Investigation and correlation of radioactive hazards with magnetic parameters and heavy metals of dwelling sand from two major rivers in south India – A comparative study

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Abstract. Cauvery and Palar, two major rivers in Tamilnadu, India, have importance for irrigation, drinking, electricity and river sand is used as a major material of building construction in India. The natural radionuclides such as uranium, thorium and potassium (238U, 232Th, 40K) isotopes are investigated through gamma ray spectrometer with NaI(Tl) detector. The average values of radionuclides and in-situ dose are measured. Related parameters like absorbed dose (ADin & ADout), Annual Effective Doe Equivalent (Ein & Eout), and also hazard indices to assess radiation exposure to human such as average radium equivalent (Raeq), external (Hex) and internal (Hin) hazard indices, Radioactive heat production (RHP), internal and external Excess Lifetime Cancer Risk (ELCRin and ELCRout), Alpha (Iα), Gamma Index (Iγ) and Annual Gonadal dose (AGDE) are computed and correlated. This study exhibits that almost all the radioactive parameters are in control by comparing to the world average. Nevertheless, the Cauvery River except site no.20 does not produce a radiological hazard. But, the palar river does slightly produce a radiological risk especially site no.6 shows three times of the world average.

1. Introduction

Several kinds of pollutants, in some cases highly harmful to health, can seriously affect the fluvial system and soil [1]. Environmental gamma radiation encounters the most dangerous threat of today’s atmospheric pollution. Soil is one of the important components for the survival of organisms. The mixtures of organic, inorganic materials and metal compounds from anthropogenic sources become soil. Well graded Sand is good for all construction activities like concrete and plastering. With the increase in construction activities, river sand demand is continuously increased. The consequence of continuous excavation produces disastrous change in the environment such as river shore sliding, water table dropdown, etc. [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, animal and sewage 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.

Natural radioactive isotopes may be blended with rocks, sand, soils, sediments and water. Artificial isotopes in the atmosphere emerge from anthropogenic sources, such as weapon testing, nuclear medicine and nuclear explosions. Atmospheric exposure of radiation occurs at various levels in the Environment, which changes due to geological variations in different regions of the world. The distribution of radionuclides in sand depends on the mechanical and chemical processes of the parent rocks from which the sands are aggregated. The origination of rocks decides the level of terrestrial background radiation. sedimentary rocks emit low radiation whereas Igneous rocks containing dark coloured heavy minerals usually emitting higher radiation.
Earth crust emits two major environmental constituents specifically cosmic rays and radiation from the radioactive isotopes. The soil, water and vegetation are the sources of earthbound radiation determined from major isotopes uranium, 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].

Now a day’s river sand is used as main material in the field of building construction. This study discloses that the natural radioactivity concentrations, magnetic susceptibility and heavy minerals and its related parameters. In addition, the statistical parameters are used to correlate radiological impact with magnetic susceptibility and heavy metals for assessing radiological risk to use river sand as building materials through statistical analysis.

2. Materials and Methods

2.1. Sample Preparation

The sand samples are collected from 26 different locations of Cauvery and 21 locations of Palar rivers as shown in Figure 1. During majority parts of the river is being 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. After the removal of pebbles and stones through sieves the homogenized sample is filled in a 250ml silicon and polythene tape sealed airtight PVC container and maintain it for minimum 30 days before being taken for gamma ray spectrometric analysis.

![Figure 1. Map of Cauvery and Palar river in Tamilnadu, India](image)
2.2. Gamma ray spectrometry
Gamma spectrometer includes 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 efficiency of the instruments for various energies with the known sample geometry. As the measurement is for the natural radioactive elements potassium-40, uranium and thorium, the gamma energies selected are 1460 keV for 40K, 1764 keV for uranium from daughter product 214Bi and 2613 keV for thorium. The minimum detectable values of the above said detector system for uranium, thorium and potassium isotopes are 2.21, 2.11 and 8.5 Bq kg\(^{-1}\) respectively for a counting time of 10,000s.

3. Results
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 is not uniform for both the rivers (Table 1 and 2). There are no proper statistical evidences for cancer, average lifetime of the people, typical health diseases, etc. in the study area. The maximum radioactivity is to be considered instead of average radioactivity [6].

3.1 Radiological Dose Parameters
Radiological dose parameters such as Indoor (AD\(_{in}\)) and Outdoor (AD\(_{out}\)) Absorbed dose, Internal (E\(_{in}\)) and External (E\(_{ex}\)) Annual Effective Dose Equivalent and Annual Gonadal dose equivalent (AGDE) are calculated and correlated (Table 3) to limit radiation exposure to living things while river sand is used as building materials.

