated as proposed by the European Commission [10]:

$$I_\gamma = \frac{C_U}{300Bqkg^{-1}} + \frac{C_{Th}}{200Bqkg^{-1}} + \frac{C_K}{3000Bqkg^{-1}} \quad (12)$$

Where; C_U, C_{Th}, and C_K are the specific activities of uranium, thorium & potassium respectively in Bq/kg.

Activity utilization index (AUI)

To simplify the estimation of air dose rates from different amalgamations of the above said basic radionuclides in sand and soils. This AUI is formulated by substituting the befitting conversion factors [21].

$$AUI = \left(\frac{C_U}{50\ Bqkg^{-1}}\right)f_U + \left(\frac{C_{Th}}{50\ Bqkg^{-1}}\right)f_{Th} + \left(\frac{C_K}{500\ Bqkg^{-1}}\right)f_K \quad (13)$$

where C_U, C_{Th}, and C_K are the actual values of the activities per unit mass (Bq/kg) of 238U, 232Th, and 40K in the building materials considered; *fU, f*Th, and *f*K belong to 0.462, 0.604 and 0.041 respectively are the fragmentary contributions due to gamma radiation from the above environmental radioactive nuclides.

Hazard percentage (H_R)

The hazard percentage and contribution due to exhaled radon in sediment samples were estimated

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using the following relation [22].

$$H_R\,\% = 100 \times \left(\frac{Hin}{Hext} - 1\right) \quad (14)$$

HR% is the radon hazard in %. The fishermen, consumers of aquatic species, tillers, and residents could be prone to health challenges due to ingestions of contaminated aquatic species and inhalation of radon exhaled from houses built by the sediment samples.

Radioactive heat production (RHP)

Radioactive heat production rate decides the thermal evaluation of the lithosphere and the above said environmental radioactive isotopes contributed more to this terrestrial heat flow. These basic radioactive elements (^{238}U, ^{232}Th, and ^{40}K) become the key factor in analyzing the nature of the mantle, crust of the earth, and their heat-generating potential [23]. The RHP rate in and around the Cauvery and Palar rivers is estimated through the following relation [24].

$$A=10^{-5}\times\rho\times(9.52\ C_U+2.56\ C_{Th}+3.48C_K) \quad (15)$$

Where A - RHP in μWm^{-3}, ρ - sample density in Kgm^{-3}, CU and CTh – uranium and thorium concentration in ppm, and CK - potassium concentration in %.

RESULTS

Activity concentration of the ^{238}U, ^{232}Th, and ^{40}K radionuclides in the river sand collected from Cauvery and Palar Rivers (table 1) are already published by the same authors [13,14] and its minimum, maximum, mean along world recommended limit is listed in table 2. Indoor and outdoor values for the above-derived parameters, annual gonadal dose equivalent (AGD), alpha (I_α) and gamma (I_g) concentration index, and activity utilization index (AUI) are additionally calculated and its minimum, maximum and average values are tabulated in table 3 &4.

Table 1. Sampling sites and its basic radioactive parameters.

CAUVERY					PALAR				
S. No.	Site Name	U	Th	K	S. No.	Site Name	U	Th	K
1	Poombhuhar	6.15	13.23	398.91	1	Sadras	9.06	11.14	542.08
2	Mayiladuthurai	5.2	16.92	448.62	2	Paandoor	9.86	32.79	584.52
3	Aduthurai	1.32	16.94	442.6	3	Paalur	12.45	53.85	668.23
4	Kumbakonam	3.13	22.87	416.47	4	Chengalpattu	8.86	7.29	707.13
5	Pappanasam	4.32	34.79	401.15	5	Valajabath	7.65	10.38	824.08
6	Tiruvaiyar	5.61	22.72	373.93	6	Kanchipuram	17.03	254.06	755.31
7	Thirukkattupalli	1.98	13.44	377.27	7	Vizhar	10.12	25.14	826.13
8	Kallanai	4.32	33.2	410.94	8	Perumbakkam	10.05	21.76	873.60
9	Srirangam	2.56	10.85	385.05	9	pudhupadi	11.21	44.16	703.11
10	Mukkombur	1.64	19.32	383.42	10	Ranipet	11.57	51.98	852.19
11	Kulithalai	2.67	12.49	353.25	11	Rathnagiri	5.64	20.59	654.29
12	Krishnarayapuram	1.88	38.75	402.22	12	Vellore	9.03	62.52	731.40
13	Mayanoor	3.01	82.93	307.61	13	Virungipuram	8.91	21.15	707.18
14	Puliyur	6.96	67.4	548.2	14	Pallikonda	8.67	6.13	756.28
15	Vangal	3.9	25.53	304.98	15	Madhanoor	8.84	20.89	884.78
16	Velayuthampalayam	1.89	14.44	304.73	16	Ambur	9.03	33.78	731.16
17	Noyyal	1.29	15.98	256.71	17	Jothiveeraraghavapuram	8.75	19.95	779.80
18	Kodumudi	4.95	20.5	294.62	18	Vaniambadi	8.93	22.79	821.96
19	Solasiranmani	8.88	28.93	256.38	19	Ambalur	18.44	52.42	483.49
20	Erode	21.49	224.79	529.44	20	Avarakuppam	9.62	19.66	532.67
21	Bavani	8.88	12.61	321.71	21	Kanaganachiammankoil	8.83	11.64	858.22
22	Kalvadangam	2.94	8.35	488.91					
23	Ammapettai	11.87	18.71	178.18					
24	Thekkanoor	12.97	24.03	1698.48					
25	Mettur	3.91	6.33	197.58					
26	Hoggenakal	12.16	50.85	353.66					

