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Radionuclides of ^{238}U, ^{232}Th and ^{40}K in beach sand of southern regions in Tamilnadu State, India (Post-Tsunami)

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The natural radioactivity content of ^{238}U, ^{232}Th and ^{40}K in beach sand of southern regions of Tamilnadu, India have been analyzed using gamma-ray spectroscopy. From the spectral analysis, the average radioactivity content of ^{238}U, ^{232}Th and ^{40}K in beach sand samples are 8.77 ±3.77, 76.48 ± 4.74 and 202.87 ± 26.72 Bq.kg^{-1}, respectively. Univariate statistics has been applied successfully to assess the distribution of radionuclides and it shows that the decay series radionuclides such as ^{238}U and ^{232}Th are non-existence of normal distribution in the sands; however non-decay series radionuclide of ^{40}K is distributed uniformly. Radiological parameters such as absorbed dose rate, annual effective dose equivalent, annual gonadal dose equivalent, radium equivalent, hazard index, gamma index, activity utilization index, alpha index and excess lifetime cancer risk have been calculated to know the complete radiological status of the coastal sands. The results of the present study indicate that the natural radioactivity content in the beach sands do not pose any radiation effect to the members of public in the southern region of Tamilnadu coast.

Keywords: Radionuclides, Radiological parameters, Tamilnadu, Post-Tsunami

1 Introduction

Environs and Human being have been exposed by ionizing radiations continuously due to the presence of naturally occurring primordial radionuclides (^{238}U and ^{232}Th and their daughter products and ^{40}K) in various geological formation like rocks, soil, beach sand, even in our building materials and homes[1,2]. Human exposure to ionizing radiation is one of the most-discussed scientific subjects that attract public attention. Hence, humans should be aware of their natural environment with regard to the radiation effects due to the naturally occurring and induced radioactive elements. The long term exposure to uranium and its daughters through inhalation has several health effects such as chronic lung diseases, acute leucopoenia, anemia and necrosis of the mouth. Thorium exposure may cause lung, pancreas, hepatic, bone, kidney cancers and leukemia[3].

The natural radioactivity present in beach sand is a key source of external exposure that contributes to an increase in the environmental dose. Therefore, the content and distributions of naturally occurring radionuclides, and its associated dose rates in the beach sand samples present in the coastal environments should necessarily be monitored. The distribution of natural radioactivity content of ^{238}U, ^{232}Th and ^{40}K in beach sand samples in different Indian coastal segments have been studied by many investigators such as Tripathi *et al.*[4] (Andhra coast), Ramasamy *et al.*[5] (Kerala coast), Narayana *et al.*[6] and Radhakrishna *et al.*[7] (Karnataka coast), Gusain *et al.*[8] (Odisha coast), Sengupta *et al.*[9], Mohanty *et al.*[10] (Orissa coast), Kannan *et al.*[11] (Kalpakkam coast) and Lakshmi *et al.*[12] (entire stretch of Tamilnadu coast).

Especially in Tamilnadu coastal region, the natural radioactivity content of ^{238}U, ^{232}Th and ^{40}K have been reported by few investigators as follows. Kannan *et al.*[11] had determined the activity content of ^{238}U, ^{232}Th and ^{40}K in the beach sand of Kalpakkam, Tamilnadu and their average values are 124, 1613 and 358 Bq.kg^{-1}, respectively[11]. Subsequently, Lakshmi *et al.*[12] had studied the entire east coast of Tamilnadu (length of the coast about 1000 km) for the determination of ^{238}U, ^{232}Th and ^{40}K in beach sand samples and reported the average activity content of ^{238}U, ^{232}Th and ^{40}K are 40, 386 and 225 Bq.kg^{-1}, respectively[12]. While the above two studies were carried out prior to the occurrence of Tsunami in December 2004 and hence the radioactivity profile data obtained in these two studies would serve as base line reference for pre-Tsunami.

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After (Post-Tsunami), Ramasamy *et al.*[13] had collected beach sand samples from Chennai to Port novo (Cuddalore) of the Tamilnadu coast and reported that the average activity content of ^{238}U= 8 Bq.kg^{-1}, ^{232}Th=25 Bq.kg^{-1} and ^{40}K=275 Bq.kg^{-1}. Kumar *et al.*[14] had collected beach sand samples from Pondicherry to Velankanni and reported that the average activity content of ^{238}U= 18.4 Bq.kg^{-1}, ^{232}Th =56.5 Bq.kg^{-1} and ^{40}K=285 Bq.kg^{-1}. The above said studies covered about 490 km stretch of east coast of Tamilnadu. In present study, rest of the Tamilnadu coastal length about 500 km stretch was chosen and thus, the observed results (Present study) and reported results (Ramasamy *et al.*[13] and Kumar *et al.*[14]) will cover the entire east coast of Tamilnadu which can be served as a baseline data to assess the radioactivity profile for post-Tsunami.

The objectives of this study are: (i) to determine the activity content of ^{238}U, ^{232}Th and ^{40}K in beach sands of southern region of Tamilnadu, India (ii) assess the spatial distribution of radionuclides in the study area using univariate statistical analysis and (iii) calculate the important radiological parameters to assess the complete radiological status of the coastal sands of southern region of Tamilnadu, India.

2 Materials and Method

2.1 Description of study area

The State of Tamilnadu is gifted with a beautiful and resource-rich coastline and second longest coastal region in India after Gujarat[15]. Tamilnadu has a coastal stretch of about 1000 km encompassed in 13 coastal districts. The present study area covers a total length of about 500 km (six coastal districts such as Thanjavur, Pudukottai, Ramanathapuram, Tuticorin, Tirunelveli and Kanyakumari), from which 50 sites were selected and numbered as S1 to S50 (Table 1). These 50 sites longitude and latitude with their name of the sites are shown in Table 1. The sampling sites were recorded in terms of degree-minute-second (Latitudinal and Longitudinal positions) using a hand-held Global Positioning System (GPS) unit (Model: GARMIN GPS map76). Each site is separated by about 10 km distance. The study area has broadly been classified into northern part (Site numbers S1 to S25) and southern part of study area (Site numbers S26 to S50).

Importance of the coastal region of the present study area is as follows. Aquaculture farms are main activity in the coastal districts of Thanjavur and Pudukottai. In Thanjavur and Pudukottai coastal districts, trace of

Table 1 – Name of the sites along with their longitude(E) and latitude(N) coordinates