3.1.1 Indoor (AD\(_{in}\)) and Outdoor (AD\(_{out}\)) Absorbed dose
The equation given below [7] is used to evaluate AD\(_{in}\) and AD\(_{out}\) with the conversion factors of \(^{238}\text{U},^{232}\text{Th}\) and \(^{40}\text{K}\) into doses (nGyh\(^{-1}\) per Bqkg\(^{-1}\)).

\[
D_{in} = (0.92 C_U + 1.1 C_{Th} + 0.081 C_K) \\
D_{out} = (0.427 C_U + 0.662 C_{Th} + 0.043 C_K)
\]

Where 0.92 and 0.427, 1.1 and 0.662, 0.081 and 0.043 are conversion factors of the elemental activities C\(_U\), C\(_Th\) and C\(_K\) in Bq kg\(^{-1}\) respectively.

3.1.2 Internal (E\(_{in}\)) and External (E\(_{ex}\)) Annual Effective Dose Equivalent
Since the sand is mainly used as building materials, the determination of E\(_{in}\) & E\(_{out}\) of river sand becomes more essential. In determining E\(_{in}\) & E\(_{out}\), outdoor and indoor occupancy factor is to be considered on the basis of 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). Majority population adopted to the above classification lifestyle in and around location who are either office workers, labourers and students. Hence 4/24 or 0.17 (17%) and 20/24 or 0.73 (73%) is adopted as indoor and outdoor occupancy factors respectively with the conversion factor of 0.70SvGy\(^{-1}\), to convert AD\(_{in}\) and AD\(_{out}\) (nGyh\(^{-1}\)) to E\(_{in}\) & E\(_{out}\) (\(\mu\)Sv y\(^{-1}\)) for this study [8].

\[
E_{in}(\mu\text{Sv y}^{-1}) = D_{in}\text{nGy y}^{-1} \times 8760 \times 0.7 \text{ Sv Gy}^{-1} \times 0.2 \times 10^{-3} \\
E_{out}(\mu\text{Sv y}^{-1}) = D_{out}\text{nGy y}^{-1} \times 8760 \times 0.7 \text{ Sv Gy}^{-1} \times 0.8 \times 10^{-3}
\]

3.1.3 Annual Gonadal dose equivalent (AGDE)
AGDE is a measure of the genetic significance of the yearly exposure of the population’s reproductive organs (gonads). The gonads (bone marrow the bone surface cells etc.,) are particularly radiosensitive. A single dose of only 0.3 Gy (30 rads) to the testes may result in temporary sterility among men; for women, a 3-Gy (300- rad) dose to the ovaries may lead to temporary sterility. Higher doses increase the period of temporary sterility UNSCEAR considered the activity of bone marrow and bone surface cells...
as the organ of interest when estimating dose equivalent. Therefore, Annual Gonadal dose equivalent is calculated using the equation below [9].

\[ AGDE = 3.09C_U + 4.18C_{Th} + 0.314C_K \]

Where 3.09, 4.18 and 0.314 are conversion factors of Cu, C\textsubscript{Th} and C\textsubscript{K} in Bqkg\textsuperscript{-1} respectively.

### Table 1. Sampling sites and its basic radioactive parameters

| 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     | Srinangam   | 2.56  | 10.85 | 385.05 | 9      | pudhupadi   | 11.21 | 44.16 | 703.11 |
| 10    | Mukkanambur | 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     | Virungiparam | 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     | Vaniambadli | 8.93  | 22.79 | 821.96 |
| 19    | Solasirammani | 8.88 | 28.93 | 256.38 | 19     | Ambalur     | 18.44 | 52.42 | 483.49 |
| 20    | Erode       | 21.49 | 224.79 | 529.44 | 20     | Avarakuppam | 9.6219 | 66.6 | 532.67 |
| 21    | Bavani      | 8.88  | 12.61 | 321.71 | 21     | Kanaganachiammankoil | 8.83 | 11.64 | 858.22 |
| 22    | Kalvdangam  | 2.94  | 8.35  | 488.91 | 22     |             |       |       |       |
| 23    | Ammapettai  | 11.87 | 18.71 | 178.18 | 23     |             |       |       |       |
| 24    | Thekkanoor  | 12.97 | 24.03 | 1698.48 | 24     |             |       |       |       |
| 25    | mettur      | 3.91  | 6.33  | 197.58 | 25     |             |       |       |       |
| 26    | Hogenakal   | 12.16 | 50.85 | 353.66 | 26     |             |       |       |       |

### 3.2 Radiological Hazardous Parameters

Some radiological hazardous indices such as H\textsubscript{In}, H\textsubscript{Ex}, Alpha Index (AI), Gamma Index (GI), Activity Utilization Index (AUI), Annual Gonadal Dose Equivalent (AGDE) are calculated and correlated (Table 4).

