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Assessment of Radiation Dose and Excessive Life Time Cancer Risk from the Exposed Sandstones of Siwalik Rocks System in the Tamman Area of Pakistan

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ABSTRACT

Siwalik System of rocks is exposed all along the Himalayan foothills from Assam to Baluchistan for about 4000 km. The Siwalik System of rocks is composed of sandstones and shales. Intermittent uranium mineralization is known in Siwalik's sandstones in India and Pakistan and is productive uranium horizon in Pakistan. Specific activities of ^{226}Ra, ^{232}Th and ^{40}K were measured in the Siwalik's sandstones exposed in Tamman area using high purity (HPGe) γ-ray spectrometer. The average activity concentration of ^{226}Ra, ^{232}Th and ^{40}K was found to be 15.93, 25.58 and 450.97 Bqkg-1 respectively. The radiation indices were also assessed which are well below the world's averages. The outdoor and indoor excessive life time cancer risk was calculated as $0.18x10^{-3}$ and $1.35\ x10^{-3}$. The Siwalik's sandstones have no excessive life time cancer risk to the local population and sand derived from the Siwalik's sandstone is a safe building material.

1. Introduction

Primordial radionuclides with half-lives around the age of the earth (4.5 billion years) and their decay products constitute the major component of radioactivity on earth. More common primordial radionuclides are ^{238}U, ^{232}Th and ^{40}K [1]. They are abundantly found everywhere in our environment especially in rocks, sand, soil etc. [2]. Cosmogenic radionuclides with short half lives are continuously produced by nuclear reactions of cosmic rays with atmospheric gases. However, their contribution to the total radiation dose on earth is insignificant. Anthropogenic radionuclides entered our environment about a century ago with the advent of nuclear activity. They constitute ≈ 1% of the total radiation dose [3].

Primordial radionuclides are the main source of radiation exposure for human beings. Therefore they are being studied in this work. The exposure level depends upon the concentration of radionuclides in the environment and duration of stay in the radiation environment. Exposure to radiation is of two types, i) outdoor exposure is due to γ-radiation emitted by the radionuclides present in the environment and ii) indoor exposure is due to the radiation emitted by radionuclides present in building materials [4]. Indoor exposure is again of two types; indoor external exposure due to γ-radiation originating from the decay series of ^{238}U and ^{232}Th and ^{40}K present in construction materials and indoor internal exposure due to ^{222}Rn gas exhaled by ^{220}Ra present in building materials and its short lived solid daughters such as ^{218}Po (t½ 3.05 min) and ^{214}Po (t½ $1.6x10^{-4}$ s). ^{222}Rn constitutes about 56 % of total annual effective dose equivalent received by a common person from various sources [4]. ^{222}Rn and its decay products may induce many forms of cancer and deoxyribonucleic acid (DNA) mutation [5, 6].

In Pakistan the Siwalik sandstones contain sporadically spread uranium mineralization. At places in the Bannu Basin and the Suleiman Range uranium is being mined from Siwalik sandstones using In-situ Leach Mining Technique (ISML). On the assumption that the study area may also contain uranium mineralization similar to Bannu Basin and Suleiman Range, radiometric studies were carried out on the exposed sandstone samples from Tamman area; Pakistan using high purity germanium (HPGe) detector based γ-ray spectrometer. The current studies were also carried out to assess the radiation dose experienced by the local population of about half a million and to evaluate the excessive life time cancer risk.

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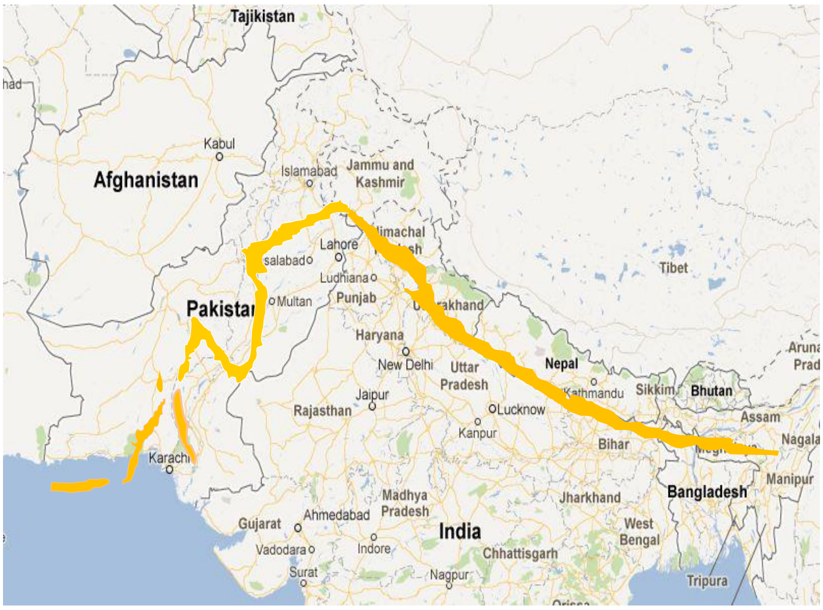