SiteNo	Name of the site	Longitude (E)	Latitude (N)	SiteNo	Name of the site	Longitude (E)	Latitude (N)
S1	Adhiramapatinam	79° 22’ 58.32’’	10° 18’ 55.20’’	S26	Vaipar	78° 17’ 12.24’’	09° 00’ 58.38’’
S2	Manora	79° 18’ 13.44’’	10° 15’ 56.22’’	S27	Sippikulam	78° 15’ 09.00’’	08° 59’ 39.36’’
S3	Adaikadevan	79° 15’ 35.88’’	10° 11’ 38.04’’	S28	Pattana Maruthur	78° 11’ 09.78’’	08° 55’ 21.96’’
S4	Manalmelkudi	79° 15’ 59.82’’	10° 02’ 17.22’’	S29	Vallaipatti	78° 10’ 00.06’’	08° 51’ 25.20’’
S5	Kottaipattinam	79° 11’ 56.88’’	09° 58’ 19.26’’	S30	Muthunagar	78° 09’ 46.26’’	08° 48’ 25.68’’
S6	Gopalapatinam	79° 09’ 09.24’’	09° 55’ 29.82’’	S31	Pazhayakayal	78° 06’ 16.80’’	08° 40’ 14.70’’
S7	Pasipattinam	79° 05’ 21.66’’	09° 49’ 32.04’’	S32	Kayalpatinam	78° 07’ 59.04’’	08° 33’ 39.84’’
S8	Thondi	79° 01’ 14.70’’	09° 44’ 29.10’’	S33	Veeramapatinam	78° 07’ 22.86’’	08° 30’ 58.20’’
S9	Devipatinam	78° 54’ 00.72’’	09° 28’ 12.24’’	S34	Tiruchendur	78° 07’ 36.30’’	08° 29’ 28.74’’
S10	Athiyuthu	78° 56’ 15.78’’	09° 24’ 31.86’’	S35	Alanthazhai	78° 06’ 09.24’’	08° 27’ 59.04’’
S11	Athankarai	78° 59’ 45.60’’	09° 20’ 47.70’’	S36	Kallamoli	78° 04’ 43.32’’	08° 25’ 17.40’’
S12	Rameswaram	79° 19’ 16.86’’	09° 17’ 23.76’’	S37	Kulasekharapatnam	78° 03’ 33.66’’	08° 23’ 48.00’’
S13	Rameswaram Dock	79° 10’ 41.04’’	09° 16’ 51.96’’	S38	Manapad	78° 03’ 41.94’’	08° 22’ 29.46’’
S14	Chathiram	79° 22’ 50.40’’	09° 11’ 58.44’’	S39	Periyathazhai	77° 58’ 29.94’’	08° 20’ 05.82’’
S15	Dhanuskodi	79° 21’ 18.30’’	09° 12’ 57.30’’	S40	Kooduthazhai	77° 55’ 37.08’’	08° 17’ 51.60’’
S16	Vadalai	79° 06’ 32.46’’	09° 15’ 54.42’’	S41	Uvari	77° 53’ 34.92’’	08° 16’ 40.62’’
S17	Periyapatinam	78° 55’ 18.90’’	09° 15’ 48.84’’	S42	Kuthenkuly	77° 46’ 57.72’’	08° 13’ 02.70’’
S18	Sethukkarai	78° 50’ 36.54’’	09° 14’ 54.00’’	S43	Idinthakarai	77° 44’ 34.62’’	08° 10’ 34.08’’
S19	Keelakarai	78° 47’ 01.68’’	09° 13’ 34.38’’	S44	Perumanal	77° 38’ 43.44’	08° 09’ 30.66’’
S20	Earvadi	78° 43’ 09.84’’	09° 11’ 39.42’’	S45	Chettikulam	77° 37’ 16.02’	08° 09’ 09.30’’
S21	Valinokkam	78° 37’ 47.22’’	09° 09’ 15.12’’	S46	Kootapuli	77° 36’ 12.00’	08° 08’48.24’’
S22	Keezhamundal	78° 35’ 09.48’’	09° 08’ 15.90’’	S47	Vattakotai Beach	77° 33’ 58.86’	08° 07’ 35.82’’
S23	Oppilan	78° 30’ 16.56’’	09° 07’ 59.58’’	S48	Lakshmipuram	77° 33’ 25.56’	08° 06’ 35.82’’
S24	Mookaiyur	78° 28’ 44.82’’	09° 07’ 40.08’’	S49	Chinnamuttom	77° 33’ 34.08’	08° 05’ 44.64’’
S25	Vembar	78° 21’ 53.76’’	09° 04’ 34.92’’	S50	Vavaturai Beach	77° 33’ 09.48’	08° 05’ 01.20’’

mangroves are affected by chemical wastes from the aquaculture farms. Ramanathapuram district has rich coastal bio-diversity and unique coral reefs found in Gulf of Mannar region on one part of its coast[16]. Most of the establishment such as harbour, fishing related activities and a variety of industries like nuclear and thermal power plant, refineries, marine chemical waste and sand mining are situated in the present study area. The harbour and fishing activities are major contribution in Tuticorin district and the river Tamirabarani adds additional stress to the coastal ecosystem[17]. It is also known that some regions of the southeast coast have significant distribution of heavy minerals namely monazite, zircon, rutile and garnet bearing sand and hence may play a major role in the marine environments. Tirunelveli and Kanyakumari districts have an abundance of heavy minerals[16]. Due to higher radioactivity content in beach sands, sand mining in Periyathalai near Titunelveli districts and nearby stretches might influence certain effect to the ecosystem. Therefore, the knowledge of the current status of the content of naturally occurring radionuclides will be great significance in the beach sands.

2.2 Sample collection and preparation techniques

Beach sand samples were collected from a pit of 100×100 cm length and width, respectively[18]. At each site, the surface beach sand samples were collected approximately 5m away from the water-line at a depth of 0-5 cm. The collected samples were uniformly mixed, sieved and air dried and further dried in an oven at temperature of 100 °C to 120 °C for an hour to remove the moisture content and stored in an airtight 250 mL plastic container for one month, prior to subjecting them to gamma ray spectral analysis. This is to ensure attaining secular equilibrium between radium and its short-lived daughter products. The net weight of the samples was determined before counting.

2.3 Gamma ray-spectroscopy

Gamma spectrometry offers a convenient, direct and non-destructive method for the measurement of radioactivity content of different radionuclides in environmental samples from their characteristic gamma energy lines. A minimum size of 3”×3” NaI(Tl) scintillation detector is generally used for spectral measurements to enable one to cover the energy spectrum of naturally occurring radionuclides up to 2.6 MeV, the gamma ray energy of ^{208}Tl, a daughter product of ^{232}Th series. In present study, a 3”×3” NaI(Tl) scintillation detector (supplied by M/S EG&G ORTEC, USA) is used for gamma spectral measurements. As the scintillation detector is covered by 150 mm lead shield, the background is reduced[1] by about 98%. Standard reference materials, procured from IAEA, RGU1 (Uranium ore), RGTh1 (Thorium ore) and RGK1 (Potassium Sulphate) having the certified activity of 1608 Bq, 1065 Bq and 4810 Bq, respectively, were used for system calibration and efficiency determination.

The sealed sand samples were placed on the top of 3”×3” NaI(Tl) detector based gamma-ray spectrometer and count spectra were obtained for each of the beach sand sample. Each sand sample was counted for 10,000 s and the net radioactivity content of the three primordial nuclides viz.; ^{40}K, ^{232}Th and ^{238}U are deduced from the count spectra and using the he efficiency factor for various energies. The peaks corresponding to 1.46 MeV (^{40}K), 1.764 MeV (^{214}Bi) and 2.614 MeV (^{208}Tl) are considered for the estimation of the primordial radionuclides. The minimum detectable activity (MDA) of each of the three primordial radionuclides with 95% confidence level (2σ) is determined from the background radiation spectrum obtained for the same counting time as was done for the sand samples. The estimated BDL values are 2.22 Bq.kg^{-1} for ^{238}U, 2.15 Bq.kg^{-1} for ^{232}Th and 8.83 Bq.kg^{-1} for ^{40}K.

3 Results and Discussion

3.1 Radionuclides content of ^{238}U, ^{232}Th and ^{40}K in beach sand

The radioactivity content (in Bq.kg^{-1}) of the primordial radionuclides ^{238}U, ^{232}Th and ^{40}K in beach sands are shown in Fig. 1; World and Indian average values are also marked in these figures by horizontal lines for comparison. Basic statistical data for activity content (in Bq.kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in the sand samples are given in Table 2.