#### 3.2.1 Internal (H\textsubscript{In}) and External (H\textsubscript{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 (\textsuperscript{222}Rn), thoron (\textsuperscript{220}Rn) and their shortliving decay products produces internal exposure. H\textsubscript{In} and H\textsubscript{Ex} is given by the following equation [10],

\[
H_{In} = \left( \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \right) \leq 1
\]
\[ H_{\text{ex}} = \left( \frac{C_U}{370} + \frac{C_{\text{Th}}}{259} + \frac{C_K}{4810} \right) \leq 1 \]

**Table 2.** Radiological Dose and Hazardous parameters, Magnetic susceptibility and Heavy Metals

| Activity Parameters | Cauvery River | Palar river | World Average | Present/world averages |
|---------------------|---------------|-------------|---------------|------------------------|
|                     | min | max | Average | min | max | Average | Ca | Ay | P |
| $^{238}$U           | 1.29 | 21.49 | 5.31 | 5.64 | 18.44 | 9.80 | 35 | 0.152 | 0.28 |
| $^{232}$Th          | 6.33 | 224.79 | 34.04 | 6.13 | 254.06 | 36.49 | 30 | 1.13 | 1.22 |
| $^{40}$K            | 178.18 | 1698.48 | 401.11 | 483.49 | 884.78 | 742.46 | 400 | 1 | 1.86 |
| $AD_{\text{in}}$   | 26.56 | 309.92 | 74.83 | 64.49 | 356.31 | 109.3 | 84 | 0.89 | 1.3 |
| $AD_{\text{out}}$  | 14.11 | 171.98 | 40.73 | 34.12 | 198.03 | 58.85 | 51 | 0.8 | 1.15 |
| $OD$                | 47   | 350  | 96.1  | 75   | 350   | 137.14 | NA | NA | NA |
| $E_{\text{in}}$    | 0.13 | 1.52 | 0.367 | 0.135 | 1.58 | 0.38 | 0.3 | 1.22 | 1.27 |
| $E_{\text{out}}$   | 0.17 | 0.21 | 0.049 | 0.15 | 0.18 | 0.042 | 0.07 | 0.7 | 0.6 |
| $H_{\text{in}}$    | 0.09 | 1.09 | 0.24 | 0.21 | 1.23 | 0.35 | <1 | 0.24 | 0.35 |
| $H_{\text{ex}}$    | 0.08 | 1.04 | 0.23 | 0.18 | 1.18 | 0.32 | <1 | 0.23 | 0.32 |
| $Ra_{\text{eq}}$   | 28.18 | 383.71 | 84.89 | 66.73 | 438.50 | 119.16 | 370 | 0.23 | 0.32 |
| RHP                 | 0.19 | 3.04 | 0.56 | 0.34 | 3.31 | 0.72 | 1 | 0.56 | 0.72 |
| AUI                 | 0.13 | 2.96 | 0.48 | 0.22 | 3.29 | 0.62 | 2 | 0.015 | 0.03 |
| ELCR$_{\text{in}}$ | 0.46 | 5.32 | 1.2849 | 0.59 | 3.4 | 1.01 | 1.16 | 1.11 | 0.87 |
| ELCR$_{\text{out}}$| 0.06 | 0.74 | 0.1748 | 0.15 | 0.85 | 0.25 | 0.29 | 0.61 | 0.86 |
| $I_{\alpha}$       | 0.01 | 0.11 | 0.03 | 0.03 | 0.09 | 0.05 | 1 | 0.03 | 0.05 |
| $I_{\gamma}$       | 0.11 | 1.37 | 0.32 | 0.27 | 1.58 | 0.46 | 1 | 0.32 | 0.46 |
| AGDE                | 0.1  | 1.17 | 0.29 | 0.25 | 1.35 | 0.42 | 0.3 | 0.97 | 1.4 |
| $H_{R}$            | 2.07 | 22.69 | 7.27 | 3.89 | 14.13 | 9.29 | NA | NA | NA |

### 3.2.2 Radium Equivalent

The total activity does not provide exact indication of the radiation hazard associated with the materials [11, 12]. Radium equivalent activity yields gamma index gives from the combination of $^{226}$Ra or $^{238}$U $^{232}$Th and $^{40}$K in the sample [13].

\[
Ra_{\text{eq}} = (C_U + A C_{\text{Th}} + BC_K)
\]

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

The assumptions used in the above equation are that 1 Bqkg$^{-1}$ of $^{226}$Ra or $^{238}$U, 0.7 Bqkg$^{-1}$ of $^{232}$Th and 13 Bqkg$^{-1}$ of $^{40}$K produce the same γ-ray dose. For the safe utilization of materials, the annual limit on the gamma ray dose (external) is to be maximum of 0.3 mSv, this corresponds to the value of 370Bqkg$^{-1}$. 