Fig. 1: Siwalik rocks are exposed for about 4000 km along the foothills of the Himalaya from Assam to southern Kashmir after that they take a southern turn and follow the present course of river Indus in Pakistan up to the Arabian Sea; shown as a yellow band. Uranium deposits are located in the Bannu Basin and the Suleiman Range in Pakistan

2. Siwalik Rocks System

The great Tethys Ocean separated the Eurasian Plate in the north from Gondwana Plate in the south during the 250-65 million years period before present day [7]. The rivers descending from the southern slopes of Eurasian Plate discharged their load into the Tethys Ocean. As a result of tectonic forces, the Indian Plate separated from the Gondwana Plate and started an upward journey finally colliding with the Eurasian Plate around 50-60 million years ago. As a result of this collision the Himalayan Mountain ranges emerged and the Tethys Ocean was reduced to a narrow river channel which was named as Siwalik River by Pascoe (1919) [8]. This river was flowing from Assam in the east of India up to the Potohar area of Pakistan and beyond where it may have fallen into the Arabian Sea after cruising along the course of the present day Indus. The Brahmaputra and the Indus were flowing in the Indian subcontinent as Ancestor Rivers well before the emergence of the Himalayas. Later on, Indus, Ganges and the Brahmaputra joined the Siwalik River under the process of water mugging.

The Siwalik River failed to maintain its entity and dried up eventually. Due to compressional forces the sediments of Siwalik River were uplifted to form the Siwalik rocks system in India and Pakistan. The Siwalik rocks system is composed of sandstones and shales of shallow marine to alluvial origin. After the uplift of Siwalik rocks system the Indus, the Ganges and the Brahmaputra again sprang up to shape the present topography of Indo-Pakistan [9]. The Siwalik rocks are exposed all along the foothills of Himalaya from Assam to southern Kashmir in India. From where they enter Pakistan and are exposed in the Potohar region and across the Indus River in the Bannu Basin and then south into the Suleiman Range, from where they continue up to the Arabian Sea (Figure 1). The total span of exposure of Siwalik system of rocks is about 4000 km.

Siwalik rocks system contains sporadically distributed uranium mineralization through the whole of its length. In India 8-significant uranium bearing zones between Himachel Pradesh and Uttar Pradesh are found in the Siwalik rocks [10]. In Pakistan intermittent uranium mineralization in Siwalik sandstone is found in the Potohar area, in the Bannu Basin and along the Suleiman Range [11].

3. Material and Methods

3.1 Study Area, Sample Collection and Preparation

The study area around Tamman is located 30 km in the northwest of Talagang. Tamman is a medium sized town with geographical coordinates 33° 40' 38" N, & 72° 51' 21" E. It's one of the oldest, well populated towns of the Attock district.

Twenty five samples were collected from representative places in the study area covering all the varieties of sandstones. To check the radiation exposure to locals, sampling was done to cover the whole area around Tamman village. The area from which samples were collected extends from Dermond village up to Soan River (Figure 2). Samples were taken from a depth of about 50 cm in order to avoid any surface contamination. Samples were sieved to a size below 1000 µm and dried in an oven at 110 ^{o}C for 30 h to remove moisture and other volatiles compounds [12-14]. About 1000 gm of

