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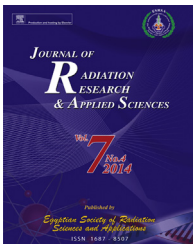

Evaluation of excessive lifetime cancer risk due to natural radioactivity in the rivers sediments of Northern Pakistan

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ABSTRACT

Naturally occurring radionuclides ^{226}Ra, ^{232}Th and ^{40}K present in the rivers sediments of Northern Pakistan were measured using HPGe γ-ray spectrometer to evaluate the radiation health hazard indices and excess lifetime cancer risk (*ELCR*). Average concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the sediments were found to be 50.66 ± 1.29, 70.15 ± 1.45 and 531.70 ± 5.45 Bq kg^{-1} respectively. Radium equivalent activity (190.89 Bq kg^{-1}), outdoor external dose (87.47 nGy h^{-1}), indoor external dose (165.39 nGy h^{-1}), and total average annual effective dose (0.92 mSv) were calculated. The hazard indices are higher than the world's average values. Total excess lifetime cancer risk (*ELCR*) was found to be 3.21 × 10^{-3} which is relatively higher. Numerous cancer deaths are annually reported from the Northern areas of Pakistan, which may be related to high radioactivity in the area.

1. Introduction

Radiation in our environment comes from the cosmogenic, anthropogenic and primordial sources. Contribution of cosmogenic and anthropogenic sources to the total environmental radioactivity is negligible. Primordial radioactivity is widespread in the earth environment, mainly in various geological formations and their disintegration products. As a result of rock weathering, the radionuclides are carried to the soils, streams and rivers by rain. Level of primordial radioactivity concentration depends on local geological conditions and geographical location of the area (UNSCEAR, 2000).

Long-term exposures to radioactivity and inhalation of radionuclides have serious health effects such as chronic lung diseases, acute leucopoenia, anemia and necrosis of the

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mouth. Exposure to radium may result in teeth fracture, anemia and cataract and may even cause cancer of various types. Thorium exposure can cause lung, pancreas, hepatic, bone and kidney cancers and leukemia (Taskin et al., 2009). These diseases are caused by γ-radiation, which is capable of traveling long distances through air to affect the human beings (www.lenntech. com/periodic/elements/ra. htm#ixzz2cg3HdHBk).

River sediments are a major source of radioactivity that contributes significantly to the background level of radiation. Knowledge of natural radioactivity in the river sediments is thus important. Therefore, concentrations of naturally occurring radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in the sediments of Hunza, Gilgit and Indus River from Northern Pakistan were measured, to evaluate the radiation health hazard indices and excess lifetime cancer risk (*ELCR*) for the local population and visitors.

Gilgit city is the major town in the Northern Pakistan with estimated population approaching to 1,000,000. For that reason, the main focus of our study was around Gilgit. Gilgit has a broad small industrial base, producing manufactured goods for local and foreign markets. The discharge waste from such industries is negligible that does not contribute toward any radioactivity.

2. Material and methods

2.1. *Study area*

The study area is located in the Northern Pakistan which comprises of parts of the Hindukush, the Karakoram Range and the Himalayas, having more than fifty peaks exceeding 6500 m. Hunza, Gilgit and Indus are the three main rivers in

Fig. 1 – Map of Pakistan showing locations of major cities including Gilgit and surrounding areas. The study area extends from Gulmit near Baltit to Chilas. All rivers originating from higher ranges join the mighty Indus River that finally falls in the Arabian Sea near Karachi.

the Northern Pakistan as shown in Fig. 1. The Gilgit River descends from the Hindukush Mountain Ranges. Hunza River coming from Karakoram Range joins the Gilgit River south of the Gilgit town. These two rivers then flow southwards and join the Indus River coming from Himalayan ranges at Jaglot about 40 km south of Gilgit. People in the area mostly reside in the villages along rivers and stream banks.

2.2. *Sampling*

Thirty sediments samples were collected in two phases from various locations along Hunza, Gilgit and Indus Rivers over a distance of 275 km (Fig. 2). The samples were taken from a depth of 10–20 cm, located away from the human trespassing. A few samples were collected from Ali Abad area from Hunza River to check the influx of radioactivity from the upper Karakoram Ranges into the river system. Seven samples were collected from south of Jaglot to check the contribution of any radioactivity coming from the Himalayan Mountains. The samples were pulverized and dried in an oven at 110 °C for 24 h to remove moisture from the samples. Then each sample was sealed in standard 1000 ml Marinelli Beaker and stored for 40 days in order to attain the secular equilibrium between ^{226}Ra and its short-lived daughters (Hamby & Tynybekov, 2002). The net weight of the sample was determined before γ-ray spectrometric measurements.

