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MEASUREMENT OF RADIONUCLIDES IN THE VICINITY OF CHASHMA NUCLEAR POWER PLANT (CNPP-1), PAKISTAN INSTITUTE OF NUCLEAR SCIENCE AND TECHNOLOGY (PINSTECH) AND OIL/GAS EXPLORATION SITES

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The radioactivity levels were investigated in the vicinity of Chashma Nuclear Power Plant (CNPP-I), PINSTECH and two oil/gas exploration sites in Chakwal by collecting and analyzing soil samples. Quantitative and qualitative analysis of the collected samples were made using Gamma Spectrometry System with the help of software win-TMCA. Radionuclides such as ^{232}Th, ^{226}Ra, ^{40}K and ^{137}Cs were found in the soil samples of CNPP-1, PINSTECH and oil/gas exploration sites. The values of mean activity concentrations of ^{232}Th, ^{226}Ra, ^{40}K and ^{137}Cs in soil samples of CNPP-I are found to be 45, 43, 547 and 2 BqKg^{-1} respectively; for PINSTECH these values are 37, 45, 430 and 3.5 Bqkg^{-1} respectively; for oil/gas site-I are 28, 29 and 468 BqKg^{-1} respectively (^{137}Cs not detected at site I) and for site-II these levels are 26, 28, 441 and 1.8 BqKg^{-1} respectively. The activity concentration of ^{232}Th, ^{226}Ra and ^{40}K in soil samples of all facilities are less than the world average value. ^{137}Cs is much lower than several places reported around the world. Mean radium equivalent (Ra_{eq}) values are 149 BqKg^{-1} for CNPP-1 samples, 131 Bqkg^{-1} for PINSTECH, 108 Bqkg^{-1} for site-I and 103 Bqkg^{-1} for site-II. The measured radiological impact assessment factor (Ra_{eq}) is also lower than the value of 370 Bqkg^{-1} recommended by UNSCEAR.

Keywords : PNRA, NORM, High purity germanium (HPGe) detector, Oil/gas sites, Research reactor, Soil

1. Introduction

Chashma site is situated in Mianwali district near Kundian at the left bank of river Indus which houses two units (C-1 and C-2) of 300 MWe Nuclear Power Plants. C-1 is in operation since 2000 while C-2 is near to start operation. Two research reactors, a 10 MW swimming pool type reactor (PARR-I) and 27 KW tank-in pool type reactor (PARR-II) which are operational in PINSTECH, Nilore, Islamabad. Releases of small quantities of radioactive material to environment may occur from the Nuclear Power Plants (NPPs) and Research Reactors (RRs) which can develop into local/regional concern depending on the extent of environmental mobility of such residues. The NPPs and RRs are designed and operated so as to keep all sources of radiation exposure under strict technical and administrative control [1]. However, long operation of NPPs and RRs are likely to increase the natural background radiation levels which necessitate continuous monitoring of radionuclides levels in the soil around such facilities. Beside NPPs and RRs there are many industries in Pakistan which are producing Naturally Occurring Radioactive Material (NORM) e.g. oil/gas exploration sites, coal mining, fertilizers etc. The natural radionuclides such as Uranium, Thorium, Potassium and their decay products like Radon etc. are source of continuous exposure to the human beings. The concentration levels of such radionuclides in soil varies widely in the world. Under Section 39 of the Ordinance III of 2001, it is the statutory responsibility of Pakistan Nuclear Regulatory Authority (PNRA) to check any build up of environmental radioactivity that might affect public [2,3]. Accordingly, PNRA initiated a plan to measure primordial as well as anthropogenic levels of radioactivity in the vicinity of NPPs, RRs and Oil/gas sites in order to get information about the impact on the environment and to estimate expected dose levels.