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5
| S. No. | ADin  | ADout | OD  | Ein  | Eout | Hex  | Hin  | HR   | S. No. | ADin  | ADout | OD  | Ein  | Eout | Hex  | Hin  | HR   |
|-------|-------|-------|-----|------|------|------|------|------|-------|-------|-------|-----|------|------|------|------|------|-------|-------|-------|-----|------|------|------|------|------|------|------|------|-----|
| C1    | 52.52 | 28.02 | 90  | 0.26 | 0.03 | 0.15 | 0.17 | 11.03| P1    | 64.50 | 34.12 | 75  | 0.32 | 0.04 | 0.18 | 0.20 | 13.59|       |       |
| C2    | 59.73 | 32.05 | 95  | 0.29 | 0.04 | 0.17 | 0.19 | 8.34 | P2    | 92.49 | 49.77 | 110 | 0.45 | 0.06 | 0.27 | 0.30 | 9.70 |       |       |
| C3    | 55.70 | 30.15 | 100 | 0.27 | 0.04 | 0.16 | 0.16 | 2.22 | P3    | 124.82| 67.60 | 150 | 0.61 | 0.08 | 0.38 | 0.41 | 8.84 |       |       |
| C4    | 61.77 | 33.49 | 85  | 0.30 | 0.04 | 0.18 | 0.19 | 4.61 | P4    | 73.45 | 38.73 | 100 | 0.36 | 0.05 | 0.20 | 0.22 | 12.03|       |       |
| C5    | 74.74 | 40.77 | 90  | 0.37 | 0.05 | 0.23 | 0.24 | 5.09 | P5    | 85.21 | 45.17 | 110 | 0.42 | 0.06 | 0.23 | 0.25 | 8.91 |       |       |
| C6    | 60.44 | 32.63 | 80  | 0.30 | 0.04 | 0.18 | 0.20 | 8.39 | P6    | 356.31| 198.03| 350 | 1.75 | 0.24 | 1.18 | 1.23 | 3.89 |       |       |
| C7    | 47.16 | 25.44 | 70  | 0.23 | 0.03 | 0.14 | 0.14 | 3.94 | P7    | 103.88| 55.51 | 110 | 0.51 | 0.07 | 0.30 | 0.32 | 9.24 |       |       |
| C8    | 73.78 | 40.20 | 65  | 0.36 | 0.05 | 0.23 | 0.24 | 5.18 | P8    | 103.94| 55.41 | 120 | 0.51 | 0.07 | 0.29 | 0.32 | 9.28 |       |       |
| C9    | 45.48 | 24.41 | 60  | 0.22 | 0.03 | 0.13 | 0.14 | 5.37 | P9    | 115.84| 62.53 | 120 | 0.57 | 0.08 | 0.35 | 0.38 | 8.73 |       |       |
| C10   | 53.82 | 29.22 | 64  | 0.26 | 0.04 | 0.16 | 0.16 | 2.79 | P10   | 136.85| 73.97 | 150 | 0.67 | 0.09 | 0.41 | 0.44 | 7.64 |       |       |
| C11   | 44.81 | 24.11 | 68  | 0.22 | 0.03 | 0.13 | 0.14 | 5.60 | P11   | 80.84 | 43.37 | 135 | 0.40 | 0.05 | 0.23 | 0.25 | 6.61 |       |       |
| C12   | 76.93 | 42.24 | 63  | 0.38 | 0.05 | 0.24 | 0.24 | 2.13 | P12   | 136.32| 74.26 | 120 | 0.67 | 0.09 | 0.42 | 0.44 | 5.84 |       |       |
| C13   | 118.91| 66.18 | 72  | 0.58 | 0.08 | 0.39 | 0.40 | 2.07 | P13   | 88.74 | 47.39 | 120 | 0.44 | 0.06 | 0.25 | 0.28 | 9.53 |       |       |
| C14   | 124.95| 68.53 | 85  | 0.61 | 0.08 | 0.39 | 0.41 | 4.79 | P14   | 75.98 | 40.04 | 140 | 0.37 | 0.05 | 0.20 | 0.23 | 11.47|       |       |
| C15   | 56.37 | 30.68 | 97  | 0.28 | 0.04 | 0.17 | 0.18 | 6.11 | P15   | 102.78| 54.83 | 140 | 0.50 | 0.07 | 0.29 | 0.31 | 8.28 |       |       |
| C16   | 42.31 | 22.91 | 56  | 0.21 | 0.03 | 0.12 | 0.13 | 4.11 | P16   | 104.69| 56.34 | 180 | 0.51 | 0.07 | 0.31 | 0.33 | 7.95 |       |       |
| C17   | 39.56 | 21.54 | 60  | 0.19 | 0.03 | 0.12 | 0.12 | 2.94 | P17   | 93.16 | 49.70 | 140 | 0.46 | 0.06 | 0.26 | 0.29 | 9.00 |       |       |
| C18   | 50.97 | 27.55 | 64  | 0.25 | 0.03 | 0.15 | 0.17 | 8.70 | P18   | 99.86 | 53.36 | 140 | 0.49 | 0.07 | 0.28 | 0.31 | 8.53 |       |       |
| C19   | 60.76 | 32.84 | 68  | 0.30 | 0.04 | 0.19 | 0.21 | 12.70| P19   | 113.79| 61.32 | 140 | 0.56 | 0.08 | 0.35 | 0.40 | 14.13|       |       |
| C20   | 309.92| 171.99| 72  | 1.52 | 0.21 | 1.04 | 1.09 | 5.61 | P20   | 73.62 | 39.26 | 110 | 0.36 | 0.05 | 0.21 | 0.24 | 12.23|       |       |
| C21   | 48.10 | 25.48 | 220 | 0.24 | 0.03 | 0.14 | 0.16 | 17.20| P21   | 90.44 | 47.93 | 120 | 0.44 | 0.06 | 0.25 | 0.27 | 9.65 |       |       |
| C22   | 51.49 | 27.48 | 190 | 0.25 | 0.03 | 0.14 | 0.15 | 5.60 |       |       |       |       |       |       |       |       |       |       |       |       |       |
| C23   | 45.93 | 24.39 | 230 | 0.23 | 0.03 | 0.14 | 0.17 | 22.69|       |       |       |       |       |       |       |       |       |       |       |       |
| C24   | 175.94| 93.54 | 63  | 0.86 | 0.11 | 0.48 | 0.52 | 7.29 |       |       |       |       |       |       |       |       |       |       |       |       |
| C25   | 26.56 | 14.11 | 58  | 0.13 | 0.02 | 0.08 | 0.09 | 13.89|       |       |       |       |       |       |       |       |       |       |       |       |
| C26   | 95.77 | 52.08 | 50  | 0.47 | 0.06 | 0.30 | 0.34 | 10.86|       |       |       |       |       |       |       |       |       |       |       |       |
Table 4. Radiological Hazardous Parameters