3. Radioactivity measurements

3.1. *System used for measurements*

Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were measured using High Purity Germanium (HPGe) γ-ray spectrometer having 10 cm thick lead shielding on all sides with inner Cu and Sn lining, to reduce the background activity to about 95%. The efficiency of the γ-ray spectrometer was 52.3% relative to 3″ × 3″ NaI (Tl) γ-ray spectrometer. Minimum detection limit of the γ-ray spectrometer was 6.35, 3.25 and 2.15 Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K respectively. Periodical measurements were made to check the background level of radioactivity in the laboratory. Weekly γ-ray measurements of the reference material were done to calibrate the system. The γ-ray photo peaks corresponding to 242 & 351 keV of ^{214}Pb and 609, 1120 &

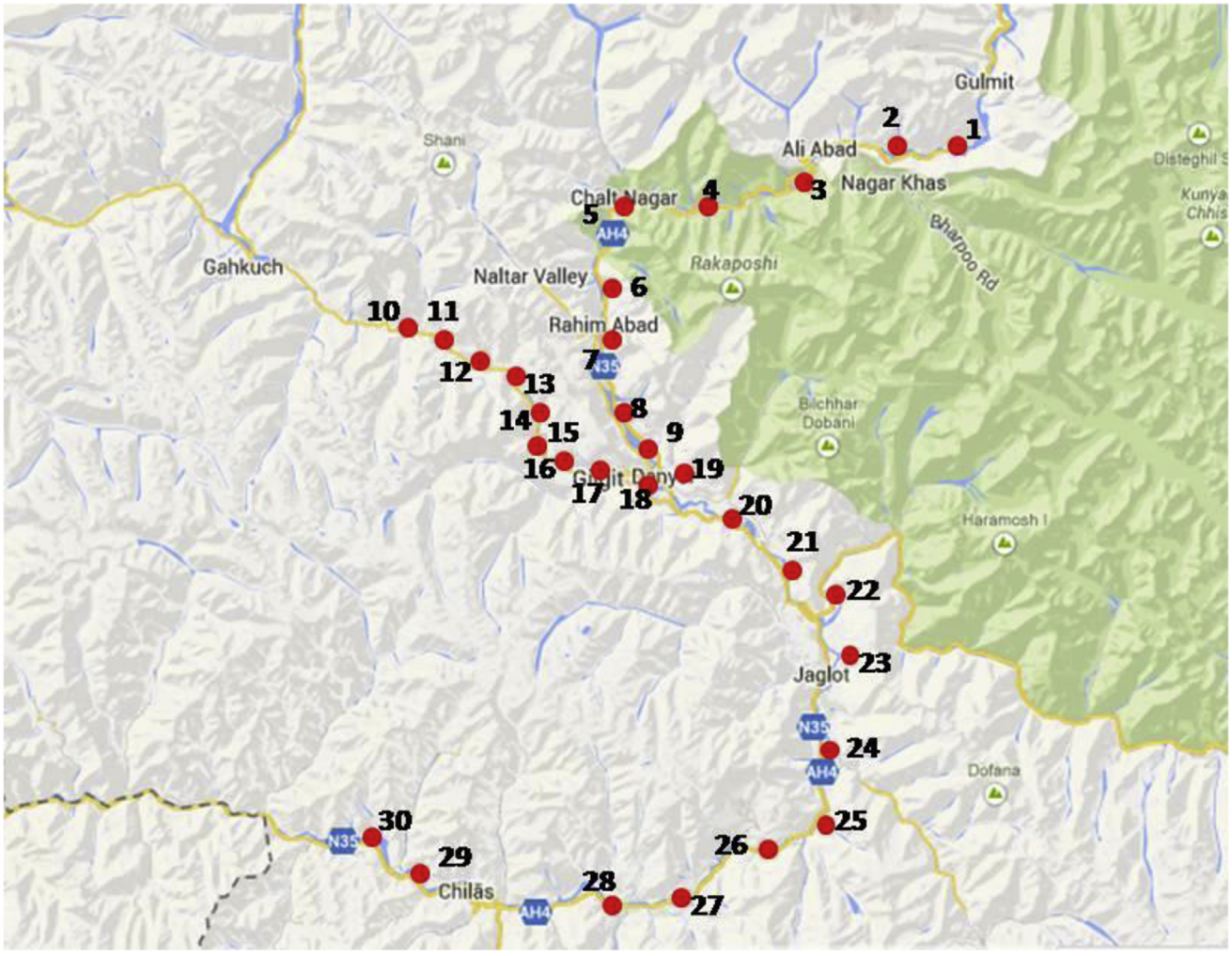

Fig. 2 – Location of sediment samples collected for the study of radioactivity in Hunza, Gilgit and Indus Rivers, Northern Pakistan. The study area extends for 275 km from Gulmit to Chilas.

Table 1 – Statistics of radionuclides and radiological hazards in the sediment of Hunza, Gilgit and Indus Rivers from Northern Pakistan.