From Table 2, the activity content of ^{238}U, ^{232}Th and ^{40}K are in the range from below detectable level (BDL) to 327.07 ±23.56 Bq.kg^{-1} with an average value of 8.77 ±3.77 Bq.kg^{-1}, BDL to 2938.31 ±26.32 Bq.kg^{-1} with an average value of 76.48 ±4.74 and BDL to 570.04 ±52.23 Bq.kg^{-1} with an average value of 202.87±26.72 Bq.kg^{-1}, respectively. In the radioactivity profile, the ^{40}K content decreases and ^{232}Th and ^{238}U content increase towards the southern part of the study area (S26 to S50) as shown in Fig. 1. From the Fig. 1, the horizontal red line represent the corresponding[19] the UNSCEAR 2000 reported world average value of 33 Bq.kg^{-1}, 45 Bq.kg^{-1} and 420

Bq.kg^{-1} for ^{238}U, ^{232}Th and ^{40}K, respectively. The activity content of ^{238}U, ^{232}Th and ^{40}K are widely varied. These wide variations in the present study may be due to the wide variety of lithological components existing and heterogeneous characteristics in the environments reported by Baeza *et al.*[20] and Iyengar and Kannan[21].

From the Fig. 1, 92% of the sampling sites (46 out of 50 sites) ^{238}U activity content is lower as compared to world average value. In the site number S48, higher activity of ^{238}U (327.07 ±23.56 Bq.kg^{-1}) is observed which is 9.9 times higher than world average value. The activity content of ^{232}Th values is lower in 68% of sites (34 out of 50 sites) when compared with

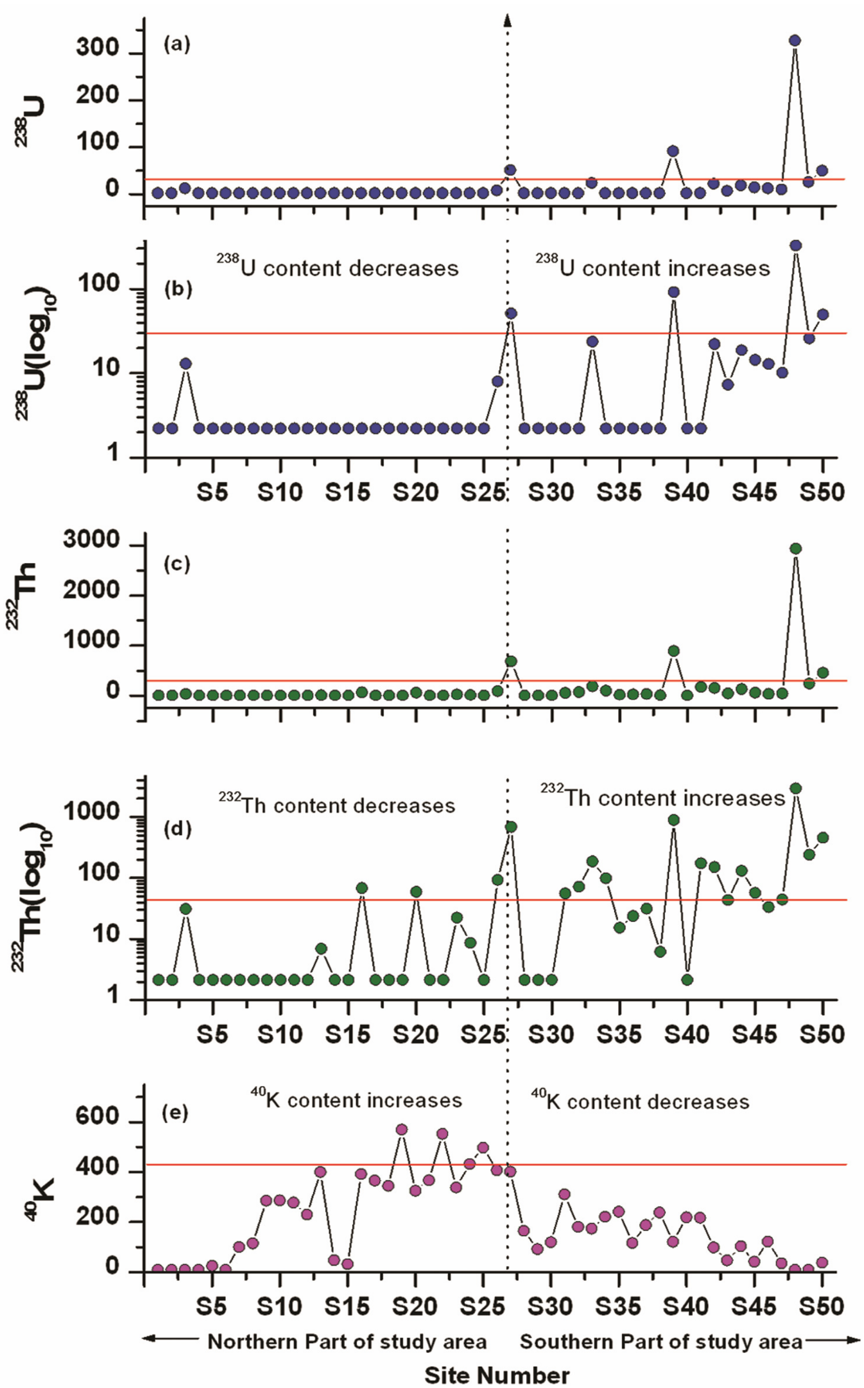

Fig 1 – Radioactivity content (Bq.kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in all sites of Tamilnadu coast

Table 2 – Statistical data for the radioactivity content of ^{238}U, ^{232}Th and ^{40}K in the beach sand samples collected at southern region of Tamilnadu coast

Statistical Parameters	Radioactivity content (Bq.kg^{-1})		
	^{238}U	^{232}Th	^{40}K
Average	8.77±3.77	76.48±4.74	202.87±26.72
Minimum	BDL[a]	BDL[a]	BDL[a]
Maximum	327.07±23.56	2938.31±26.32	570.04±52.23
Median	2.22	7.83	177.22
Standard Deviation	16.33	171.19	157.87
Skewness	3.58	3.58	0.54
Kurtosis	14.58	13.58	-0.65
Frequency Distribution	Log Normal	Log Normal	Normal

[a]BDL (below detectable limit)

world average value. The higher activity of ^{232}Th (2938.31 ±26.32 Bq.kg^{-1}) is observed again at the same site number S48, which is 65 times higher than world average value. In most of the sampling sites (46 out of 50 sites), ^{40}K activity content is lower as compared to world average value as shown in Fig. 1.

The highest ^{238}U and ^{232}Th activity were seen in site S48 (Lakshmipuram), S39 (Periyathazhai) and S27 (Sippikulam) in that order. Also, it may be noted that in S48, activity of ^{40}K is BDL (8.83 Bq.kg^{-1}), in S39 ^{40}K is above BDL (121.58 ±42.9 Bq.kg^{-1}) and in S27 it is much higher (402.1 ±52.23 Bq.kg^{-1}) than the above said two sites (S48 and S39).

In site number S48 (Lakshmipuram), activities of both ^{238}U and ^{232}Th are higher. However in the same site, activity content of ^{40}K is BDL. In this site number S48, the color of the beach sand is mostly black. Carvelho *et al.*[22] and Ramasamy *et al.*[5] reported that the black sand contains heavy minerals such as monazite, zircon, magnetite and illmenite. Higher activity in the site number S48 (Lakshmipuram) may be due to the presence of above said heavy minerals.