| No. | CAUVERY | PALAR |
|-----|---------|-------|
|     | Raeq    | RHP   | ELCRin | ELCRout | Hex | Hn | Hn | Al | AUI | GI |
|     |         |       |        |         |     |   |    |    |     |    |
| C1  | 55.78   | 0.32  | 0.90   | 0.12    | 0.15| 0.17| 11.03| 0.03| 0.25| 0.22|
| C2  | 63.94   | 0.34  | 1.03   | 0.14    | 0.17| 0.19| 8.14 | 0.03| 0.29| 0.25|
| C3  | 59.62   | 0.28  | 0.96   | 0.13    | 0.16| 0.16| 2.22 | 0.01| 0.25| 0.24|
| C4  | 67.90   | 0.36  | 1.06   | 0.14    | 0.18| 0.19| 4.61 | 0.02| 0.34| 0.26|
| C5  | 84.96   | 0.51  | 1.28   | 0.17    | 0.23| 0.24| 5.09 | 0.02| 0.49| 0.32|
| C6  | 66.89   | 0.40  | 1.04   | 0.14    | 0.18| 0.20| 8.39 | 0.03| 0.36| 0.26|
| C7  | 50.25   | 0.25  | 0.81   | 0.11    | 0.14| 0.14| 3.94 | 0.01| 0.21| 0.20|
| C8  | 83.44   | 0.51  | 1.27   | 0.17    | 0.23| 0.24| 5.18 | 0.02| 0.47| 0.32|
| C9  | 47.72   | 0.24  | 0.78   | 0.10    | 0.13| 0.14| 5.37 | 0.01| 0.19| 0.19|
| C10 | 58.79   | 0.32  | 0.92   | 0.13    | 0.16| 0.16| 2.79 | 0.01| 0.28| 0.23|
| C11 | 47.73   | 0.25  | 0.77   | 0.10    | 0.13| 0.14| 5.60 | 0.01| 0.20| 0.19|
| C12 | 88.26   | 0.58  | 1.32   | 0.18    | 0.24| 0.24| 2.13 | 0.01| 0.52| 0.33|
| C13 | 145.29  | 1.06  | 2.04   | 0.28    | 0.39| 0.40| 2.07 | 0.02| 1.05| 0.53|
| C14 | 145.55  | 0.97  | 2.15   | 0.29    | 0.39| 0.41| 4.79 | 0.03| 0.92| 0.54|
| C15 | 63.89   | 0.41  | 0.97   | 0.13    | 0.17| 0.18| 6.11 | 0.02| 0.37| 0.24|
| C16 | 46.00   | 0.25  | 0.73   | 0.10    | 0.12| 0.13| 4.11 | 0.01| 0.22| 0.18|
| C17 | 43.91   | 0.25  | 0.68   | 0.09    | 0.12| 0.12| 2.94 | 0.01| 0.23| 0.17|
| C18 | 56.95   | 0.37  | 0.88   | 0.12    | 0.15| 0.17| 8.70 | 0.02| 0.32| 0.22|
| C19 | 69.99   | 0.53  | 1.04   | 0.14    | 0.19| 0.21| 12.70| 0.04| 0.45| 0.26|
| C20 | 383.71  | 3.13  | 5.32   | 0.74    | 1.04| 1.09| 5.61 | 0.11| 2.96| 1.37|
| C21 | 51.68   | 0.36  | 0.83   | 0.11    | 0.14| 0.16| 17.20| 0.04| 0.26| 0.20|
| C22 | 52.53   | 0.25  | 0.88   | 0.12    | 0.14| 0.15| 5.60 | 0.01| 0.17| 0.21|
| C23 | 52.35   | 0.43  | 0.79   | 0.10    | 0.14| 0.17| 22.69| 0.06| 0.35| 0.19|
| C24 | 178.12  | 0.80  | 3.02   | 0.40    | 0.48| 0.52| 7.29 | 0.06| 0.55| 0.73|
| C25 | 28.18   | 0.17  | 0.46   | 0.06    | 0.08| 0.09| 13.89| 0.02| 0.13| 0.11|
| C26 | 112.11  | 0.79  | 1.64   | 0.22    | 0.30| 0.34| 10.86| 0.06| 0.76| 0.41|
3.2.3 Internal (ELCR\textsubscript{in}) and External (ELCR\textsubscript{out}) Excess lifetime cancer risk
Cancer is one of the life threat diseases and the percentage of this disease increases all over the world due to various reasons. One of the reasons is the radiation effect on biological cell. Excess lifetime cancer risk (ELCR) is computed using the below equation [14,15].