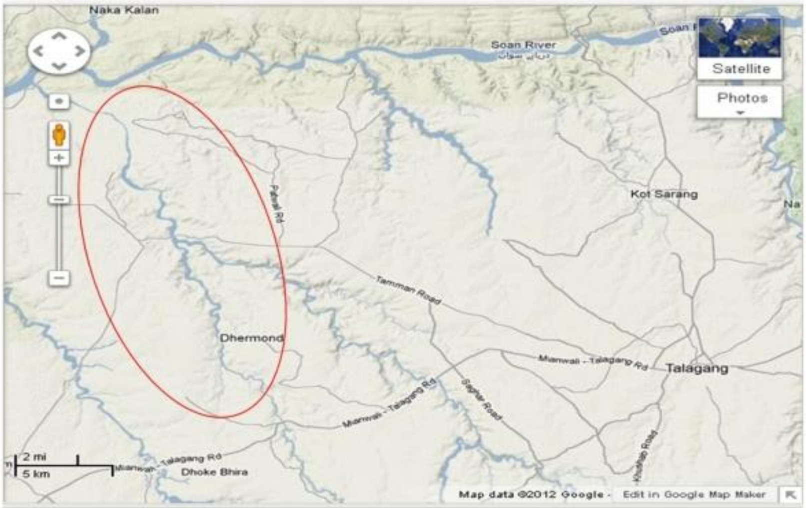

Fig. 2: Map of Tamman area near Tallagang, Pakistan with reference to other geographic features. The sampling area is shown with an oblique circle that extends from south of Dhermond up to Soan river (Terrain picture from Google Map)

each sample was sealed in airtight standard Marinelli plastic beakers [15]. Reference materials (RMs) RG-set "(RGU, RGTh and RGK)", and Soil-6 from the International Atomic Energy Agency (IAEA), were also sealed in Marinelli plastic beakers under identical conditions. The samples and the RMs were then stored for 40 days to bring radon (^{222}Rn) and its short lived progeny in equilibrium with radium [16-18].

3.2. Activities Measurements

Activities of ^{226}Ra, ^{232}Th and ^{40}K in the samples were measured using a high purity germanium (HPGe) detector based γ-ray spectrometer. The HPGe detector is encased in a lead shielding of 10 cm thickness with additional inner Cu and Al lining. Background spectra were obtained weekly for 20,000 s to check the radioactivity in the laboratory. Photo peak efficiencies (γ) were determined for the energies reported in literature [19]. Spectra of sandstone samples was also taken for 20,000 s and stored in the computer. The gamma-ray photo peaks corresponding to 352 and 295 keV for ^{214}Pb, 609, 1729.6 and 1120.28 keV for ^{214}Bi, 1764 keV for ^{226}Ra, 239 keV for ^{212}Pb, 583 keV for ^{208}Tl and 911 keV for ^{228}Ac were used while ^{40}K was recognized from its single peak of 1460.80 keV [21].

3.3 Assessment of Radiation Indices And Excessive Life Time Cancer Risk

Gamma dose, radiological hazards, annual effective dose and excessive life time cancer risk were calculated from the activities of ^{226}Ra, ^{232}Th and ^{40}K obtained for the Siwalik sandstone samples as per formulae given in literature. Details are given in the results section where results obtained are also presented and discussed.

3.3 Determination of U, Th and K Contents of Siwalik Sandstones

Uranium, thorium and potassium contents of the Siwalik sandstones were calculated on the basis of γ-activities of these radionuclides in the samples using the conversion factor of 12.35 $Bqkg^{-1}$ for ^{238}U equal to 1 ppm of uranium, 4.06 $Bqkg^{-1}$ of ^{232}Th equal to 1 ppm of thorium and 313 $Bqkg^{-1}$ of ^{40}K equal to 1000 ppm of potassium [22].

4. Results and Discussion

4.1 Measured Activities

As shown in Table 1 activities of ^{226}Ra, ^{232}Th and ^{40}K in the Siwalik sandstones from Tamman area respectively vary from 10.77 to 28.76, 14.18 to 43.09 and 353.29 to 537.87 $Bqkg^{-1}$ with an average value of 15.93, 25.58 and 450.97 $Bqkg^{-1}$ respectively. Average activities of ^{226}Ra, and ^{232}Th are less than the world average of sand (35 & 30 $Bqkg^{-1}$ respectively) [23]. The activity of ^{40}K is higher than the worldwide average of sand (400 $Bqkg^{-1}$). The activity of ^{40}K (91.57%) in Tamman sandstones is much higher than the ^{226}Ra (3.23%) and ^{232}Th (5.19%) values. This may be attributed to the greater abundance of K bearing minerals forming Siwalik rocks. ^{232}Th/^{226}Ra ratio of 1.62 indicates the presence of slightly more thorium bearing minerals like monazite, thorite and ferrithorite as compared to uranium bearing minerals such as zircon, sphene, apatite etc. in the sandstones. Correlation between the activities of ^{226}Ra, and ^{232}Th with a trend line drawn among the data points using regression technique is given in Figure 3. The figure indicates that ^{226}Ra and ^{232}Th bearing minerals have similar physical properties like resistivity, crystal system, density, size etc. due to which they are found concentrated at one place.