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2. Geological Location

Figure 1 shows the map of Pakistan indicating major cities; Chashma site is situated at the left bank of river Indus in Mianwali district, about 32 Km to the south of Mianwali, 280 Km to the southwest of Islamabad and 1160 Km to the northeast of Karachi. The site is situated at 32°26′N 71°25′E [4]. PINSTECH is located near Lehtrar road about 24 Km east of Rawalpindi and 24 Km south east of Islamabad and is at 33º39´N 73º15´E [5]. The two oil/gas sites (I & II) are located in Chakwal district near Islamabad. (Chakwal district is at 32° 55'N. and 72°51'E) [6].

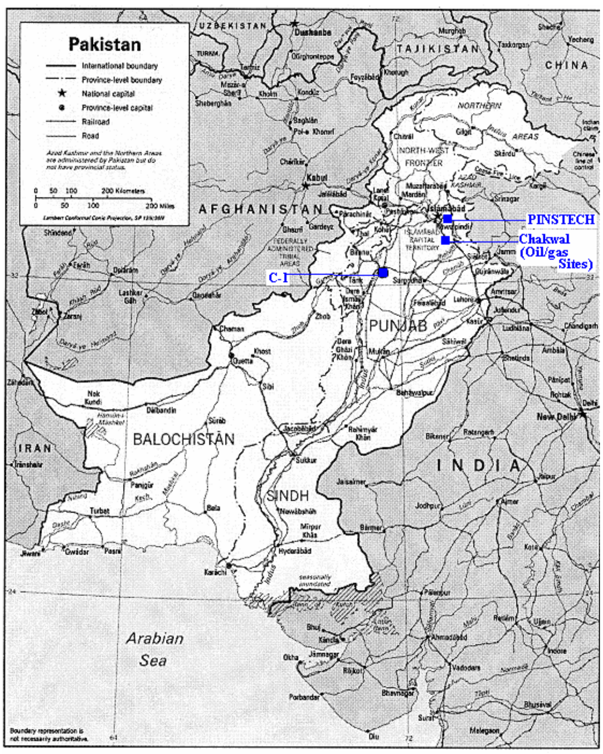

Figure 1. Map of Pakistan showing C-1 site, PINSTECH and Chakwal district (oil/gas Sites).

3. Sampling and Sample Preparation

Twenty six soil samples (thirteen surface & thirteen sub-surface) were collected around C-1 (Eight sampling points lying within a radius of 10 Km with centre at C-1 and five sampling points within plant boundary). Thirty two soil samples (sixteen surface & sixteen sub-surface) were collected around PINSTECH. Five soil samples were collected from each (I & II) oil/gas site, four samples were collected adjacent to facility and one sample as background soil sample was collected from area near to the oil/gas sites to be geologically similar, but distant enough not to be impacted by the production operations. Soil samples, weighing 1Kg each were collected at each point; samples were collected from the surface (2-3 cm top sand/soil) as well from a depth of 15cm (upto plough line) to study the distribution pattern of radionuclides. Samples were air-dried, ground into fine powder, sieved through 2 mm mesh, homogenized, stored in plastic containers and appropriately coded. Homogeneity of the soil samples was checked by analyzing ^{40}K content in the samples. For this purpose these samples were subdivided into four sub samples and activities of ^{40}K were checked in these samples. The coefficients of variation around the mean values were less than 5% demonstrating that the processed samples were adequately homogeneous. The containers were sealed to avoid any possibility of out gassing of radon and kept for a period of more than 1 month to attain the state of secular equilibrium.