In site number S39 (Periyathazhai), second highest activity values of ^{238}U (91.61 ±12.73 Bq.kg^{-1}) and ^{232}Th (894.29 ±14.18 Bq.kg^{-1}) are observed. However, in this site, activity content of ^{40}K (121.58 ±42.9 Bq.kg^{-1}) is just higher than the BDL. The reddish-brown color of sand is mostly presented in this site and this type of reddish-brown color of sand is primary ore of thorium, cerium and lanthanum as reported by Ramasamy *et al.*[5]. Therefore, the reddish-brown color sands are may be reason for higher activities (^{238}U and ^{232}Th) in the site. It is one of the sand mining sites of Tamilnadu coastal region, India.

In site number S27 (Sippikulam), the third highest activity values of ^{238}U and ^{232}Th are observed. However, ^{40}K activity also was found to be higher than the above said two sites (S48 and S39) as well as below the world average value of 420 Bq.kg^{-1}. According[23] to Saroja and Roy, the higher radionuclides are observed along the coastal line, which is due to the transport of this radionuclide contents through the river estuary into coast. Therefore, the river estuary is interface between the river and coastal region. Moreover, the river estuary adds the additional amount of radionuclides in the coastal region. Ramasamy *et al.*[24] found and reported that the activity content of ^{232}Th and ^{40}K are increasing as well as clay mineral is increasing as one approaches the mouth of the river (river estuary). Similar observation is observed in the present study too. In this site number S27 (Sippikulam), one of the river estuary of present study area and therefore, the higher level of activity content may be due to the presence of clay mineral[24].

The highest ^{40}K (570.04 ±34.06 Bq.kg^{-1}) activity is observed at site number S19 (Keelakarai) followed by S22 (Keezhamundal) and S25 (Vembar). Interestingly, at these three sites, activities of both ^{238}U and ^{232}Th are BDL. The reason for the highest ^{40}K activity observed at these three sites may be due to the presence of light minerals[5,22]. The activity of the three primordial radionuclides is compared with the values reported for coastal regions of Tamilnadu and other parts of India[4-10] as well as coastal regions all over the world[25-44] (Table 3).

The activity of ^{238}U in present samples are lower than all coastal regions of India, whereas activity of ^{232}Th is lower than the all coastal regions of India, except Andhra Pradesh coast (Table 3). The activity content of ^{40}K is higher in six out of eight coastal regions of India (Table 3). Comparison results of coastal regions of other countries shows that the

Table 3 – Comparison of the radioactivity content of ^{238}U, ^{232}Th and ^{40}K in the beach sand samples of other parts of Tamilnadu coasts and different countries

S No	Name of the locations/counties	Radioactivity content (Bq.kg^{-1})			References
		^{238}U	^{232}Th	^{40}K	
Indian coastal region					
Tamilnadu coast (Southern region)		8.77	76.48	202.87	Present study
1	Andhra Pradesh	36	75	782	(4)
2	Kerala	170	547	117	(5)
3	Karnataka	249	489	55	(6)
4	Karnataka (Ullal coast)	374	1842	158	(7)
5	Odisha (Eastern coastal)	46.7	250	429	(8)
6	Orissa (Erasama beach)	350	2000	200	(9)
7	Orissa (Chhatrapur beach)	230	2500	120	(10)
Other countries					
9	Baltic sea	98	83	893	(25)
10	Bangladesh	14.53	34.8	302	(26)
11	Brazil	192	1673	217	(27)
12	China	14.6	10.9	396	(28)
13	Egypt (North Sinai)	56	83.4	88	(29)
14	Egypt (Safaga)	190	177	815	(30)
15	Hong Kong	37.1	29.8	1210	(31)
16	Iran	61	49	537	(32)
17	Izmit bay	18	24	568	(33)
18	Jordan	25	14.62	188	(34)
19	Kuwait	36	6	227	(35)
20	Nigeria	12.9	25.3	174.26	(36)
21	Pakistan	23.48	22.08	562	(37)
22	Saudi coastline	11.42	19.26	641	(38)
23	Spain	5.28	3.73	231	(39)
24	Sri Lanka	450	2100	220	(40)
25	Sudan	29.6	6	158	(41)
26	Thailand	22.6	26.4	523	(42)
27	Turkey (Ezine region)	290	532	1160	(43)
28	Yugoslavia	7.8	6.7	150	(44)
India		28	63	400	(19)
World		33	45	420	(19)

average activity content of ^{238}U was lower except Spain and Yugoslavia coasts (Table 3). The activity of ^{232}Th is higher when compared with other country except Baltic Sea, Brazil, Egypt (North Sinai and Safaga), Srilanka and Turkey (Ezine region) coasts (Table 3). As in the case of ^{238}U, the activity content of ^{40}K is lower at majority of locations except at Egypt (North Sinai), Jordan, Nigeria, Sudan and Yugoslavia coasts (Table 3). Thus, in the present study, activity content of ^{238}U and ^{40}K are lower than the most of the counties whereas activity of ^{232}Th alone is higher than some countries (Table 3). As compared with Indian and world average values with the values found in present study, the activity content of ^{232}Th alone is higher than the both Indian and world average values[19].

3.2 Univariate statistical analysis

Standard deviation, Median, Skewness and Kurtosis are calculated for activity content of ^{238}U, ^{232}Th and ^{40}K in the sand samples of Tamilnadu coast (Table 2). However, it is mentioned here that the extreme activity content values of ^{238}U (327.07 ±23.56 Bq.kg^{-1}), and ^{232}Th (2938.31 ±26.32 Bq.kg^{-1}) obtained for site S48 (Lakshmipuram near Kanyakumari) has been excluded while arriving at the statistical analysis and average value. The standard deviation values of the activity content of ^{238}U and ^{232}Th are higher than the average value except ^{40}K. This indicates that these radionuclides having the low degree of uniformity[5]. The median value can be used to identify the middle value of each radionuclides as shown in Table 2. From the Table 2, the median value for ^{40}K alone is higher than standard deviation value. This indicates that the activity content of ^{40}K values are uniformly distributed.

Adam and Eltayeb[45] reported that the positive skewness value indicates a distribution with an asymmetric tail extending towards higher values that are more positive and negative values indicates a distribution with an asymmetric tail extending toward lower values that are more negative. Kurtosis is a measure of the peakness of the probability distribution of a real valued random variable. It characterizes the relative peakness of flatness of a distribution compared with the normal distribution. Positive kurtosis indicates a relatively peaked distribution. Negative kurtosis indicates a relatively flat peaked distribution. Higher kurtosis means more of variance is result of infrequent extreme deviations, as opposed to frequent modestly sized deviations. In present study, the frequency distribution of activity content of ^{238}U, ^{232}Th, and ^{40}K are given in Figs 2, 3 and 4.

It can be observed from Figs 2 and 3, the values of skewness for ^{238}U (3.58) and ^{232}Th (3.58) are not closer to the null value, indicating the non-existence of normal distribution. Similarly, the values of kurtosis coefficient of 14.58 (^{238}U) and 13.58 (^{232}Th) are higher, and it represents the peaked distribution. Thus, the frequency distribution clearly indicates that the distributions are highly skewed towards lower activity levels and do not follow normal distribution. On the contrary, the value of skewness for ^{40}K (0.54) is close to null value and the negative values of kurtosis coefficient (-0.65) obtained for ^{40}K indicate the flat peaked distribution, which is symmetrical and bell-shaped as shown in Fig. 4. Hence, the obtained result indicates the normal distribution.