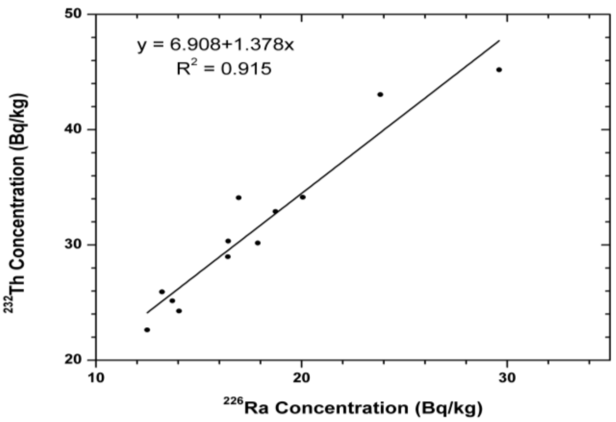

Fig. 3: Correlation between ^{226}Ra and ^{232}Th in Siwalik sandstones exposed in Tamman, Pakistan

A comparison of the activities of ^{226}Ra, ^{232}Th and ^{40}K of the Siwalik sandstones with sand/soil samples from eight locations in Indo-Pakistan is presented in Table 2. As per Table 2 the activities of these radionuclides in Siwalik sandstones of Tamman are lower than the activities of ^{226}Ra, ^{232}Th, and ^{40}K in sand deposits of Lawrencepur, river sands of Indus & Kabul, sand deposits from the northern areas of Pakistan. The activities of ^{226}Ra, ^{232}Th, and ^{40}K in Siwalik rocks of Tamman area are also lower than activities of ^{226}Ra, ^{232}Th and ^{40}K in soil derived from the Siwalik rocks/sand of Punjab, Punchkul and Ludhiana of India. The soil derived from the Siwalik rocks found at Punchkul, India have much higher concentration of ^{226}Ra (97 Bqkg^{-1}), ^{232}Th (132 Bqkg^{-1}) and ^{40}K (1100 Bqkg^{-1}) as compared to Siwalik sandstones found near Tamman. This is due to the presence of higher uranium contents in the Punchkul area, India.

Table 1: Activities of ^{226}Ra, ^{232}Th and ^{40}K, corresponding gamma-dose, radiological hazards, annual effective dose and excessive life time cancer risk of the Siwalik's sandstones exposed in Tamman, Pakistan. World's average of ^{226}Ra, ^{232}Th and ^{40}K in sand, limiting values of radiological hazards, gamma-dose, annual effective dose and allowable limits of excessive life time cancer are also given for comparison