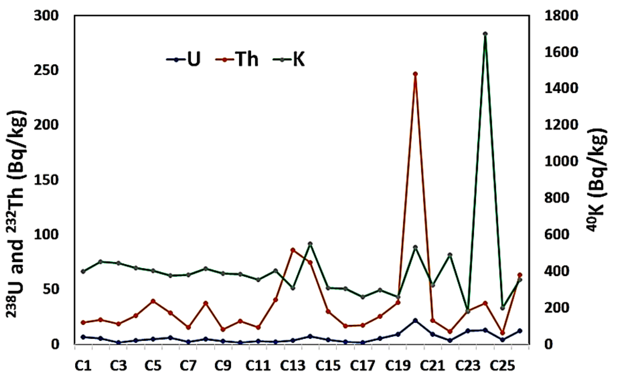

Figure 2. Distribution of Radionuclides in Cauvery river.

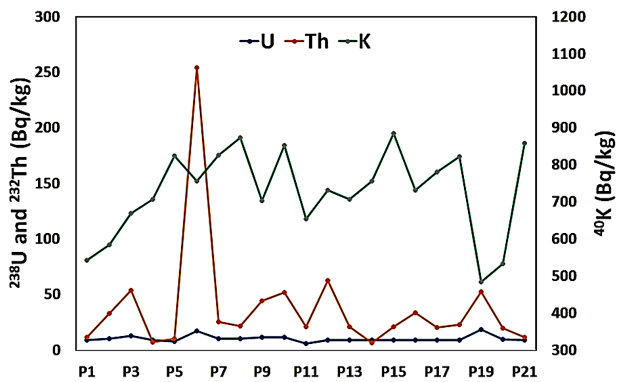

Figure 3. Distribution of Radionuclides in Palar river.

Table 2. Radiological dose and hazardous parameters, magnetic susceptibility and heavy metals.

Activity Parameters	Cauvery River			Palar river			Ratio of Present/ world averages		World Average[a]
	min	max	Average	min	max	Average	Cauvery	Palar	
^{238}U	1.29	**21.49**	5.31	5.64	18.44	9.80	0.152	0.28	35
^{232}Th	6.33	**224.79**	**34.04**	6.13	254.06	**36.49**	1.13	1.22	30
^{40}K	178.18	**1698.48**	**401.11**	483.49	884.78	**742.46**	1	1.86	400
D_{in}	26.56	**309.92**	74.83	64.49	356.31	**109.3**	0.89	1.3	84
D_{out}	14.11	**171.98**	40.73	34.12	198.03	**58.85**	0.8	1.15	51
OD	47	**350**	96.1	75	350	137.14	NA	NA	NA
AE_{in}	0.13	**1.52**	0.367	0.135	1.58	**0.38**	1.22	1.27	0.3
AE_{out}	0.17	**0.21**	0.049	0.15	0.18	0.042	0.7	0.6	0.07
H_{in}	0.09	**1.09**	0.24	0.21	1.23	0.35	0.24	0.35	<1
H_{ex}	0.08	**1.04**	0.23	0.18	1.18	0.32	0.23	0.32	<1
Ra_{eq}	28.18	**383.71**	84.89	66.73	**438.50**	119.16	0.23	0.32	370
RHP	0.19	**3.04**	0.56	0.34	**3.31**	0.72	0.56	0.72	1
AUI	0.13	**2.96**	0.48	0.22	**3.29**	0.62	0.015	0.03	2
$ELCR_{in}$	0.46	**5.32**	**1.28**	0.59	**3.4**	1.01	1.11	0.87	1.16
$ELCR_{out}$	0.06	**0.74**	0.1748	0.15	**0.85**	0.25	0.61	0.86	0.29
Iα	0.01	0.11	0.03	0.03	0.09	0.05	0.03	0.05	2
Ig	0.11	**1.37**	0.32	0.27	**1.58**	0.46	0.32	0.46	2
AGD	0.1	**1.17**	0.29	0.25	1.35	**0.42**	0.97	1.4	0.3
H_R	2.07	**22.69**	7.27	3.89	14.13	9.29	NA	NA	NA