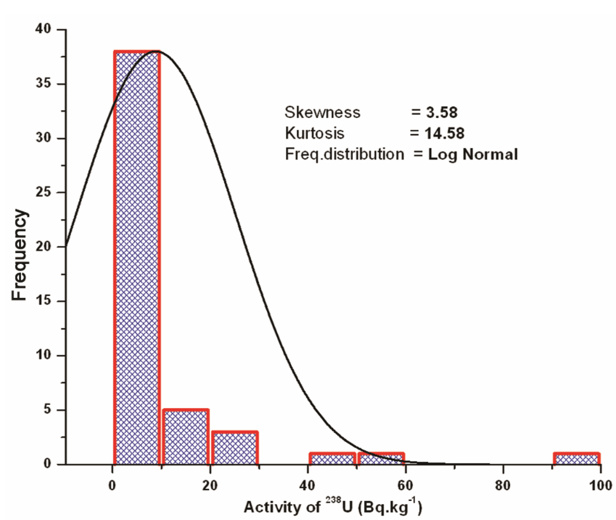

Fig 2 – Frequency distribution of ^{238}U (Bq.kg^{-1})

3.3 Radiological parameters

The main objective of measuring radioactivity is to make an estimate of radiation dose likely to be delivered externally to the general public or environment. Exposure to radiation levels can be defined in terms of many radiological parameters. In this study, the radiological parameters such as absorbed dose rate (D), annual effective dose equivalent (AEDE), annual gonadal effective dose equivalent (AGDE), radium equivalent (Ra_{eq}), hazard index (H_{ext}), gamma index (I), activity utilization index (I_U), alpha index (I_α) and excess lifetime cancer risk (ELCR) are calculated[46,47] and compared with

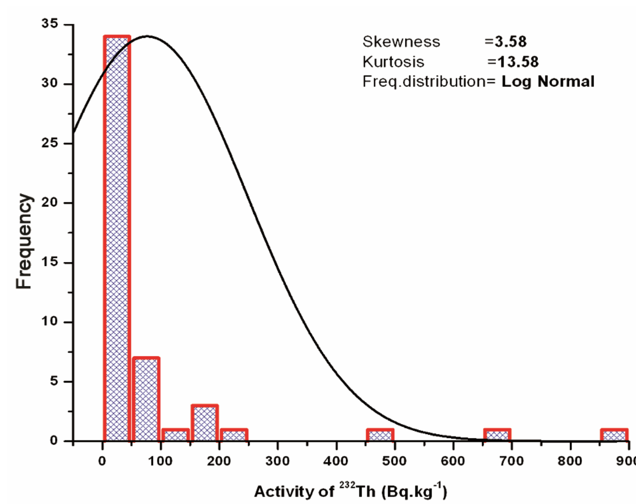

Fig 3 – Frequency distribution of ^{232}Th (Bq.kg^{-1})

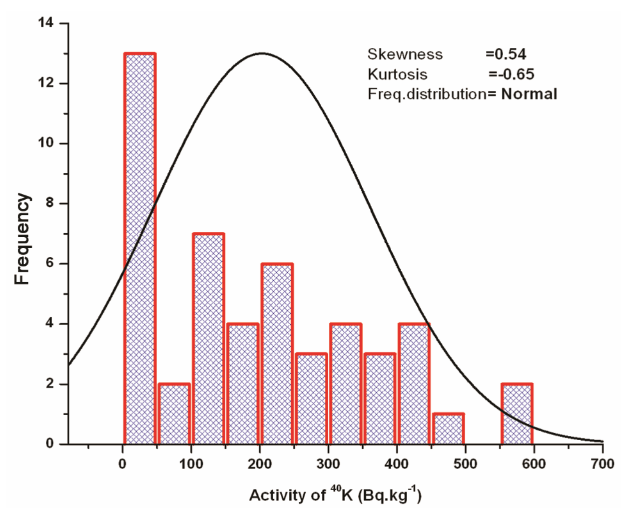

Fig 4 – Frequency distribution of ^{40}K (Bq.kg^{-1})

reported data. The calculated absorbed dose rate (*D*), annual effective dose equivalent (AEDE), annual gonadal effective dose equivalent (AGDE) and radium equivalent (Ra_{eq}) values increase ones and approach the southern part of the study area (S26 to S50) as shown in Fig. 5. From Fig. 5, the horizontal red line represents the corresponding world average and/or safe limit[46].

3.3.1 Absorbed dose rate

It is the first step for calculating the health risk for members of public residing in the environs. With regard to biological effects, the radiological and clinical effects are directly related to the absorbed dose rate. If the specific activities of ^{238}U, ^{232}Th and ^{40}K are known, then its absorbed dose rate in air at 1 m above the ground can be calculated using UNSCEAR 2000 conversion factors of 0.462, 0.604 and 0.0417 (nGy.h^{-1} per Bq.kg^{-1}), respectively. These factors are used to arrive the total absorbed dose rate (*D*) using the following equation:

$$D \text{ (nGy.h}^{-1}\text{)} = (0.462\, A_U) + (0.604\, A_{Th}) + (0.0417\, A_K) \quad \ldots (1)$$

where A_U, A_{Th} and A_K are the activity content of ^{238}U, ^{232}Th and ^{40}K (Bq.kg^{-1}), respectively. The absorbed dose rates vary from 2.69 nGy.h^{-1} to 1926.21±27.15 nGy.h^{-1} with an average value of 58.70 ±5.72 nGy.h^{-1}, which is marginally higher than the world average value (57nGy.h^{-1})[19]. The extreme value of 1926.21 ±27.15 nGy.h^{-1} obtained at site number S48 has not been taken into account while arriving at the average value. The highest absorbed dose rate is observed at site number S48 (1926.21 ±27.15 nGy.h^{-1}), which is 34 time of world average value.

In the present study, the calculated absorbed dose rate in the beach segment (about 250 km) of northern part of the study area from site number S1 (Adhiramapatinam) to site number S25 (Vember) a re observed to be much lower, except adjacent to site number S20 (Earvadi) as may be seen in Fig. 5. However, the absorbed dose rate in southern part of study area from site number S26 (Vaippar) to site number S50 (Kanyakumari) are comparatively higher and it is generally showing increasing trend as one approaches southern-most tip of Tamilnadu coast (Fig. 5). Similar studies have been carried out by various authors for the other parts of Indian coastal region and the absorbed dose rate values obtained in these studies are compared and given in Fig. 6. It may