S. No	Activities (BqKg^{-1})			Radiological Hazards Indices		Gamma-Dose ($nGyh^{-1}$)		Annual Effective Dose ($mSvy^{-1}$)		Excessive Life Time Cancer Risk $x10^{-3}$	
	^{226}Ra	^{232}Th	^{40}K	H_{out}	H_{in}	D_{out}	D_{in}	E_{out}	E_{in}	$ELCR_{out}$	$ELCR_{in}$
1	15.80	22.11	487.91	0.23	0.27	41.00	77.89	0.05	0.38	0.18	1.34
2	14.86	23.52	456.56	0.23	0.27	40.11	76.07	0.05	0.37	0.17	1.31
3	12.98	20.03	446.95	0.21	0.24	36.73	69.73	0.05	0.34	0.16	1.20
4	12.95	22.02	451.78	0.21	0.25	38.12	72.28	0.05	0.35	0.16	1.24
5	20.02	37.66	443.79	0.29	0.35	50.50	95.35	0.06	0.47	0.22	1.64
6	28.76	18.61	537.87	0.26	0.34	46.96	89.96	0.06	0.44	0.20	1.54
7	18.02	35.04	395.06	0.27	0.31	45.96	86.73	0.06	0.43	0.20	1.49
8	14.35	23.63	441.61	0.22	0.26	39.32	74.52	0.05	0.37	0.17	1.28
9	14.44	24.87	476.45	0.23	0.27	41.56	78.76	0.05	0.39	0.18	1.35
10	10.91	19.04	353.29	0.18	0.21	31.27	59.24	0.04	0.29	0.13	1.02
11	18.08	29.58	477.22	0.26	0.31	46.12	87.35	0.06	0.43	0.20	1.50
12	12.38	17.89	471.86	0.20	0.23	36.20	68.82	0.04	0.34	0.15	1.18
13	12.33	17.56	491.41	0.20	0.24	36.79	69.97	0.05	0.34	0.16	1.20
14	21.99	43.09	423.77	0.31	0.37	53.86	101.53	0.07	0.50	0.23	1.74
15	14.96	29.85	446.58	0.25	0.29	43.56	82.32	0.05	0.40	0.19	1.41
16	15.08	22.80	478.72	0.23	0.27	40.70	77.25	0.05	0.38	0.17	1.33
17	13.77	20.64	428.39	0.21	0.24	36.69	69.64	0.05	0.34	0.16	1.20
18	13.89	20.82	432.12	0.21	0.25	37.01	70.25	0.05	0.34	0.16	1.21
19	15.64	28.26	436.84	0.24	0.28	42.51	80.42	0.05	0.39	0.18	1.38
20	10.77	14.18	473.41	0.18	0.21	33.28	63.38	0.04	0.31	0.14	1.09
21	17.67	30.59	432.39	0.26	0.30	44.67	84.50	0.05	0.41	0.19	1.45
22	15.82	26.01	468.15	0.24	0.28	42.54	80.62	0.05	0.40	0.18	1.38
23	17.49	30.50	444.20	0.26	0.30	45.03	85.18	0.06	0.42	0.19	1.46
24	18.35	31.34	444.01	0.26	0.31	45.92	86.88	0.06	0.43	0.20	1.49
25	16.96	29.91	434.03	0.25	0.30	44.00	83.23	0.05	0.41	0.19	1.43
Min	10.77	14.18	353.29	0.18	0.21	31.27	59.24	0.04	0.29	0.13	1.02
Max	28.76	43.09	537.87	0.31	0.37	53.86	101.53	0.07	0.50	0.23	1.74
Av	15.93	25.58	450.97	0.24	0.28	41.62	78.87	0.05	0.39	0.18	1.35
W. Av	35*	30*	400*	≤1**	≤1**	57*	84*	≤1*	≤2*	0.29***	1.16***

*World average of sand and gamma dose and limits of annual effective dose are after (UNSCEAR, 2000) [23]; ** Limiting values of radiological hazards indices and *** excessive life time cancer risk are after Baretka and Mathew, 1985 [5] and Taskin et al., 2009 [35].

4.2 Radiological Hazard Indices

Two radiological hazard indices namely external hazard criterion *(H_{out})* and internal hazard criterion *(H_{in})* were calculated. Details of the calculation of radiological hazards indices are given below while the data obtained are tabulated in Table 1:

4.2.2 Internal Hazard Criterion (H_{in})

Radon and its decay products are hazardous for our respiratory organs. Exposure to radon and its decay products are quantified by internal hazard criterion *(H_{in})* as defined by Krieger (1981) [25]. *(H_{in})* for the Siwalik sandstones from Tamman were calculated using the following equation by Beretka and Mathew (1985):

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \qquad (2)$$

From Table 1 it can be see that *(H_{in})* estimated during present study is 0.28, with a range from 0.21 to 0.37, which is less than the limiting value of unity. As per European Commission Report, (1999) [26] and Turhan et al., (2008) [27] the Siwalik sandstones exposed at Tamman do not pose any radiological hazard to the local populace and are safe construction material.

4.3 Gamma Dose

Gamma dose was calculated to assess the annual effective dose which in turn was used for the determination of excessive life time cancer risk.

4.3.1 Outdoor External γ-dose (D_{out})

The outdoor external γ-dose *(D_{out})* for any area one meter above the ground surface is calculated by converting the activities of ^{226}Ra, ^{232}Th and ^{40}K present in the environment into effective dose. Three conversion factors 0.462 nGyh^{-1}Bq^{-1}kg^{-1} for ^{226}Ra, 0.604 nGyh^{-1}Bq^{-1}kg^{-1} for ^{232}Th and 0.0417 nGyh^{-1}Bq^{-1}kg^{-1} for ^{40}K [23] were used to calculate *(D_{out})* as per equation given below;.

$$D_{out} = 0.462 * A_{Ra} + 0.604 * A_{Th} + 0.0417 * A_K \qquad (3)$$

While formulating the above equation it was assumed that ^{137}Cs, ^{90}Sr and the ^{235}U decay series have insignificant contribution to the total dose from environmental background [25, 28, 29]. In Siwalik sandstones from Tamman area, the values of (D_{out}) range from 31.27 to 53.56 nGyh^{-1} with an average value of 41.42 nGyh^{-1}. The global average outdoor levels of (D_{out}) are in the range of 50-59 nGyh^{-1} [23].