\[
\text{ELCR}_{\text{in}} = E_{\text{in}} \times DL \times RF
\]
\[
\text{ELCR}_{\text{out}} = E_{\text{out}} \times DL \times RF
\]

where \(E_{\text{in}}\) and \(E_{\text{out}}\), DL and RF is the indoor and outdoor annual effective dose equivalent, average duration of life (70 years) 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 [16].

3.2.4 Alpha (I\textsubscript{\alpha}) and Gamma Activity Concentration Index (I\textsubscript{\gamma})
The alpha or internal hazard indices was proposed to evaluate the exposure level due to radon inhalation emanated from building materials. The alpha index is estimated by the following formula [17].

\[
I_{\alpha} = \frac{C_{U}}{200\text{Bqkg}^{-1}} \leq 1
\]

In order to check out whether the safety requirements for building materials are being fulfilled, a activity concentration index or external hazard, \(I_{\gamma}\) is calculated as proposed by the European Commission [7]:

\[
I_{\gamma} = \frac{C_{U}}{300\text{Bqkg}^{-1}} + \frac{C_{Th}}{200\text{Bqkg}^{-1}} + \frac{C_{K}}{3000\text{Bqkg}^{-1}} \leq 1
\]

where \(C_{U}\), \(C_{Th}\) and \(C_{K}\) are the specific activities of uranium, thorium & potassium respectively in Bqkg\(^{-1}\).

3.2.5 Activity Utilization Index (AUI)
In order 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 [18].

\[
\text{AUI} = \left( \frac{C_{U}}{50\text{Bqkg}^{-1}} \right) f_{U} + \left( \frac{C_{Th}}{50\text{Bqkg}^{-1}} \right) f_{Th} + \left( \frac{C_{K}}{500\text{Bqkg}^{-1}} \right) f_{K}
\]

where \(C_{U}\), \(C_{Th}\) and \(C_{K}\) are the actual values of the activities per unit mass (Bq kg\(^{-1}\)) of \(^{238}\text{U}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\) in the building materials considered; \(f_{U}\), \(f_{Th}\) and \(f_{K}\) belongs to 0.462, 0.604 and 0.041 respectively are the fragmentary contributions due to gamma radiation from the above environmental radioactive nuclides.

3.2.6 Hazard Percentage (HR\%)
The hazard percentage and contribution due to exhaled radon in sediment samples was estimated using the following relation [19].

\[
HR\% = 100 \times \left( \frac{H_{\text{in}}}{H_{\text{ext}}} - 1 \right)
\]

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

3.2.7 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 (\(^{238}\text{U}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\)) becomes the key factor of analyzing the nature of the mantle, crust of the earth and their heat generating potential [20]. The RHP rate in and around the Cauvery and Palar rivers is estimated through the following relation [21].

\[
A = 10^{-5} \times \rho \times (9.52 C_{U} + 2.56 C_{Th} + 3.48 C_{K})
\]