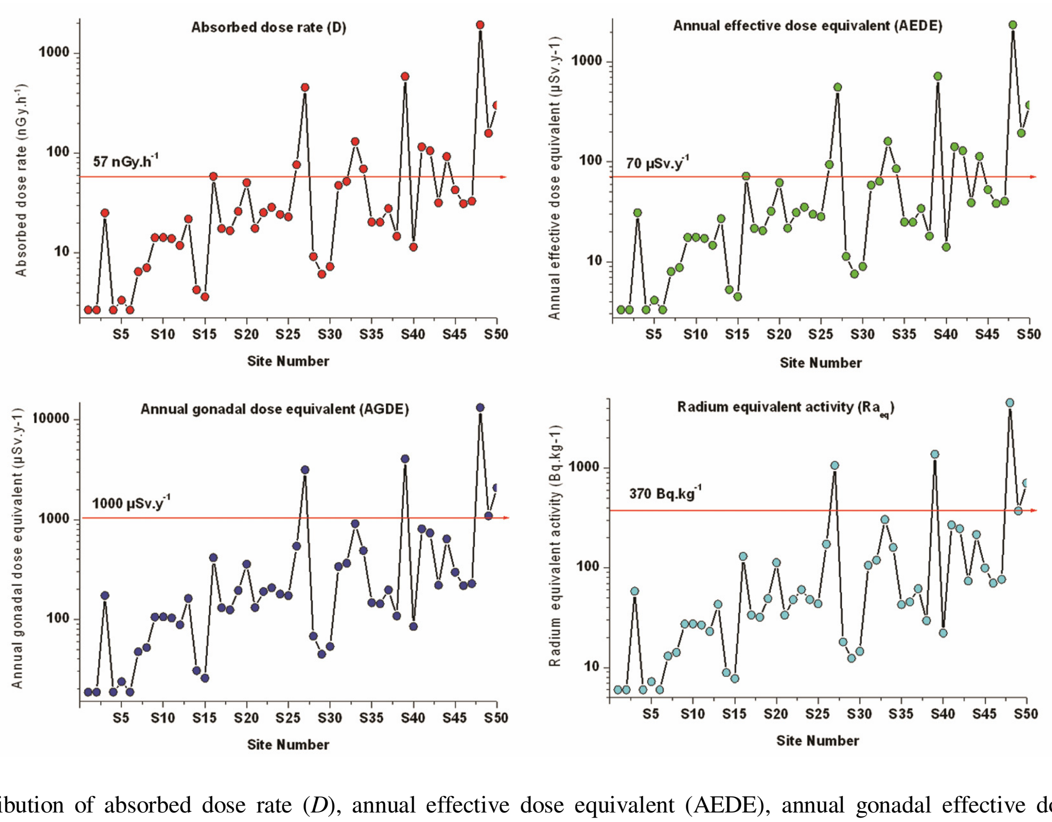

Fig 5 – Distribution of absorbed dose rate (*D*), annual effective dose equivalent (AEDE), annual gonadal effective dose equivalent (AGDE) and radium equivalent (Ra_{eq}) in all the sites of Tamilnadu be seen from Fig. 6 that the value of 58.70 ±5.72 $nGy.h^{-1}$ obtained in the present study for Tamilnadu coastal region is lower when compared to the absorbed dose rate values reported for other Indian coastal regions.

In addition, the fractional contribution of radionuclides to the total absorbed dose rate is given for each site in Fig. 7. It clearly indicates that the fractional contribution of ^{40}K activity is higher than ^{232}Th in about 50% of the sites of northern part of study area (S1 to S25) while the contribution of ^{232}Th to the absorbed dose rate values are much higher than ^{40}K in the remaining 50% sites in the southern part of study area (S26 to S50) in Tamilnadu coast (Fig. 7).

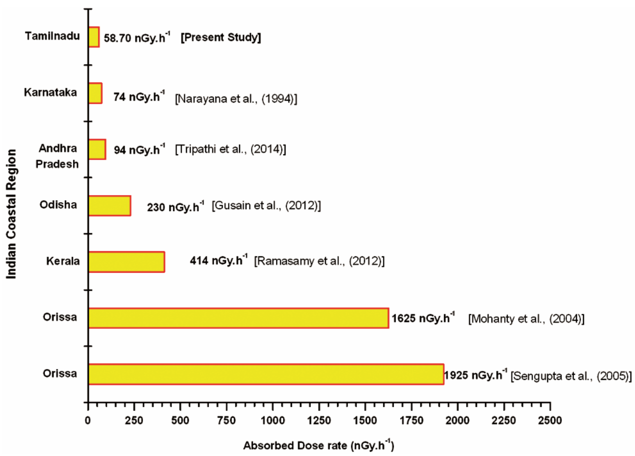

Fig 6 – Comparison of absorbed dose rate in beach sand of different parts of India

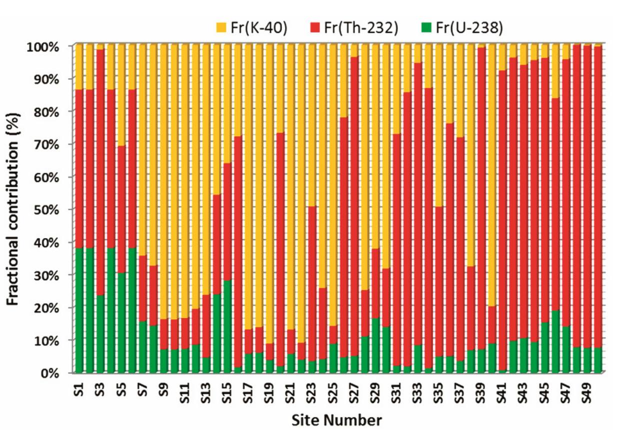

Fig 7 – Fractional contribution of ^{238}U, ^{232}Th and ^{40}K to absorbed dose rate in all the sites of Tamilnadu coast. [*NB: Fr (U-238), Fr(Th-232) and Fr(K-40) represents fractional contribution of* ^{238}U, ^{232}Th *and* ^{40}K *to the total absorbed dose rate respectively; Northern part of study area (S1 to S25) and Southern part of study area (S26 to S50)*].

3.3.2 Annual effective dose equivalent

In order to make rough estimate for the annual effective dose equivalent to be received by the member of public due to natural radioactivity of ^{238}U, ^{232}Th and ^{40}K, the gamma absorbed dose rates in $nGy.h^{-1}$ are converted to annual effective dose equivalent (AEDE) in $mSv.y^{-1}$ as proposed[19] by UNSCEAR 2000. A typical resident in a location/site, both male and female, would spend about 8 h of the day in an office or classroom or laboratory, 11 h indoors and the remaining 5 h outdoors. This applies to the greater part of the population in a location who are either office workers or public/students. Hence, 19/24 (0.8) and 5/24 (0.2) is adopted as the indoor (80%) and outdoor occupancy factor (20%), respectively, with a conversion factor of 0.7 $Sv.Gy^{-1}$ to convert absorbed dose rate ($nGy.h^{-1}$) to annual effective dose equivalent ($\mu Sv.y^{-1}$) for this study[24]. The AEDE is calculated for outdoor using the formula given below:

$$\text{AEDE (Outdoor)} = D\,(nGy.h^{-1}) \times 8760\text{ h} \times 0.7\text{ Sv.Gy}^{-1} \times 0.2 \times 10^{-3}\ (\mu Sv.y^{-1}) \quad \ldots (2)$$

Calculated AEDE is varying from 3.30 $\mu Sv.y^{-1}$ to 2362.31±33.30 $\mu Sv.y^{-1}$ with an average value of 71.99 ±7.01 $\mu Sv.y^{-1}$, which is marginally higher than the world average (70 $\mu Sv.y^{-1}$). The higher AEDE is observed at again same site number S48 (2362.31 ±33.30 $\mu Sv.y^{-1}$), which is 34 times higher than world average of 70 $\mu Sv.y^{-1}$. The extreme value of 2362.31 ±33.30 $\mu Sv.y^{-1}$ obtained for Lakshmipuram (Site number S48) has not been taken into account while arriving at the average value. Similarly, annual effective dose equivalents are showing increasing trend in the southern part of Tamilnadu (Fig. 5). The annual effective dose equivalent values obtained for other Indian coastal regions are: 120 $\mu Sv.y^{-1}$ in Andhra coast[4], 507 $\mu Sv.y^{-1}$ in Kerala[5], 2360 $\mu Sv.y^{-1}$ in eastern coast of Orissa[9] and 2360 $\mu Sv.y^{-1}$ in Chhatrapur beach of Orissa[10]. All these values are higher than the average value obtained in the present study (71.99 ±7.01 $\mu Sv.y^{-1}$).