4.3.2 Indoor External γ-dose (D_{in})

The indoor external γ-dose *(D_{in})* imparted by ^{226}Ra, ^{232}Th and ^{40}K present in the indoor environment (a standard room of 4m x 5m x 2.8m dimension with wall thickness of 20 cm) is calculated by converting the activities of ^{226}Ra, ^{232}Th and ^{40}K present in the environment 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. Conversion factors for the calculation of indoor external dose have higher magnitude because of the

Table 2: Comparison of activities of ^{226}Ra, ^{232}Th and ^{40}K (BqKg^{-1}) in Siwalik's sandstones exposed in the Tamman area, Pakistan with some sands and soils of Pakistan and India. Averages of Earth crust, building materials and world's sands have also been given for comparison

Country	Activities (Bq kg^{-1})			Reference
	^{226}Ra	^{232}Th	^{40}K	
Sands Pakistan (Tamman)	15.93±4.85	25.58±7.83	450.97±5.70	Present studies
Pakistan (Lawrencepur)	17.77±0.15	31.41±0.16	521.47±1.44	36
Pakistan (Indus & Kabul Rivers)	30.50±11.4	53.20±19.50	531±49	37
Pakistan (Northern areas)	19±9	30±15	769±461	38
India, Nopar District	63 ±3.80	87±2.5	775±7.9	39
India average	28.67	63.83	327.60	23
Soils				
India Punchkul Siwaliks	97	132	1100	39
India Punjab Siwaliks	28.3-81.0	61.2-140.3	363.4-1002.2	40
India Ludhiana Siwaliks	28.58	50.95	569.59	41
Averages				
Earth Crust	40	40	400	28
Building Materials	50	50	500	42
World's Sands	35	30	400	23

stronger impact of ^{226}Ra, ^{232}Th and ^{40}K concentrations in the indoor environment. By utilizing the above mentioned conversion factors the following equation was obtained to calculate *(D_{in})* as per European Commission (1999) [26].

$$D_{in}\left(nGy.h^{-1}\right) = 0.92 * A_{Ra} + 1.1 * A_{Th} + 0.081 * A_K \quad (4)$$

From Table 1 it can be seen that average value of 78.87 $nGyh^{-1}$ was calculated for (D_{in}), which is lower than the world's average of 84 $nGyh^{-1}$ [23] as an indoor exposure.

4.4 Annual Effective Dose

4.4.1 Annual Outdoor Effective Dose (E_{out})

Annual outdoor effective dose *(E_{out})* is the radiation dose received by a person during one year's stay in any area. It is estimated from the net outdoor γ-dose *(D_{out})*, for the fraction of time of stay of a person in the area and dose conversion factor (CF). Following equation has been used for the calculation of (E_{out}):

$$E_{out} = D_{out} * 8760 * OF * CF \quad (5)$$

where *(D_{out})* is the outdoor γ-dose calculated in this study, 8760 are the hours in a year, OF is the occupancy factor (0.2), that corresponds to the fraction of the time spent outside and CF is the conversion factor ($0.7\ SvGy^{-1} x\ 10^{-6}$) [30,31]. Putting these values of OF and CF the equation (5) is modified to :

$$E_{out} = 1.227 * 10^{-3} * D_{out}\left(mSv.y^{-1}\right) \quad (6)$$

Annual outdoor effective dose in the Tamman area was calculated using equation (6). The average value of (E_{out}) comes out to be 0.05 $mSvy^{-1}$ with a range from 0.04 to 0.07 $mSvy^{-1}$. This is well below the criterion limit of 1 $mSvy^{-1}$ as per International Commission on Radiation Protection (ICRP, 1994) [32]. For radiation workers, the limit of E_{out} is 20 $mSvy^{-1}$ [32, 33]. The limits of 1 $mSvy^{-1}$ and 20 $mSvy^{-1}$ indicate that there is no dose limit below which there would be no effect. This means that any amount of dose will cause a proportional increase in the chances of health damage.