	Minimum	Maximum	Average	St deviation	World average
Radionuclides					
^{226}Ra (Bq kg^{-1})	21.37 ± 1.01	110.51 ± 2.01	50.66 ± 1.29	23.48	25[a]
^{232}Th (Bq kg^{-1})	11.65 ± 0.5	172.06 ± 1.79	70.15 ± 1.45	34.58	25[a]
^{40}K (Bq kg^{-1})	173.96 ± 3.3	825.43 ± 7.1	531.70 ± 5.45	139.88	370[a]
^{226}Ra + ^{232}Th + ^{40}K (Bq kg^{-1})	258.98	1108.00	652.52	164.18	420[a]
^{226}Ra/^{40}K	0.04	0.25	0.10	0.05	0.067[a]
^{232}Th/^{40}K	0.02	0.34	0.14	0.07	0.067[a]
^{226}Ra/^{232}Th	0.34	1.83	0.77	0.26	1.00[a]
Radiation indices					
Ra_{eq} (Bq kg^{-1})	75.54	393.29	190.89	71.71	370[b]
D_{out} (nGy h^{-1})	37.75	175.03	87.47	31.39	59[b]
D_{in} (nGy h^{-1})	71.50	329.39	165.39	58.98	84[b]
E_{out} (mSv y^{-1})	0.05	0.21	0.11	0.04	0.07[b]
E_{in} (mSv y^{-1})	0.35	1.62	0.81	0.29	0.41[b]
$E_{out} + E_{in}$ (mSv y^{-1})	0.40	1.83	0.92	0.33	0.52[c]
(ELCR) × 10^{-3}$_{(out)}$	0.61	0.75	0.37	0.13	0.29[c]
(ELCR) × 10^{-3}$_{(in)}$	1.23	5.66	2.84	1.01	1.16
(ELCR) × 10^{-3}$_{(Total)}$	1.39	6.41	3.21	1.15	1.45

[a] UNSCEAR (1988).
[b] UNSCEAR (2000).
[c] Taskin et al. (2009).

1749 keV of ^{214}Bi were considered for identifying the ^{226}Ra. The γ-ray photo peaks of 338 & 911 keV of ^{228}Ac, 585 keV of ^{208}Tl, 911 keV of ^{228}Ac and 2590 keV of ^{208}Te were used to identify ^{232}Th in the samples (Akhtar, Tufail, Ashraf, & Iqbal, 2005). The ^{40}K was recognized from its single peak of 1460 keV (IAEA, Technical Report 309, 1989). Spectrum acquisition of the samples was taken for 20,000 s and the spectra were stored in the computer.

3.2. Radiation indices measurements

Human beings are exposed to γ-rays and α-particles, mainly from the ^{226}Ra, ^{232}Th and ^{40}K present in terrestrial materials. To assess the collective impact of activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in a single quantity; radiation indices namely radium equivalent activity, outdoor and indoor doses, annual effective dose and excessive lifetime cancer risk were calculated as per procedures given in the literature.

4. Results

4.1. Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the sediments of Hunza, Gilgit and Indus Rivers vary from 21.37 ± 1.01 to 110.51 ± 2.01, 11.65 ± 0.5 to 172.06 ± 1.79 and 173.96 ± 3.3 to 825.43 ± 7.1 Bq kg^{-1} with average values of 50.66 ± 1.29, 70.15 ± 1.45 and 531.70 ± 5.45 Bq kg^{-1} respectively as shown in Table 1. Profile of the activity concentration of various radionuclides with reference to sample Nos. in the sediments river sediments and world's averages are shown in Fig. 3(A)–(D). The total activity concentration (^{226}Ra + ^{232}Th + ^{40}K) varies from 258.98 to 1108.00 Bq kg^{-1} from Ali Abad down to the end of study area near Chillas with average value of 652.52. Except five samples the total activity concentration of rest of the samples ranges from 500 to 800 Bq kg^{-1}. The samples having higher activity concentration contains about 60% feldspar, 30% quartz, 2% amphibole and 8% ore that is close to granitic composition. The ore may contain radium–thorium minerals. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K is higher in samples collected from the southern part of the study area. In general, the concentration of ^{40}K > ^{232}Th > ^{226}Ra.

The average activity concentration of ^{226}Ra (50.66 ± 1.29 Bq kg^{-1}), ^{232}Th (70.15 ± 1.45 Bq kg^{-1}) and ^{40}K (531.70 ± 5.45 Bq kg^{-1}) is higher than world's average concentration of these radionuclides in the river sediments that is 25, 25 and 370 Bq kg^{-1} respectively as per (UNSCEAR Report, 1988). The average of total activity concentration of ^{226}Ra + ^{232}Th + ^{40}K (652.52 Bq kg^{-1}) in the sediments is also higher than the world's average of total activity concentration of these radionuclides in the river sediments that is 420 Bq kg^{-1}. The ^{226}Ra/^{40}K and ^{232}Th/^{40}K ratios given in Table 1 are relatively higher than the world's average of 0.067. This indicates that the study area is composed of rocks having low potassic values. However, the ^{226}Ra/^{232}Th ratio is lower than the world's average of 1. For comparison, the total activity concentration in sediments of Hunza, Gilgit and Indus Rivers and some other countries of the world is represented in Table 2. The total activity concentration of river's sediments from Northern Pakistan (653 Bq kg^{-1}) falls in the category of moderately high activity concentration.