3.3.3 Annual gonadal dose equivalent

The activity bone marrow and the bone surface cells are considered as the organs of interest by UNSCEAR (2000). Therefore, the annual gonadal dose equivalent due to the activity content of ^{238}U, ^{232}Th and ^{40}K is calculated using the formula given below[5]:

$$\text{AGDE } (\mu\text{Sv.y}^{-1}) = (3.09\, A_U) + (4.18\, A_{Th}) + (0.314\, A_K) \quad \ldots (3)$$

The annual gonadal dose equivalents vary from 18.62 μSv.y^{-1} to 13295.5 ±185.59 μSv.y^{-1} with an average value of 410.46 ±39.83 μSv.y^{-1}, which is much lower than the world average value (1000 μSv.y^{-1}). The extreme value of 13295.5 ±185.59 μSv.y^{-1} obtained for Lakshmipuram (Site number S48) has not been taken into account while arriving at the average value. In majority of the sampling sites (Except S27, S39 and S48 to S50), the AGDE values are lower as compared to world average value (indicating horizontal red line) as shown in Fig. 5.

3.3.4 Radium equivalent

Exposure can be defined in terms of many radiological parameters. It is well known that radium equivalent (Ra_{eq}) activity is one of the common and widely used radiological hazard indices[1]. The Ra_{eq} activity and the external hazard index are closely linked to each other. It was defined on the assumption that 10 Bq.kg^{-1} of ^{238}U, 7 Bq.kg^{-1} of ^{232}Th and 130 Bq.kg^{-1} of ^{40}K produce the same gamma-ray dose rate reported by Beretka and Mathew[46] and it was calculated through the relation given by Beretka and Mathew[46]:

$$Ra_{eq} = A_U + 1.43\, A_{Th} + 0.077\, A_K \text{ (Bq.kg}^{-1}) \quad (4)$$

The range of calculated Ra_{eq} levels varies from 5.97 Bq.kg^{-1} to 1379.81 ±38.95 Bq.kg^{-1} with an average of 133.75 ±12.60 Bq.kg^{-1}. The extreme value of 1379.81 ±38.95 Bq.kg^{-1} obtained for Lakshmipuram (site number S48) has not been taken into account while arriving at the average value. About 90% of sites are not exceeding the recommended limit of 370 Bq.kg^{-1} except for few sites such as S27, S39 and S48 to S50 and also the Ra_{eq} values are increasing trend observed at southern part of Tamilnadu (Fig. 5). The observed Ra_{eq} values are found to be lesser as compared to other coastal regions of India reported by Tripathi *et al.*[4] (203 Bq.kg^{-1} for Andhra Coast) and Ramasamy *et al.*[5] (961.8 Bq.kg^{-1} for Kerala coast). The average values of Ra_{eq} obtained in the present study for Tamilnadu coastal sands are lower than the recommended safe limit[45] of 370 Bq.kg^{-1} for the safe use of materials in the construction of buildings.

3.3.5 External hazard index

The external hazard index (H_{ext}) is calculated for the sand samples using the following equation on the basis of model proposed by Beretka and Mathew[46]:

$$H_{ext} = A_U/370 + A_{Th}/259 + A_K/4810 \quad \ldots (5)$$

The calculated external hazard index values are increases ones approaches the southern part of the study area (S26 to S50) as shown in Fig. 8; the horizontal red line represents the corresponding safe limit[46]. The calculated external hazard index varies from 0.02 to 12.23 ±0.17 with an average value of 0.36±0.03 which is much less than unity. Here too, the extreme value of 12.23 obtained for Lakshmipuram (Site number S48) has not been taken into account while arriving at the average value. As in the case of radium equivalent activity (Ra_{eq}) activity, about 90% of sites having lesser hazard index values as shown in Fig. 8. This indicates that the external hazard index (reflecting external exposure) is lesser (90% of sites having beach sands) than the recommended safe limits [46] and hence, it may not be pose radiation effect to member of public or tourists while staying in beaches.

3.3.6 Gamma index

It is one of the gamma radiation hazard index and it is also known as representative level index. Gamma index is used to regulate all the building materials, which would produce an effective annual dose to the inhabitants higher than 1 mSv. For building materials, the three types of gamma index values are suggested on the basis of annual dose criterion. First, the exemption dose criterion (0.3 mSv.y^{-1}) corresponds to $I \le 0.5$. It is recommended that constraints should be set to a gamma index value range of 0.5 to 1 ($0.3 \le 1$ mSv.y^{-1}) and finally when $I > 1$, building materials should be avoided[46]:

$$I = A_U/300 + A_{Th}/200 + A_K/3000 \quad \ldots (6)$$

The calculated gamma index values are increases ones approaches the southern part of the study area (S26 to S50) as shown in Fig. 8; the horizontal red line represents the corresponding safe limit[46]. The calculated gamma index varies from 0.02 to 15.78±0.21 with an average value of 0.48±0.05 which is lesser than recommended limit of 0.5. Here too, the extreme value of 15.78 obtained for Lakshmipuram (Site number S48) has not been taken into account while arriving at the average value. In most of the sites (38 sites out of 50 sites), the gamma index values are not exceeding the gamma dose level of 0.3 mSv.y^{-1} ($I \le 0.5$). Moreover, about 90% of sites (45 sites out of 50 sites) are within the recommended limit[46] of 1 mSv.y^{-1} ($I > 1$) as shown in Fig. 8.

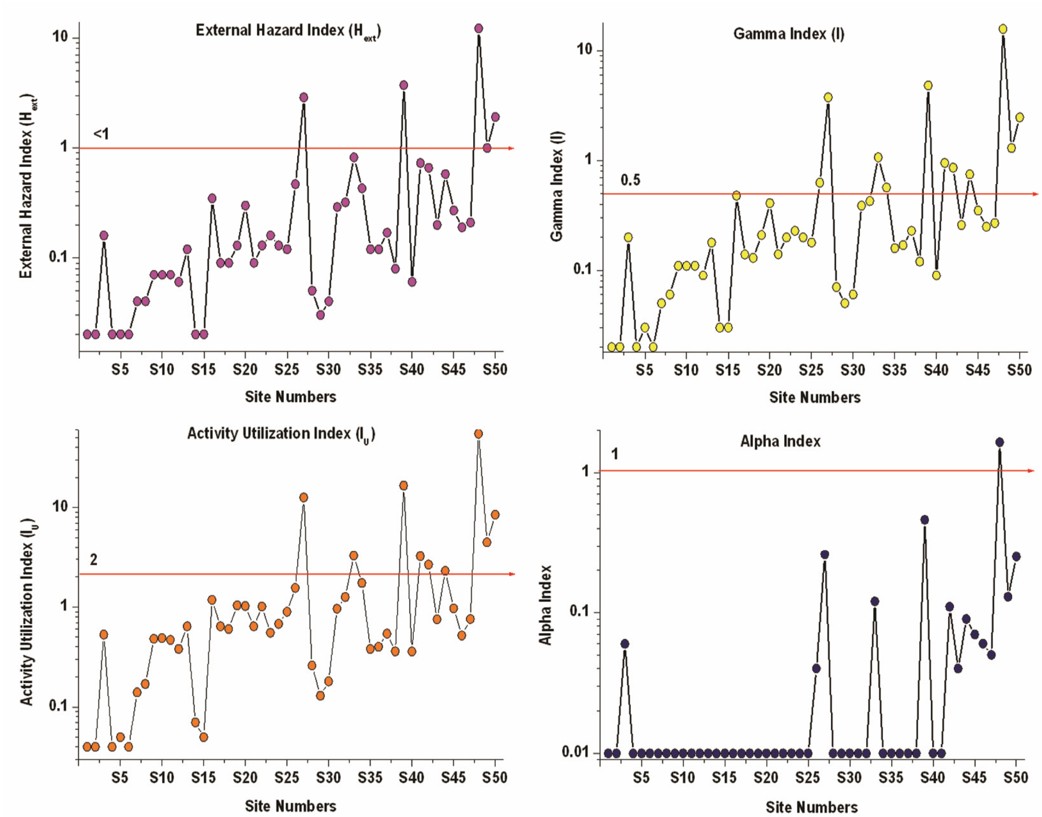

Fig 8 – Distribution of hazard index (H_{ext}), gamma index (I_r), activity utilization index (I_U) and alpha index in all the site of Tamilnadu coast