4.4.2 Annual Indoor Effective Dose (E_{in})

For a person living in a building utilizing Siwalik's sandstone as a construction material, the annual indoor effective dose *(E_{in})* is calculated on the basis of occupancy factor (OF) and the conversion coefficient (0.7 Svy^{-1}) from absorbed dose in air to effective dose. In Tamman and its surrounding areas, summers are very hot and winters are cold. The time spent indoors may be taken around 80%, which is 8760 x 0.8 h y^{-1}. The equation for calculating (E_{in}) for Tamman sandstone or any other material may be deduced as follows:

$$E_{in} = D_{in} * \left(8760 * 0.8 * hy^{-1} * 0.7 * 10^{-6}\right)\left(mSv.y^{-1}\right) \quad (7)$$

$$E_{in} = D_{in} * 4.908 * 10^{-3}\left(mSv.y^{-1}\right) \quad (8)$$

The average value of (**E_{in}**) for Tamman sandstones is 0.39 *($mSvy^{-1}$)* with a range of 0.29 to 0.50 *($mSvy^{-1}$)*. The annual indoor effective dose *(E_{in})* of (0.39 $mSvy^{-1}$) is less than the world average of 0.41 $mSvy^{-1}$ and is less than the limiting value of 2 $mSvy^{-1}$ [23]. The dwellings in and around Tamman are thus safe as far as indoor external radiation exposure due to naturally occurring radioactive materials in the Siwalik's sandstones are concerned.

4.5 Excessive Life Time Cancer Risk (ELCR)

All of us are under threat of getting cancer at some stage of life as we live in a radioactive world. According to the Surveillance, Epidemiology, and End Results (SEER) Cancer Statistics Review, American men have a 44% lifetime cancer risk, while women are prone to a 38% lifetime risk [34]. This means that there is a chance of 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 additional radiation for a longer time. Chance of occurrence of cancer depends upon the annual effective dose. By putting the world's average value of annual effective dose of 0.46 ($mSvy^{-1}$) in equation $(ELCR_{total}) = (E_{avg}) * LE * RF$ we get a probable limit of cancer occurrence of 1.45 $*10^{-3}$. Any excessive annual dose will cause a proportionate chance of excessive life time cancer risk.

Based upon values of annual outdoor effective dose *(E_{out})* and annual indoor effective dose *(E_{in})* calculated during current study; the outdoor excess lifetime cancer risk *($ELCR_{out}$)* and indoor excess lifetime cancer risk *($ELCR_{in}$)* was calculated using the following equations;

$$\left(ELCR_{out}\right) = \left(E_{out}\right) * LE * RF \quad (9)$$

$$\left(ELCR_{in}\right) = \left(E_{in}\right) * LE * RF \quad (10)$$

The (LE) or life expectancy has been taken as 70 years and RF (Sv^{-1}) is fatal risk factor per Sievert, which is 0.05 as per International Commission on Radiation Protection-60 [30]. The average values of outdoor and indoor excess lifetime cancer risk calculated during the present study are 0.18 x 10^{-3} and 1.35 x 10^{-3} respectively as given in Table 1. The indoor excess lifetime cancer risk (1.35 x 10^{-3}) is slightly higher than the world's average probability of cancer occurrence (1.16x10^{-3}) to an individual. However, total outdoor and indoor excess lifetime cancer risk (1.53x10^{-3}) is almost equal to the world's average of 1.45 x 10^{-3}. On this basis one can assume that there is no chance of excess lifetime cancer risk for a person living in the environment of Tamman. Tamman area is thus safe from a radiological point of view for settlement.

4.6 U, Th and K contents of Siwalik sandstones

The U, Th and K contents of Siwalik sandstones from Tamman area were calculated as 1.29, 6.3 and 1440.80 ppm respectively as per conversion factors for the calculation of these radionuclides form their activities given in IAEA Technical Report 309, (1989). Overall the uranium deposits found in Siwalik system of rocks in Pakistan are of low grade localized and of high In-situ Leach Mining (ISLM) cost [11]. The Siwalik rocks are exposed over a large area in the Potohar region including Tamman but no uranium deposit could be located despite extensive exploration. The deposits in the Bannu Basin and the Suleiman Range have uranium content of ≈ 400 ppm [11]. According to International Atomic Energy Commission's (IAEA) Technical Report 309, (1989) the uranium in sandstones of Bannu Basin and Suleiman Range was upgraded by repeated water table fluctuation [22]. From the low contents of U, Th and K contents in the Siwalik sandstones from Tamman area it appears that no natural uranium up-gradation has taken place in this area to enhance the grade of uranium to form a deposit.