Where A - RHP in \(\mu\text{Wm}^{-3}\), \(\rho\) - sample density in Kgm\(^{-3}\), \(C_{U}\) and \(C_{Th}\) - uranium and thorium concentration in ppm and \(C_{K}\) - potassium concentration in %.
4. Discussion
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 [11,12]. Indoor and outdoor values for the above derived parameters, annual gonadal dose equivalent (AGDE), alpha ($I_\alpha$) and gamma ($I_\gamma$) concentration index and activity utilization index (AUI) are additionally calculated and its minimum, maximum and average values are tabulated and shown in Figure 2 & Table 2. Many authors have shown similar range of concentrations of $^{238}$U, $^{232}$Th and $^{40}$K [14,20, 22-26] in soil, but beach sands are exceptional, where observed values are significantly higher. The average activity concentrations of $^{238}$U is 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 [5,20]. $^{40}$K dominates $^{238}$U and $^{232}$Th like what normally happens in soil whereas slightly lower $^{40}$K in Cauvery than Palar may be attributed to Cation Exchange Capacity (CEC), pH of soil and leaching due to heavy rainfall [27].

![Figure 2. Comparison of Radioactive parameters](image-url)

4.1. Radiological Dose Parameters
4.1.1. Absorbed dose ($AD_{\text{in}}$ and $AD_{\text{out}}$) Rate
In Cauvery river the indoor absorbed dose rate ($AD_{\text{in}}$) ranges 26.56 - 309.92 with an average 74.83 nGy/h and the outdoor absorbed dose rate ($AD_{\text{out}}$) ranges 14.11 - 171.98 with an average 40.73 nGy/h. Even higher $AD_{\text{in}}$ is observed at C20/21, C21 (Erode) is showing three times of the world average (see Table 3). However, the average $AD_{\text{in}}$ and $AD_{\text{out}}$ is lower than the world average. Indoor Absorbed dose rate of nearly six sites have exceeded the recommended limit. Average contribution of $^{238}$U, $^{232}$Th and $^{40}$K to $AD_{\text{in}}$ and $AD_{\text{out}}$ is 6.8, 43.62, and 49.56 % and 3.27, 48.29, and 48.70% respectively. The average contribution of $^{40}$K and $^{232}$Th to Indoor and outdoor absorbed dose rate is almost equal greater than contribution of $^{238}$U. The average contribution of activity concentrations in Bq/kg to average absorbed dose rate (indoor and outdoor) in nGy/h$^{-1}$ is of the order of $^{232}$Th $>$ $^{238}$U $>$ $^{40}$K.
In Palar river the indoor ($AD_{\text{in}}$) and outdoor ($AD_{\text{out}}$) absorbed dose rates are ranged from 64.5 to 356.31 with an average 109.30 nGy/h and from 34.12 to 198.03 with an average 58.85 nGy/h respectively.
Higher AD<sub>i</sub>n is observed in almost all the sites except P1/11/14/20 especially site no P6 (Kancheepuram) shows four times of the world average. But, AD<sub>out</sub> of P6 only exceeds the world average. Average contribution of 238U, 232Th and 40K to the indoor absorbed dose rate is 8.46, 33.63, and 58.02 % and to outdoor absorbed dose rate is 7.32, 37.47, and 57.52 % respectively. Here also the average contribution of activity concentration to average absorbed dose rate shows the similar trend.

4.1.2. Annual Effective Dose Equivalent (E<sub>in</sub> and E<sub>out</sub>) Rate
In Cauvery River the E<sub>in</sub> and E<sub>out</sub> range 26.56 to 309.92 with an average 74.83 µSv y<sup>-1</sup> and 14.11 to 171.98 with an average 40.73 µSv y<sup>-1</sup> respectively. Nevertheless, the mean of E<sub>in</sub> and E<sub>out</sub> are lesser than the world average and the higher values are observed in C13/14/20/24. In Palar river the E<sub>in</sub> ranges from 167.37 to 971.45 with an average 288.69 µSv y<sup>-1</sup> and E<sub>out</sub> ranges from 41.84 to 242.86 with an average 72.17 µSv y<sup>-1</sup> and the mean E<sub>out</sub> equals to world average whereas mean E<sub>in</sub> is slightly greater. Not like Cauvery E<sub>in</sub> in almost all the sites except P1/11/14/20 and E<sub>out</sub> 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 increased conversion coefficient of absorbed dose to annual effective dose [5].

4.1.3. Observed Dose Rate (OD)
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. The mean observed dose rate of Palar river is higher than the Cauvery river. The ERDM dose rates (observed) are nearly two times of absorbed dose rate. This difference is due to background contribution from cosmic rays, high energy beta particles and x-rays. In the present study the OD ranges 47-350 with an average 96.1 nGy h<sup>-1</sup> and 75 - 350 with an average 137.14 nGy h<sup>-1</sup> for Cauvery and Palar River respectively.