Table 3. Radiological dose parameters.

CAUVERY							PALAR						
S.No.	$_{in}$D	$_{out}$D	OD	AE_{in}	AE_{out}	AGD	S.No.	$_{in}$D	$_{out}$D	OD	AE_{in}	AE_{out}	AGD
C1	52.52	28.02	90	0.26	0.03	0.200	P1	64.50	34.12	75	0.32	0.04	0.245
C2	59.73	32.05	95	0.29	0.04	0.228	P2	92.49	49.77	110	0.45	0.06	0.351
C3	55.70	30.15	100	0.27	0.04	0.214	P3	124.82	67.60	150	0.61	0.08	0.473
C4	61.77	33.49	85	0.30	0.04	0.236	P4	73.45	38.73	100	0.36	0.05	0.279
C5	74.74	40.77	90	0.37	0.05	0.285	P5	85.21	45.17	110	0.42	0.06	0.326
C6	60.44	32.63	80	0.30	0.04	0.230	P6	356.31	198.03	350	1.75	0.24	1.352
C7	47.16	25.44	70	0.23	0.03	0.181	P7	103.88	55.51	110	0.51	0.07	0.395
C8	73.78	40.20	65	0.36	0.05	0.281	P8	103.94	55.41	120	0.51	0.07	0.396
C9	45.48	24.41	60	0.22	0.03	0.174	P9	115.84	62.53	120	0.57	0.08	0.440
C10	53.82	29.22	64	0.26	0.04	0.206	P10	136.85	73.97	150	0.67	0.09	0.521
C11	44.81	24.11	68	0.22	0.03	0.171	P11	80.84	43.37	135	0.40	0.05	0.309
C12	76.93	42.24	63	0.38	0.05	0.294	P12	136.32	74.26	120	0.67	0.09	0.519
C13	118.91	66.18	72	0.58	0.08	0.453	P13	88.74	47.39	120	0.44	0.06	0.338
C14	124.95	68.53	85	0.61	0.08	0.475	P14	75.98	40.04	140	0.37	0.05	0.290
C15	56.37	30.68	97	0.28	0.04	0.215	P15	102.78	54.83	140	0.50	0.07	0.392
C16	42.31	22.91	56	0.21	0.03	0.162	P16	104.69	56.34	180	0.51	0.07	0.399
C17	39.56	21.54	60	0.19	0.03	0.151	P17	93.16	49.70	140	0.46	0.06	0.355
C18	50.97	27.55	64	0.25	0.03	0.194	P18	99.86	53.36	140	0.49	0.07	0.381
C19	60.76	32.84	68	0.30	0.04	0.229	P19	113.79	61.32	140	0.56	0.08	0.428
C20	309.92	171.99	72	1.52	0.21	1.172	P20	73.62	39.26	110	0.36	0.05	0.279
C21	48.10	25.48	220	0.24	0.03	0.181	P21	90.44	47.93	120	0.44	0.06	0.345
C22	51.49	27.48	190	0.25	0.03	0.198							
C23	45.93	24.39	230	0.23	0.03	0.171							
C24	175.94	93.54	63	0.86	0.11	0.674							
C25	26.56	14.11	58	0.13	0.02	0.101							
C26	95.77	52.08	50	0.47	0.06	0.361							

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Table 4. Radiological hazardous parameters.