4.2. Radium equivalent activity (Ra_{eq})

The ^{226}Ra, ^{232}Th and ^{40}K emit different γ-doses even if present in the same amount in any material. So the radiation hazards

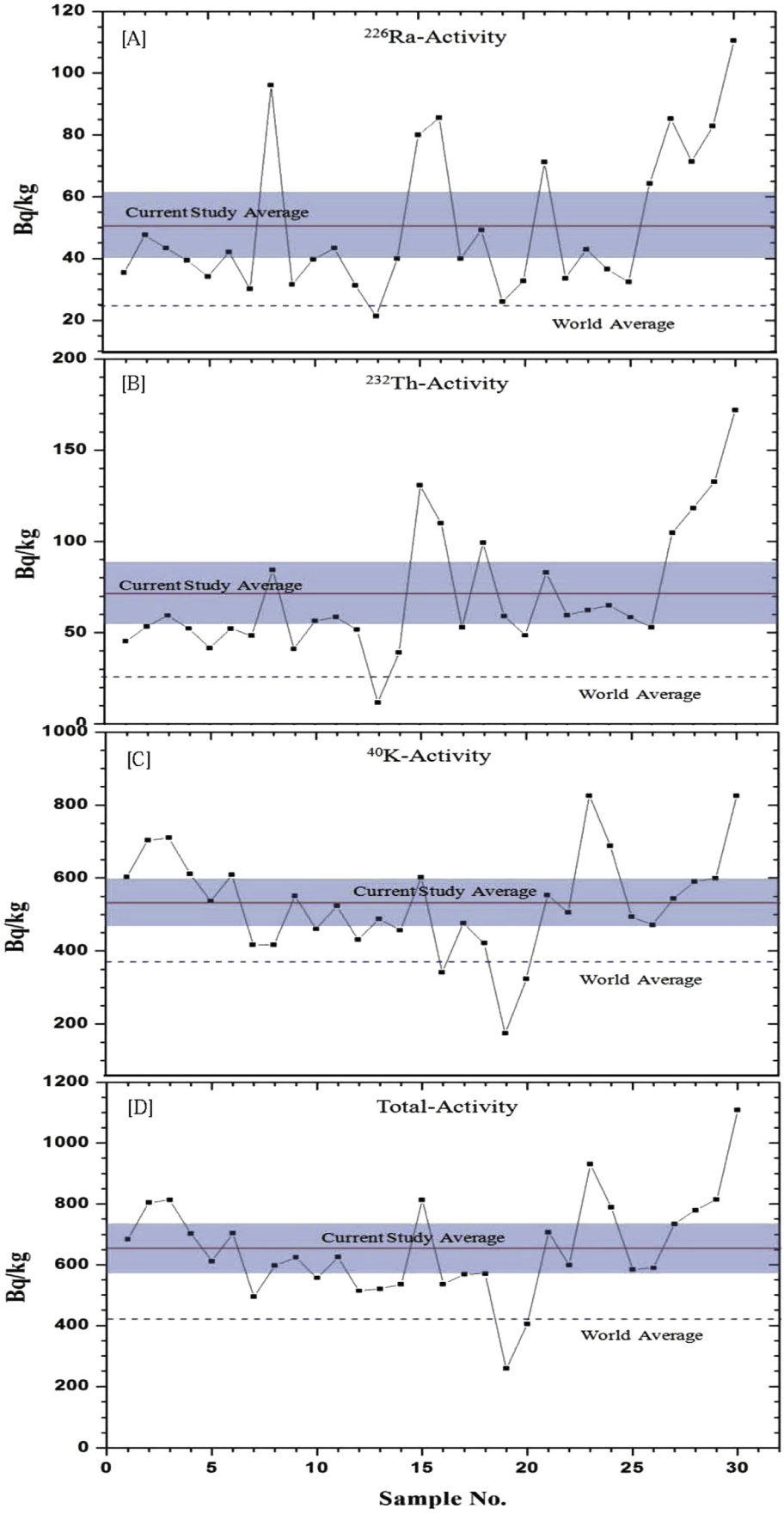

Fig. 3 – Total activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the sediments of Hunza, Gilgit and Indus Rivers, Northern Pakistan. In general the activity concentration of ^{40}K > ^{232}Th > ^{226}Ra. The shaded area shows the standard deviation from the original values.

Table 2 – Comparison of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the sediments of Hunza, Gilgit and Indus Rivers, Northern Pakistan with some other countries of the world.