4.1.4. Annual Gonadal Dose Equivalent (AGDE)
The ADGE ranges 0.1 - 1.17 with an average 0.29 mSv y<sup>-1</sup> and 0.25-1.35 with an average 0.42 mSv y<sup>-1</sup> for Cauvery and Palar river respectively. AGDE values observed in S13/14/20/24 and S25 and P2/3/5-13/15-19/21 are higher and also the average Cauvery is lower whereas the Palar is higher than the world average.

4.2. Radiological Hazardous Parameters

4.2.1. Hazard Indices (H<sub>i</sub>n and H<sub>ex</sub>)
The maximum value of H<sub>i</sub>n and H<sub>ex</sub> were observed in C20 (1.09 and 1.04) and P6 (1.23 and 1.18). Those sites ≥1 may produce harmful effect to the people living in this region. The average of palar is slightly higher than the Cauvery.

4.2.2. Alpha (I<sub>α</sub>) and Gamma Activity Concentration Index (I<sub>γ</sub>)
The EC suggested gamma dose criterion limit for building materials as 0.3 – 1 mSv y<sup>-1</sup>. Most of the countries are considering the upper value (1 mSv y<sup>-1</sup>) as the optimum limit. If the exemption level of 0.3 mSv y<sup>-1</sup>is considered, then the values of I<sub>γ</sub> should be below 0.5 for materials used in bulk (i.e., brick and cement); however, if the upper level of 1 mSv y<sup>-1</sup> is considered, then the values of I<sub>γ</sub> should be below 1. For superficial building materials with restricted use (i.e., tiles and board), I<sub>γ</sub> should be below 2 and 6, supposing control values of 0.3 and 1 mSv y<sup>-1</sup>, respectively. The obtained higher values of I<sub>γ</sub> are 0.11 & 1.37 in C20 (Cauvery) and 0.09 & 1.58 in P6 (Palar). Activity Concentration Index in C20 and P6 are exceeding world average.

4.2.3. Activity Utilization Index (AUI)
AUI varies from 0.13 to 2.96 with the mean of 0.48 and 0.22 to 3.29 with an average 0.62 for Cauvery and Palar rivers respectively. Beretka and Mathew [13] reveals that I < 2, which corresponds to an annual effective dose < 0.3 mSv y<sup>-1</sup>. The AUI of site C20 and P6 are greater than 2. This result can be utilized for the safe usage of building materials.
4.2.4. Internal (ELCR\text{in}) and External (ELCR\text{out}) Excess lifetime cancer risk
The indoor and outdoor excess lifetime cancer risk of Cauvery ranges from 0.46 to 5.32 and 0.06 – 0.7382 with the average of 1.28 and 0.15 – 0.85 with the corresponding average values of 1.01 and 0.25 mSv/y for Palar. Average indoor annual effective dose is above the worldwide average [4]. The ELCR\text{in} and ELCR\text{out} are high in C14/20/C24 and P6/P10/P12. The average of ELCR\text{in} only exceeds the world average value for both rivers.

4.2.5. Radium Equivalent (Ra\text{eq})
The Ra\text{eq} ranges 28.18 – 383.71 with an average 84.89 Bqkg\text{-}1 and 66.73 – 438.5 with an average 119.16 Bqkg\text{-}1 for Cauvery and Palar respectively. The Ra\text{eq} in C20 and P6 are slightly higher than the world average. The low concentration of Ra\text{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.

4.2.6. Hazard Percentage (H\text{R})
H\text{R}\% indicates the radon exhalation capacity of the sample and the sampling sites from the possibility of H\text{ex} by comparing to its H\text{in}, 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 mean H\text{R}\% of Cauvery is slightly less than Palar with the higher values of C23 (22.69) and P21 (14.13).

4.2.7. Radioactive Heat Production (RHP)
The heat production rate of Cauvery River is ranged from 0.19 to 3.04 with an average 0.57 µWm\text{-}3 and Palar river is ranged 0.34 - 3.31 with an average 0.72 µWm\text{-}3 for this study. Higher radioactive heat production rate is observed in C13/14/20 and P6/12 when compare with world average. But, the average radioactive heat production rate of both the rivers show the low RHP rate (below 1µWm\text{-}3). The potassium and thorium play a major role in RHP and its increase in those concentrations reflect in integrated effect of heat production rate.

5. Conclusion
In the present study mean activity concentration and absorbed dose rate for Cauvery river is lower than the Palar river and also world average. The mean annual effective dose equivalent of Cauvery and Palar river are 0.71 times and 1.03 times with that of world average (70µSvy\text{-}1) respectively. The mean of Ra\text{eq}, H\text{ex} and H\text{in} of both the rivers are lower than the world average. Therefore, this sand does not pose source of radiation hazard while 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 are living in and around those two sites (C20 and P7) are highly exposed to radiation, which leads to harmful effect to living things.

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