CAUVERY											PALAR										
S. No.	Ra_{eq}	$ELCR_{in}$	$ELCR_{out}$	H_{ex}	H_{in}	H_R	AI	AUI	GI	RHP	S. No.	Ra_{eq}	$ELCR_{in}$	$ELCR_{out}$	H_{ex}	H_{in}	H_R	AI	AUI	GI	RHP
C1	55.78	0.90	0.12	0.15	0.17	11.03	0.03	0.25	0.22	0.32	P1	66.73	1.11	0.15	0.18	0.20	13.59	0.05	0.26	0.27	0.36
C2	63.94	1.03	0.14	0.17	0.19	8.14	0.03	0.29	0.25	0.34	P2	101.76	1.59	0.21	0.27	0.30	9.70	0.05	0.54	0.39	0.60
C3	59.62	0.96	0.13	0.16	0.16	2.22	0.01	0.25	0.24	0.28	P3	140.91	2.14	0.29	0.38	0.41	8.84	0.06	0.82	0.53	0.85
C4	67.90	1.06	0.14	0.18	0.19	4.61	0.02	0.34	0.26	0.36	P4	73.73	1.26	0.17	0.20	0.22	12.03	0.04	0.23	0.30	0.32
C5	84.96	1.28	0.17	0.23	0.24	5.09	0.02	0.49	0.32	0.51	P5	85.95	1.46	0.19	0.23	0.25	8.91	0.04	0.26	0.35	0.37
C6	66.89	1.04	0.14	0.18	0.20	8.39	0.03	0.36	0.26	0.40	P6	438.49	6.12	0.85	1.18	1.23	3.89	0.09	3.29	1.58	3.16
C7	50.25	0.81	0.11	0.14	0.14	3.94	0.01	0.21	0.20	0.25	P7	109.68	1.78	0.24	0.30	0.32	9.24	0.05	0.46	0.43	0.58
C8	83.44	1.27	0.17	0.23	0.24	5.18	0.02	0.47	0.32	0.51	P8	108.43	1.78	0.24	0.29	0.32	9.28	0.05	0.43	0.43	0.55
C9	47.72	0.78	0.10	0.13	0.14	5.37	0.01	0.19	0.19	0.24	P9	128.50	1.99	0.27	0.35	0.38	8.73	0.06	0.69	0.49	0.81
C10	58.79	0.92	0.13	0.16	0.16	2.79	0.01	0.28	0.23	0.32	P10	151.52	2.35	0.32	0.41	0.44	7.64	0.06	0.80	0.58	0.93
C11	47.73	0.77	0.10	0.13	0.14	5.60	0.01	0.20	0.19	0.25	P11	85.46	1.39	0.19	0.23	0.25	6.61	0.03	0.35	0.34	0.45
C12	88.26	1.32	0.18	0.24	0.24	2.13	0.01	0.52	0.33	0.58	P12	154.75	2.34	0.32	0.42	0.44	5.84	0.05	0.90	0.59	1.04
C13	145.29	2.04	0.28	0.39	0.40	2.07	0.02	1.05	0.53	1.06	P13	93.61	1.52	0.20	0.25	0.28	9.53	0.04	0.40	0.37	0.51
C14	145.55	2.15	0.29	0.39	0.41	4.79	0.03	0.92	0.54	0.97	P14	75.67	1.30	0.17	0.20	0.23	11.47	0.04	0.22	0.31	0.34
C15	63.89	0.97	0.13	0.17	0.18	6.11	0.02	0.37	0.24	0.41	P15	106.84	1.76	0.24	0.29	0.31	8.28	0.04	0.41	0.43	0.54
C16	46.00	0.73	0.10	0.12	0.13	4.11	0.01	0.22	0.18	0.25	P16	113.63	1.80	0.24	0.31	0.33	7.95	0.05	0.55	0.44	0.65
C17	43.91	0.68	0.09	0.12	0.12	2.94	0.01	0.23	0.17	0.25	P17	97.32	1.60	0.21	0.26	0.29	9.00	0.04	0.39	0.39	0.51
C18	56.95	0.88	0.12	0.15	0.17	8.70	0.02	0.32	0.22	0.37	P18	104.81	1.71	0.23	0.28	0.31	8.53	0.04	0.43	0.42	0.57
C19	69.99	1.04	0.14	0.19	0.21	12.70	0.04	0.45	0.26	0.53	P19	130.63	1.95	0.26	0.35	0.40	14.13	0.09	0.84	0.48	0.99
C20	383.71	5.32	0.74	1.04	1.09	5.61	0.11	2.96	1.37	3.13	P20	78.75	1.26	0.17	0.21	0.24	12.23	0.05	0.37	0.31	0.49
C21	51.68	0.83	0.11	0.14	0.16	17.20	0.04	0.26	0.20	0.36	P21	91.56	1.55	0.21	0.25	0.27	9.65	0.04	0.29	0.37	0.47
C22	52.53	0.88	0.12	0.14	0.15	5.60	0.01	0.17	0.21	0.25											
C23	52.35	0.79	0.10	0.14	0.17	22.69	0.06	0.35	0.19	0.43											
C24	178.12	3.02	0.40	0.48	0.52	7.29	0.06	0.55	0.73	0.80											
C25	28.18	0.46	0.06	0.08	0.09	13.89	0.02	0.13	0.11	0.17											
C26	112.11	1.64	0.22	0.30	0.34	10.86	0.06	0.76	0.41	0.79											