No.	Country	Activity concentration (Bq kg^{-1})				Reference
		^{226}Ra	^{232}Th	^{40}K	Total	
1	Egypt, Lake Nasser	21	23	155	199	Ibrahiem, Shawky, and Amer (1995)
2	Antarctica, Livingston Island	8	10	210	228	Baeza et al. (1994)
3	Kuwait	36	6	227	269	Saad and Al-Azmi (2002)
4	Nile Delta and Middle Egypt	18	17	316	351	Ibrahiem, Abd El Ghani, Shawky, Ashraf, and Farouk (1993)
5	Bangladesh	36	66	272	374	Mantazul, Alam, and Hazari (1999)
6	India, Palar River	10	36	472	645	Ramasamy, Murugesan, and Mullainathan (2006)
7	Republic of Ireland	60	26	350	436	Mc Aualy and Moran (1988)
8	Serbia, Danube River	31	26	395	452	Krmar et al. (2009)
9	Italy, AbanoTerme	ND	33	443	476	Doretti, Ferran, Barison, Gerbasi, and Battiston (1992)
10	Turkey, Maritza River	64	36	472	572	Aytas et al. (2012)
11	*Hunza, Gilgit and Indus Rivers*	51	70	532	653	*Present study*
12	China	50	90	524	664	Ziqiang, Yin, and Mingqiang (1988)
13	Reedy River, South Carolina	21	45	609	665	Powell et al. (2007)
14	French Rivers	38	38	599	675	Lambrechts, Foulquier, and Gamier-Laplace (1992)
15	Spain River Tagus,	42	63	572	677	Baeza, del Rio, Miro, and Paniagua (1992)
16	Nigeria, Ogun river	45	49	650	744	Jibiri and Okeyode (2011)
17	French Rivers	28	44	700	772	Descamps and Foulquier (1988)
18	Greece South Aegean Sea	50	60	881	991	Florou and Kriditis (1992)
19	Greece Aegean Sea	212	43	1130	1385	Trabidou, Flouro, Angelopoulos, and Sakelliou (1996)
	World average in sediments	25	25	370	420	UNSCEAR Report (1988)
	Range	8–160	4–130	100–700	197–1385	UNSCEAR Report (1988)

of a material are estimated by calculating the net effect of ^{226}Ra, ^{232}Th and ^{40}K present in the material as radium equivalent activity (Ra_{eq}). During this study (Ra_{eq}) was calculated using the following equation by Ibrahiem (1999):

$$Ra_{eq} = \left(\frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810}\right) \times 370 \quad (1)$$

The A_{Ra}, A_{Th} and A_K represent the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K as (Bq kg^{-1}) respectively.

The (Ra_{eq}) is the weighted sum of activities of ^{226}Ra, ^{232}Th, and ^{40}K in a material. It is based on the assumption that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th, and 4810 Bq kg^{-1} of ^{40}K produce the same γ-radiation dose rate (OECD, 1979). The values of the (Ra_{eq}) calculated for the sediments of Hunza, Gilgit and Indus Rivers range from 75.54 to 393.29 Bq kg^{-1} with an average of 190.89 Bq kg^{-1}. The average is less than the world's average of 370 Bq kg^{-1} (Al-Trabulsy, Khater, & Habbani, 2011) and meets the recommended limit set by OECD (1979). Detail of (Ra_{eq}) and other radiation indices calculated during the present study are given in Table 1. The variation of (Ra_{eq}) with reference to sample location is shown in Fig. 4(A).

4.3. *Outdoor external dose (D_{out})*

The (D_{out}) at 1 m above the ground surface is assessed from the γ-radiation originating from ^{226}Ra, ^{232}Th and ^{40}K supposed to be equally distributed in ground. For the conversion of γ-radiation originating from ^{226}Ra, ^{232}Th and ^{40}K, the factors of 0.436 nGy h^{-1} Bq^{-1} kg^{-1} for ^{226}Ra, 0.599 nGy h^{-1} Bq^{-1} kg^{-1} for ^{232}Th and 0.0417 nGy h^{-1} Bq^{-1} kg^{-1} for ^{40}K were used for calculating the (D_{out}). The conversion factors have been taken as means of those reported by Beck (1980), Saito and Jacob (1995), Clouvas, Xanthos, Antonopoulos-Domis, and Silva (2000) and Quindos, Fernandez, Rodenas, Gomez-Arozamena, and Arteche (2004). It is assumed that ^{137}Cs, ^{90}Sr and the ^{235}U decay series have insignificant contribution to the total dose from the environmental background (Jacob, Paretzke, Rosenbaum, & Zankl, 1986; Kocher & Sjoreen, 1985).

The (D_{out}) was calculated using the following equation by European Commission, 1999:

$$D_{out} = 0.436A_{Ra} + 0.599 + 0.0417A_K \quad (\text{nGy h}^{-1}) \quad (2)$$

The outdoor external doses (D_{out}) due to the presence of ^{226}Ra, ^{232}Th and ^{40}K in the sediments of Hunza, Gilgit and Indus Rivers were calculated which range from 37.75 to 175.03 nGy h^{-1} with an average value of 87.47 nGy h^{-1} (Table 1). The average is higher than the worlds' average of 59 nGy h^{-1} as per UNSCEAR Report (2000).