5. Comparison of Radiation Indices and Excessive Life Time Cancer Risk of Siwalik's Sandstones with Some Other Localities

Hazard indices, gamma doses and excessive life time cancer risk for 13 Siwalik derived sands and soils from India and Pakistan were calculated for ^{226}Ra, ^{232}Th and ^{40}K activities reported by various researches [31-36]. These results are compared with the results of present study in Table 3. Apart from the soils of Pathankot, the values of radiation indices of Siwalik sandstones from Tamman are lower than other locations of India and Pakistan. This means that this area is safer from a radiological point of view for settlement.

Table 3: Comparison of radiological hazards, gamma-dose, annual effective dose and excessive life time cancer risk of Siwalik's sandstones exposed in Tamman, Pakistan with sands and soil derived from the Siwalik system of rocks from India and Pakistan. Values of various hazard indices of Tamman sandstone are lowest except those of Pahtankot soils of India

Country/Region	Radiological Hazards		Gamma-Dose ($nGyh^{-1}$)		Annual Effective Dose ($mSvy^{-1}$)		Excessive Life Time Cancer Risk $x10^{-3}$		Reference
	H_{out}	H_{in}	D_{out}	D_{in}	E_{out}	E_{in}	$ELCR_{out}$	$ELCR_{in}$	
Siwalik sandstones, Tamman, Pakistan	0.24	0.28	41.62	78.87	0.05	0.39	0.18	1.35	Present study
Punjab India Ave of 4 soils	0.49	0.64	79.42	149.65	0.10	0.73	0.34	2.57	^{226}Ra, ^{232}Th and ^{40}K data given in Singh et al; (2005) [43]
Hamachal Pradesh India Ave of 6 soils	0.54	0.70	88.75	166.70	0.11	0.82	0.38	2.86	
Haryana India soils	0.37	0.49	60.21	113.49	0.07	0.56	0.26	1.95	^{226}Ra, ^{232}Th and ^{40}K data given in Gupta et al; (2010) [44]
Haryana India sands	0.26	0.34	44.04	83.26	0.05	0.41	0.19	1.43	
Bathanda, India Ave of 6 soils	0.59	0.74	97.46	183.40	0.12	0.90	0.42	3.15	^{226}Ra, ^{232}Th and ^{40}K data given in Mehra & Singh (2012) [45]
Amritsar, India Ave of 6 soils	0.51	0.66	85.04	160.38	0.10	0.79	0.37	2.75	
Pathankot, India Ave of 6 soils	0.21	0.26	34.65	185.75	0.04	0.32	0.15	1.12	
Dalhousie, India Ave of 6 soils	0.60	0.77	99.03	130.26	0.12	0.92	0.43	3.21	
Mirpure Pakistan Ave of 20 soils	0.39	0.46	66.10	124.61	0.08	0.61	0.28	2.14	^{226}Ra, ^{232}Th and ^{40}K data given in Rafique et al; (2011) [46]
Mirpure Pakistan Ave of 6 sands	0.31	0.37	52.89	99.88	0.06	0.49	0.23	1.72	
Kundian, Pakistan soils	0.40	0.50	68.99	130.26	0.08	0.64	0.30	2.24	^{226}Ra, ^{232}Th and ^{40}K data given in Malik et al; (2011) [47]
Rawalpindi/Islamabad, Pakistan soils	0.45	0.56	76.79	145.44	0.09	0.71	0.33	2.50	Tufail, 1992, Ph. D Thesis [48]
Lahore, Pakistan soils	0.57	0.76	98.18	186.26	0.12	0.91	0.42	3.20	

6. Conclusion

- Siwalik sandstones exposed in Tamman, Pakistan have average activities of ^{226}Ra, ^{232}Th and ^{40}K as 15.93, 25.58 and 450.97 Bqkg^{-1} respectively, which are lower than the world average of building materials (50, 50 & 500 Bqkg^{-1} respectively). These activities are sufficiently lower than the values of these radionuclides in soils derived from the Siwalik rocks exposed in the Indian states of Punjab, Punchkul and Ludhiana.

- Hazard indices, gamma dose and annual effective dose rates were found to be well below the permissible limits for samples collected from Tamman.
- Total outdoor and indoor excessive life time cancer risk (1.53 x 10^{-3}) is almost equal to the world average value of 1.45 x 10^{-3}. Therefore no excessive life time cancer risk exists for people living in the Tamman area.
- Average uranium, thorium and potassium content of Siwalik sandstones from the Tamman area are 1.29, 6.3 and 1440.8 ppm respectively. This area is still tectonically active and stable geochemical environments required for the formation of uranium deposits have not been sustained.

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