In the Cauvery River, the indoor absorbed dose rate (D_{in}) ranges 26.56 - 309.92 with an average of 74.83 nGy/h and the outdoor absorbed dose rate (D_{out}) ranges 14.11 - 171.98 with an average of 40.73 nGy/h. In Palar River the indoor (D_{in}) and outdoor (D_{out}) absorbed dose rates ranged from 64.5 to 356.31 with an average of 109.30 nGy/h and from 34.12 to 198.03 with an average of 58.85 nGy/h respectively. In Cauvery River the AE_{in} and AE_{out} range 26.56 to 309.92 with an average of 74.83 μSvy^{-1} and 14.11 to 171.98 with an average of 40.73 μSvy^{-1} respectively. In Palar River the AE_{in} ranges from 167.37 to 971.45 with an average of 288.69 μSvy^{-1} and AE_{out} ranges from 41.84 to 242.86 with an average of 72.17 μSvy^{-1}.

The Observed (*insitu*) gamma dose rate is also been measured using the Environmental Radiation Dosimeter (ERDM) at approximately 1m from the ground in each location of the rivers. In the present study, the OD ranges 47-350 with an average of 96.1 nGyh^{-1} and 75 - 350 with an average of 137.14 nGyh^{-1} for Cauvery and Palar River respectively. The ADG ranges 0.1 - 1.17 with an average of 0.29 mSvy^{-1} and 0.25-1.35 with an average of 0.42 mSvy^{-1} for the Cauvery and Palar rivers respectively. The maximum value of H_{in} and H_{ex} were observed in C20 (1.09 and 1.04) and P6 (1.23 and 1.18). The value of Iα and Ig is equal to the criterion of 2 corresponding to an effective dose of 0.3 mSv. The obtained higher values of Iα and Iγ are 0.11 & 1.37 in C20 (Cauvery) and 0.09 & 1.58 in P6 (Palar).

AUI varies from 0.13 to 2.96 with the mean of 0.48 and 0.22 to 3.29 with an average of 0.62 for Cauvery and Palar rivers respectively. Beretka and Mathew [15] reveal that *I* <2, which corresponds to an annual effective dose <0.3 mSv y^{-1}. The AUI of sites C20 and P6 is greater than 2. The indoor and outdoor excess lifetime cancer risk of Cauvery ranges from 0.46 to 5.32 and 0.06 to 0.7382 with an average of 1.28 and 0.17mSv/y respectively and the same parameters ranged from 0.59 to 3.4 and 0.15 to 0.85 with the corresponding average values of 1.01 and 0.25 mSv/y for Palar.

The Ra_{eq} ranges 28.18 – 383.71 with an average of 84.89 Bqkg^{-1} and 66.73 – 438.5 with an average of 119.16 Bqkg^{-1} for Cauvery and Palar respectively. The Ra_{eq} in C20 and P6 are slightly higher than the world average. H_R% indicates the radon exhalation capacity of the sample and the sampling sites from the possibility of H_{in} by comparing to its H_{ex}, which ranges from 2.07 to 22.69 with the mean of 7.27 for Cauvery and ranges from 3.89 to 14.13 with the mean of 9.29 for Palar. The heat production rate of the Cauvery River is ranged from 0.19 to 3.04 with an average of 0.57 μWm^{-3} and the Palar river is ranged 0.34 - 3.31 with an average of 0.72 μWm^{-3} for this study.