4.4. *Indoor external dose (D_{in})*

The γ-ray dose (D_{in}) imparted by ^{226}Ra, ^{232}Th and ^{40}K present in the indoor is calculated by converting the absorbed dose rate into effective dose using the three conversion factors; 0.92 nGy h^{-1} per Bq kg^{-1} for ^{226}Ra, 1.1 nGy h^{-1} per Bq kg^{-1} for ^{232}Th and 0.081 nGy h^{-1} per Bq kg^{-1} for ^{40}K. By utilizing the above mentioned conversion factors following equation was used to calculate the (D_{in}) (European Commission, 1999).

$$D_{in} = 0.92A_{Ra} + 1.1A_{Th} + 0.081A_K \quad (\text{nGy h}^{-1}) \quad (3)$$

The values of (D_{in}) calculated during present study range from 71.50 to 329.39 with an average of 165.39 nGy h^{-1}, which is 1.97 times higher than the world's average of 84 nGy h^{-1} as per

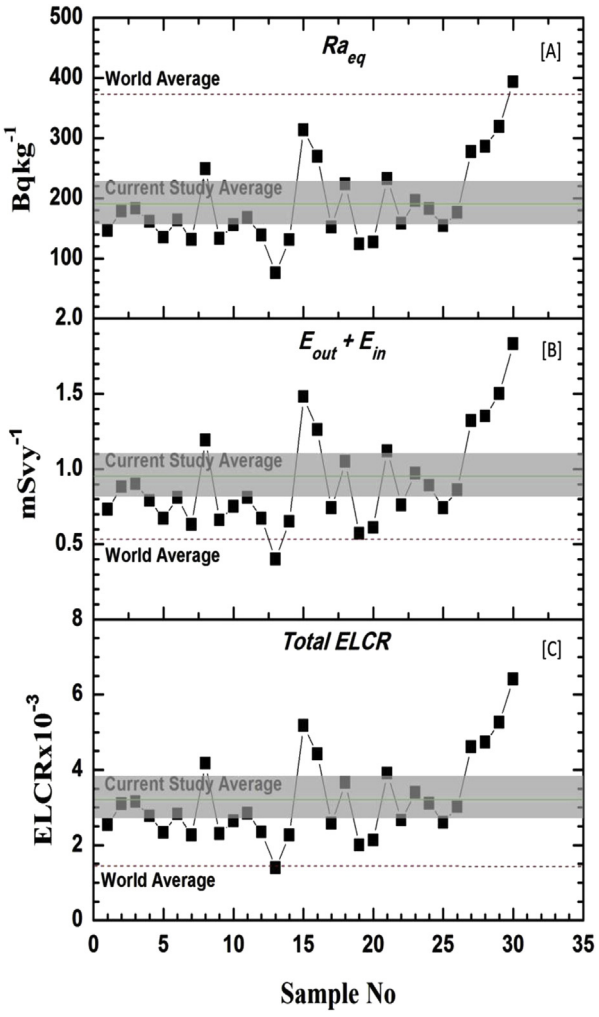

Fig. 4 – Current study averages of radium equivalent activity (Ra_{eq}), total annual effective dose ($E_{out} + E_{in}$) and total excess lifetime cancer risk (*ELCR*) against world averages due to river sediments of Hunza, Gilgit and Indus Rivers from Northern Pakistan. The marked gray region is the width of the standard deviations from their respective mean values.

UNSCEAR Report (2000).

4.5. *Annual effective dose*

The annual effective dose is of two types. The annual outdoor effective dose (E_{out}) and annual indoor effective dose (E_{in}).

4.5.1. *The annual outdoor effective dose (E_{out})*

The (E_{out}) is estimated from the outdoor external dose rate (D_{out}), time of stay in the outdoor or occupancy factor (*OF* = 20% of 8760 h in a year) and the conversion factor (*CF* = 0.7 Sv Gy^{-1}) to convert the absorbed dose in air to effective dose.

During the present study, the (E_{out}) was calculated using the following equations as per UNSCEAR Report (2000);

$$E_{(out)} = D_{(out)}\ (\text{nGy h}^{-1}) \times 20\%\ \text{of}\ 8760\ \text{h} \times 0.7\ (\text{Sv Gy}^{-1}) \quad (4)$$

$$= D_{(out)} \times 1.226\ \mu\text{Sv} \quad (5)$$

The value of (E_{out}) ranges from 0.05 to 0.21 mSv y^{-1} with an average of 0.11 mSv y^{-1} which is higher than the world's average of 0.07 mSv y^{-1}.

4.5.2. *The annual indoor effective dose (E_{in})*

The (E_{in}) is the dose which a person receives in the indoor environment. The (E_{in}) depends on the indoor external dose (D_{in}) that is the γ-ray dose within the buildings, dose conversion factor (*CF* that is 0.7 Sv Gy^{-1}) and the time of stay in the indoor (*OF* that is 80% of the in a year). The annual indoor effective dose (E_{in}) was calculated as per equations given below;

$$E_{(in)} = D_{(in)}\ (\text{nGy h}^{-1}) \times 80\%\ \text{of}\ 8760\ \text{h} \times 0.7\ (\text{Sv Gy}^{-1}) \quad (6)$$

$$= D_{(in)} \times 4.905\ \mu\text{Sv} \quad (7)$$

The (E_{in}) calculated for the rivers sediments of Northern Pakistan are given in Table 1. It ranges from 0.35 to 1.62 with an average of 0.81 mSv y^{-1} which is twice the world's average of 0.41 mSv y^{-1} (UNSCEAR, 2000).

The total annual effective dose ($E_{in} + E_{out}$) was estimated to be (0.11 + 0.81) 0.92 mSv y^{-1} which is 1.77 times higher than the world's average of 0.52 mSv y^{-1} but slightly lower than the

Table 3 – Statistics of radionuclides, radiological hazards indices and world averages in soil and river sediments.