3.3.7 Activity utilization index

Absorbed dose rate in indoors mainly depends on the different building materials. Consequently, absorbed dose level in indoors (Dwelling) mainly due to the naturally occurring primordial radionuclides presence in construction materials namely fired and non-fired clay bricks, cement, river sediment and beach sand. Of late, the beach sands are being extensively used for construction activities. Therefore, activity utilization index (I_U) is calculated for this reason using the formula given below[24]:

$$I_U = (A_U/50)f_U + (A_{Th}/50)\,f_{Th} + (A_K/500)\,f_K \qquad (7)$$

The f_U, f_{Th} and f_K represent the fractional contribution to the total dose of ^{238}U, ^{232}Th and ^{40}K (Bq.kg^{-1}), respectively. The calculated activity utilization index values are increases ones approaches the southern part of the study area (S26 to S50) as shown in Fig. 8; the horizontal red line represents the corresponding safe limit[24]. The calculated activity utilization index varies from 0.04 to 54.66 ±0.50 with an average value of 1.56 ±0.09 which is lesser than the recommended value[24] of 2. Here too, the extreme value of 54.66 obtained for Lakshmipuram (Site number S48) has not been taken into account while arriving at the average value. In the majority of the sites (42 sites out 50 Sites), the activity utilization index values are not exceeding the recommended value of 2 as shown in Fig. 8 (Indicating horizontal red line). Therefore, about 85% (42 sites out 50 Sites) of the beach sand samples can be used for safe construction of buildings as shown in Fig. 8.

3.3.8 Alpha index

The alpha index may estimate the exposure to radon (radioactive gaseous isotope) originating from the naturally occurring primordial radionuclides in building material. The alpha index was proposed on the basis of the assumption that if activity content of ^{238}U content exceeds 200 Bq.kg^{-1}, it is possible that the indoor radon concentration will exceed 200 Bq.m^{-3}. The alpha radiation due to the radon concentration (one of the daughters of ^{238}U series) originating from building material is estimated using the relation given below[47]:

$I_\alpha = A_U/200$ … (8)

Alpha index (I_α) should be lower than the maximum permissible limit of I_α=1, which corresponds to 200 Bq.kg^{-1}. The calculated alpha index values are increases ones approaches the southern part of the study area (S26 to S50) as shown in Fig. 8, the horizontal red line represents the corresponding safe limit[47]. In the present study, the alpha index value ranged from 0.01 to 1.64 ±0.12 with an average value of 0.04 ±0.02 which is much lesser than the permissible limit of one. In the present study (as mentioned earlier), 92 % of the sampling sites (46 out of 50 sites) ^{238}U activity content is lower as compared to world average value. Therefore, the alpha index value is much lesser in the all the sites of Tamilnadu coast except site number S48 (Lakshmipuram). Here too, the extreme value of 1.64 obtained for Lakshmipuram (Site number S48) has not been taken into account while arriving at the average value. From the observation of results indicate that the radon concentration will not exceed the 200 Bq.m^{-3} in beach sand of Tamilnadu coast.

3.3.9 Excess lifetime cancer risk

Excess lifetime cancer risk (ELCR) is calculated using the following equation:

ELCR= AEDE × DL × RF … (9)

where AEDE, DL and RF is the annual effective dose equivalent, duration of life time (70 years) and risk factor (Sv^{-1}), fatal cancer risk per Sievert. For stochastic effects, ICRP 60 uses values of 0.05 for the public[3]. The calculated excess lifetime cancer risk values are increases ones approaches the southern part of the study area (S26 to S50) as shown in Fig. 9; the horizontal red line represents the corresponding safe limit[24]. The calculated excess lifetime cancer risk (ELCR) varies from 0.01 to 8.27 ±0.12 ×10^{-3} with an average value of 0.25 ±0.02 × 10^{-3} which is lower than the world average value (0.29×10^{-3}). Here too, the extreme value of 8.27×10^{-3} obtained for Lakshmipuram (Site number S48) has not been taken into account while arriving at the average value. In the most of the sites (39 sites out 50 Sites), the excess lifetime cancer risk (ELCR) values are not exceeding the world average value[3] (0.29×10^{-3}) as shown in Fig. 9.

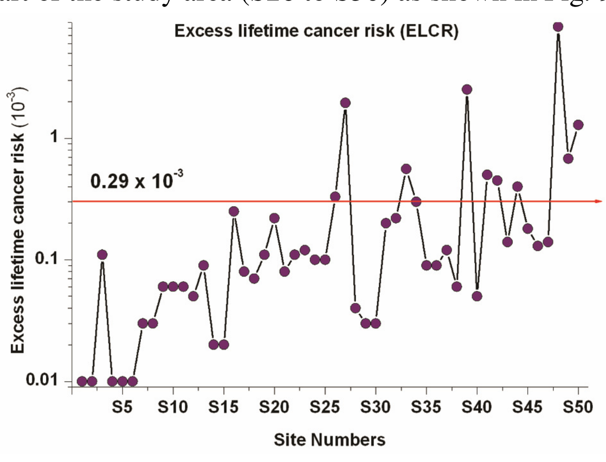

Fig 9 – Distribution of excess lifetime cancer risk (ECLR) in all the site of Tamilnadu coast

4 Conclusions

The radioactivity content of ^{238}U, ^{232}Th and ^{40}K in beach sand samples of southern region of Tamilnadu, India have been analyzed successfully. As compared to Indian and World average values, the radioactivity content of ^{238}U and ^{40}K are lower whereas it is higher for ^{232}Th. However, the radioactivity of ^{232}Th is mostly lesser than that of other coastal regions of Indian States. The radioactivities of both ^{238}U and ^{232}Th are non-existence of normal distribution whereas ^{40}K content is distributed uniformly in the sands. The series radionuclides of ^{232}Th and ^{238}U (except ^{40}K) and all the calculated radiological parameters are generally showing increasing trend as one approaches southern-most tip of Tamilnadu coast. From the results of the present study, the absorbed dose rate (58.70 ±5.72 nGy.h^{-1}) and annual effective dose equivalent (71.99 ±7.01 µSv.y^{-1}) are marginally higher than world average value of 57 nGy.h^{-1} and 70 µSv.y^{-1}, respectively. Other radiological parameters such as Annual gonadal dose equivalent (AGDE), radium equivalent (Ra_{eq}), hazard index (H_{ext}), gamma index (I), activity utilization index (I_U), alpha index (I_α) and excess lifetime cancer risk (ELCR) are lesser than the recommended safe limits. The results of the present study indicate that the natural radioactivity content in the coastal sands do not pose any radiation effect to the member of public in the environmental of southern region of Tamilnadu.

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