DISCUSSION

Residential houses and other building constructions in Tamilnadu and nearby states are mostly built by the river sand. The distribution of uranium, thorium, and potassium isotopes in environmental matrices are not uniform for both the

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rivers. Many authors have shown a similar range of concentrations of ^{238}U, ^{232}Th, and ^{40}K [17, 23, 25-29] in soil, but beach sands are exceptional, where observed values are significantly higher. The average activity concentrations of ^{238}U are lower than the other radionuclides whereas ^{232}Th of both the rivers is almost equal to and ^{40}K is higher than the world average and all India average [5, 21]. ^{40}K dominates ^{238}U and ^{232}Th like what normally happens in the soil whereas slightly lower ^{40}K in Cauvery than Palar may be attributed to Cation Exchange Capacity (CEC), pH of the soil, and leaching due to heavy rainfall [30]. Even higher AD_{in} is observed at C20/21, C21 (Erode) is showing three times the world average (see table 3). However, the average AD_{in} and AD_{out} are lower than the world average. The Indoor Absorbed dose rate of nearly six sites has exceeded the recommended limit. The average contribution of 238U, 232Th, and 40K to AD_{in} and AD_{out} is 6.8, 43.62, 49.56 %, and 3.27, 48.29, 48.70% respectively. The average contribution of ^{40}K and ^{232}Th to Indoor and outdoor absorbed dose rate is almost equal and greater than the contribution of ^{238}U. The average contribution of activity concentrations in Bq/kg to the average absorbed dose rate (indoor and outdoor) in nGy/h is of the order of $^{232}Th > ^{238}U > ^{40}K$. Higher AD_{in} is observed in almost all the sites except P1/4/11/14/20 especially site no P6 (Kancheepuram) shows four times the world average. But, AD_{out} of P6 only exceeds the world average. The average contribution of ^{238}U, ^{232}Th, and ^{40}K to the indoor absorbed dose rate is 8.46, 33.63, and 58.02 %, and to the outdoor absorbed dose rate is 7.32, 37.47, and 57.52 % respectively. Here also the average contribution of activity concentration to the average absorbed dose rate shows a similar trend. The mean E_{in} and E_{out} of the Cauvery River are lesser than the world average and the higher values are observed in C13/14/20/24. But, the mean E_{out} of the Palar equals to world average whereas the mean E_{in} is slightly greater. Not like Cauvery E_{in} in almost all the sites except P1/11/14/20 and E_{out} in P3/6/9/10/12 /19 is higher than the world average. Particularly C20 and P6 are more than 2 times greater than the world average. The children and infants are slightly (10% and 30% respectively) higher for world average because of the increased conversion coefficient of absorbed dose to annual effective dose [5]. AGD values observed in S13/14/20/24 and S25 and P2/3/5-13/15-19/21 are higher and the average is lower than the world average whereas the Palar is higher. H_{in} and H_{ex} observed in C20 and P6 (≥1) may produce a harmful effect on the people living in this region. The average of Palar is slightly higher than the Cauvery. The European Commission suggested gamma dose and alpha criterion limit as 0.3 – 1 mSv/y for building materials. Alpha and Gamma Activity Concentration Index of those two rivers are not exceeding the world average. But the higher values of I_α and I_g are observed in C20 and P6 whereas the AUI is exceeding the world average in the same sites. The low concentration of Ra_{eq} may be because of the radioactive transportation by weathering and flow of water due to heavy rainfall in its origin and also high concentration is related to sedimentation beyond weathering and water flow. The mean H_R% of Cauvery is slightly less than Palar with higher values in C23 (22.69) and P21 (14.13). A higher radioactive heat production rate is observed in C13/14/20 and P6/12 when compared with the world average. But, the average radioactive heat production rate of both the rivers shows a low RHP rate (below 1μWm^{-3}). The potassium and thorium play a major role in RHP and its increase in those concentrations reflect in the integrated effect of heat production rate.

CONCLUSION

In the present study mean activity concentration and absorbed dose rate for the Cauvery River is lower than the Palar river and also the world average. The mean annual effective dose equivalent of Cauvery and Palar rivers are 0.71 times and 1.03 times that of the world average (70μSv/y) respectively. The mean of Ra_{eq}, H_{ex} and H_{in} of both the rivers are lesser than the world average. Therefore, this sand does not pose a source of radiation hazard when utilizing it for construction works. Among all the sites. C20 and P7 show more than two times of world average of absorbed, observed, annual effective dose equivalent, Radium equivalent hazard indices, and RHP rate. This indicates that the people living in and around those two sites (C20 and P7) are highly exposed to radiation, which leads to harmful effects on living things.

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