Indices	Soil		River sediments		World average
	Kirklareli, Turkey Taskin et al., 2009	Azad Kashmir, Pakistan Rafique et al., 2014	Ponnaiyar River, India Ramasamy et al., 2009	Northern Pakistan Current study	
Ra (Bq kg^{-1})	37	NA	7	50.66 ± 1.29	25[a]
^{232}Th (Bq kg^{-1})	40	NA	47	70.15 ± 1.45	25[a]
^{40}K (Bq kg–1)	667	NA	384	531.70 ± 5.45	370[a]
Ra_{eq} (Bq kg^{-1})	NA	NA	NA	190.89	370[b]
D_{out} (nGy h–1)	118	105	47	87.47	84[b]
D_{in} (nGy h^{-1})	NA	107	73	165.39	59[b]
E_{out} (mSv y^{-1})	0.14	0.13	0.06	0.11	0.07[b]
E_{in} (mSv y^{-1})	NA	0.52	0.35	0.81	0.41[b]
$E_{out} + E_{in}$ (mSv y^{-1})	NA	0.65	0.41	0.92	0.52

[a] UNSCEAR (1988).
[b] UNSCEAR (2000).

Table 4 – Comparison of excessive lifetime cancer risk calculated during various studies.

No.	Study area	Medium	(*ELCR*) × 10^{-3} (outdoor)	(*ELCR*) × 10^{-3} (indoor)	(*ELCR*) × 10^{-3} (total)	(*ELCR*) × 10^{-3} (world's av)	Reference
1	Niger Delta, Nigeria	Soil	Negligible	NA	Negligible	Outdoor 0.29	Emelue, Jibiri, & Eke, 2014
2	Kerala, India	Soil	1.7	NA	1.7		Ramasamy, Sundarrajan, Paramasivam, Meenakshisundaram, & Suresh, 2013
3	Kirklareli, Turkey	Soil	0.50	NA	0.50		Aytas et al., 2012
4	Karnataka & Tamilnadu, India	Sediments	0.20	NA	0.20		Ramasamy et al., 2009
5	Tulkarem Province-Palestine	Soil	0.17	0.78	0.95		Thabayneh & Jazzar, 2012
6	Azad Kashmir, Pakistan	Soil	0.54	1.63	2.17	Total	Rafique et al., 2014
7	Northern Pakistan	Sediments	0.37	2.84	3.21	1.45	Present study

criterion limit of 1 mSv y^{-1} as per ICRP-60. Spatial distribution of total annual effective dose in study area is shown in Fig. 4(B). A comparison of radionuclides and radiological hazard indices is given in Table 3. From table it can be seen that values of radionuclides and radiation hazard indices of Hunza, Gilgit and Indus Rivers estimated during present study are relatively on higher side.

4.6. *Excess lifetime cancer risk (ELCR)*

Based upon calculated values of annual effective dose excess lifetime cancer risk (*ELCR*) was calculated using the following equation;

$$(ELCR)(\text{Outdoor}) = (E_{out}) \times \text{LE} \times \text{RF} \quad (8)$$

$$(ELCR)(\text{Indoor}) = (E_{in}) \times \text{LE} \times \text{RF} \quad (9)$$

where (E_{out}) and (E_{in}) are the annual effective doses, LE life expectancy (66 years) and RF (Sv^{-1}) is fatal risk factor per Sievert, which is 0.05 as per ICRP-60.

The (*ELCR*) for outdoor exposure, given in Table 1, ranged from 0.16 × 10^{-3} to 0.75 × 10^{-3} with an average value of 0.37 × 10^{-3}. For indoor exposure it is from 1.23 × 10^{-3} to 5.66 × 10^{-3} with an average of 2.84 × 10^{-3}. The total (*ELCR*) ranges from 1.39 × 10^{-3} to 6.41 × 10^{-3} with an average value of 3.21 × 10^{-3}. The total (*ELCR*) is 2.21 times higher than the world's average of 1.45 × 10^{-3}. The samples having higher (*ELCR*) were picked from the lower part of the study area. The profile (*ELCR*) in samples is shown in Fig. 4(C).

5. Discussion

This paper presents an account of radiological studies carried out on sediments of Hunza, Gilgit and Indus Rivers. The study area is composed of hard and rigorous terrain with harsh climate where movement and sampling is quite difficult. Sediments of the three rivers show some, but negligible, variation in activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K from site to site, which is normal for the sediments coming from various sources (Krmar, Slivka, Varga, Bikit, & Veskovic, 2009). In general, the total activity concentration in the river sediments from one end of the study area to the other end ranges from 500 to 800 Bq kg^{-1}. The river sediments coming from Karakoram Ranges, Hindukush Mountains and from Himalayan highlands show a reasonable uniformity in the radiation. So there is no effect of the source area on the radioactivity of sediments of the rivers. A worldwide comparison of total activity concentration of ^{226}Ra, ^{232}Th and ^{40}K shows that the river sediments of study area have moderately high values.

Radium equivalent activity (190.89 Bq kg^{-1}) is lower than the world's average of 370 Bq kg^{-1}. The outdoor external dose (87.47 nGy h^{-1}), indoor external dose (165.39 nGy h^{-1}), outdoor annual effective dose (0.11), indoor annual effective dose (0.81) and total annual effective dose (0.92 mSv y^{-1}) are higher than the world's average limits. The river sediments of Hunza, Gilgit and Indus River pose a radiological threat to locals and tourists who visit the Northern Pakistan for trekking.

Long-term exposure to radiation is assumed to have some risks of causing cancer. This means that all people have a risk of getting cancer. According to the Surveillance, Epidemiology, and End Results (SEER) Cancer Statistics Review, American men have a 44% lifetime risk of cancer, while women have a 38% lifetime risk (National Cancer Institute, 2009). This means that there is chance of 33% (or 0.33) that a person will get some type of cancer at some stage of life. "Excess lifetime cancer risk" (*ELCR*) is additional risk that someone might have of getting cancer if that person is exposed to cancer-causing materials for a longer time. The Department of Environmental Quality (DEQ) considers an additional or excess 1 in 100,000 chance (1 × 10^{-5}) allowable.

The (*ELCR*) factor assessed during present study on the basis of outdoor (E_{out}) and indoor annual dose (E_{in}) was found to be 3.21 × 10^{-3} which is more than the twice of world's average of 1.45 × 10^{-3} (Table 1). According to Pakistan Institute of medical sciences (PIMS) Islamabad numerous cancer deaths cases are reported from the Northern Pakistan. The cancer deaths may be related to the higher radioactivity in the area. The areas which are more prone to the excessive lifetime cancer risk are located in the southern part of study area around Chillas, which can be seen in Figs. 2 and 4(C).

A number of studies have been carried out worldwide for the determination of (*ELCR*) due to Gamma Radiation. A few of them have been given in Table 4. In some studies only the outdoor annual dose (E_{out}) has been accounted to evaluate

the (*ELCR*). These studies include the determination of (*ELCR*) in and around Warri Refining and Petrochemical Company in Niger Delta, Nigeria, by Emelue et al. (2014). As per their report the risk of developing cancer is below the standard. In another study by Ramasamy et al. (2013), in high background radiation area, Kerala, India the average (*ELCR*) value calculated is 1.7×10^{-3}, which is six times higher than the world average (0.29×10^{-3}). Taskin et al. (2009) reported the (*ELCR*) value as 0.50×10^{-3} in Kirklareli, Turkey. Ramasamy, Suresh, Meenakshisundaram and Gajendran (2009) carried out the evaluation of (*ELCR*) in river sediments of Karnataka and Tamilnadu, India. The average of (*ELCR*) was found to be 0.20×10^{-3} which is less than the world average.

In some studies both outdoor (E_{out}) and indoor annual effective doses (E_{in}) were taken into account for the calculation of (*ELCR*). In a study by Kaleel and Mohammad (2012) the natural radioactivity levels and estimation of radiation exposure in environmental in soil samples from Tulkarem Province-Palestine was carried out. For outdoor exposure the (*ELCR*) was calculated as 0.17×10^{-3} where as for indoor exposure it was assessed as 0.78×10^{-3} .The total (*ELCR*) ranged from 0.70×10^{-3} to 1.33×10^{-3} with an average of 0.95×10^{-3} which is 3.27 times higher than the world's average for which negligible risk of developing cancer has been stated. In another study by Rafique et al. (2014) evaluation of (*ELCR*) in Jhelum valley was calculated. The (*ELCR*) measured for indoor exposure ranged from 1.057×10^{-3} to 2.377×10^{-3} with an average value of 1.629×10^{-3}. For outdoor exposure, (*ELCR*) varies from 0.352×10^{-3} to 0.792×10^{-3} with mean value of 0.543×10^{-3}.

In most of the studies the (*ELCR*) has been calculated but overall mortality and lifetime risk of cancer has not been linked to the population of area having high (*ELCR*). Comparison of excessive lifetime cancer risk due to soils and river sediments presented in Table 4 indicates that the lifetime cancer risk due to the sediment of Hunza, Gilgit and Indus Rivers of Northern Pakistan is relatively higher.

6. Conclusion

1. The average and total activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the sediments of Hunza, Gilgit and Indus Rivers is higher than the worldwide reported average values. Total activity concentrations in the samples from Karakoram Ranges, Hindukush Mountains or from Himalayan highlands do not show much variation. So there is no effect of the source area on the radioactivity of the sediments of Hunza, Gilgit and Indus Rivers.
2. Sediments of Hunza, Gilgit and Indus Rivers pose a radiological threat to locals and tourists who visit the Northern Pakistan for trekking.
3. The river sediments when used as a building material do pose a radiological threat within the dwellings. Locals should avoid the liberal use of the river sediments for construction purpose.
4. The excessive lifetime cancer risk factor in the Northern Pakistan is 3.21×10^{-3} which is on higher side. Numerous cancer deaths are annually reported from the Northern area of Pakistan.

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