4. Analysis using Gamma-ray Spectrometry System

For the identification and quantification of radionuclides present in the soil samples, a P-type coaxial high purity germanium (HPGe) detector was used in combination with a PC based Multi-channel employing win-TMCA software for spectrum analysis. The detector is housed inside a thick lead shield to reduce the background. The gamma-ray spectrometry set-up has a resolution of 2.2 keV with respect to full energy peak at 1332 keV of ^{60}Co. The Peak/Compton ratio has been found to be 40: 1. Most of the radionuclides identified in a γ-ray spectrum are from two series, one starting with ^{238}U and the other with ^{232}Th. Since ^{238}U and ^{232}Th both emit very weak γ-rays, they are estimated by the presence of their progenies in their decay series. For ^{232}Th series all the decay products come into secular radioactive equilibrium with each other, thus measuring any radionuclide in the series will provide concentration of the rest of the members in the series. For ^{238}U series, the decay products are in equilibrium with ^{226}Ra and not with ^{238}U because of some physiochemical processes in the earth, such as leaching and emanation [7]. Therefore, ^{226}Ra is reported instead of ^{238}U. The activity concentration of ^{226}Ra was measured through gamma-ray peaks of 351KeV of ^{214}Pb and 609KeV of ^{214}Bi. ^{232}Th was determined through gamma-ray peak of 239 keV of ^{212}Pb, 583 keV of ^{208}Tl and 911 keV of

^{228}Ac, whereas ^{40}K activities were measured directly through its gamma-ray peak of 1460 keV and ^{137}Cs was determined through gamma-ray peak of 661.6 keV.

5. Results and Discussion

The range and mean value of activity concentration of natural radionuclides (^{232}Th, ^{226}Ra and ^{40}K) and artificial radionuclide (^{137}Cs), in surface and sub-surface soil samples of C-1 and PINSTECH is shown in Tables 1 and 2 respectively and for OGDCL sites (I and II) is shown in Table 3. The results reveal uniformity in the concentration levels in surface and subsurface layers of soil.

5.1 Chashma Nuclear Power Plant (C-1)

Around C-1, the activity concentrations of ^{232}Th, ^{226}Ra and ^{40}K in surface soil samples ranged from 27 to 63 BqKg^{-1}, 37 to 62 BqKg^{-1} and 293 to 690 BqKg^{-1} respectively and in sub-surface ranged from 36 to 62 BqKg^{-1}, 36 to 59 BqKg^{-1} and 487 to 643 BqKg^{-1} respectively. The mean values of ^{232}Th, ^{226}Ra and ^{40}K in surface soil samples are 44 BqKg^{-1}, 43 BqKg^{-1} and 540 BqKg^{-1} respectively and in subsurface soil samples are 46 BqKg^{-1}, 44 BqKg^{-1} and 555 BqKg^{-1}. The overall (surface & subsurface) average values of activity concentration for ^{232}Th, ^{226}Ra and ^{40}K are 45, 43 and 547 BqKg^{-1} respectively.

The activity concentration of ^{137}Cs in surface and subsurface samples varies from 0.1 to 7.1 BqKg^{-1}. The presence of slight contamination around the site is not due to operation of NPP as ^{137}Cs has neither been detected nor reported by C-1 in its annual/semi-annual effluent release report. Moreover, ^{134}Cs has not been detected in the samples analyzed. Therefore, it can be concluded that there has been no release of ^{137}Cs from the C-1. Presence of ^{137}Cs in the soil can be attributed to Chernobyl fallout.

5.2 PINSTECH

Around PINSTECH, the range of specific activity concentration for ^{232}Th in surface soil samples varied from 25 to 50 BqKg^{-1} with a mean value of 36 BqKg^{-1}, 30 to 60 BqKg^{-1} with a mean value of 44 BqKg^{-1} for ^{226}Ra, 293 to 516 BqKg^{-1} with a mean value of 410 BqKg^{-1} for ^{40}K and in subsurface soil samples varied from 25 to 75 BqKg^{-1} with a mean value of 38 BqKg^{-1} for ^{232}Th , 27 to 95 BqKg^{-1} with a mean of 46 BqKg^{-1} for ^{226}Ra and 292 to 744 BqKg^{-1} with a mean value of 450 BqKg^{-1} for ^{40}K. The radio analytical results show that overall mean values (surface and subsurface) of specific activity of ^{232}Th, ^{226}Ra and ^{40}K in soil samples collected from the vicinity of PINSTECH are 37, 45 and 430 BqKg^{-1} respectively.

^{137}Cs was also found in the samples collected from the surface and subsurface of soil which ranged from 0.03 to 9.1 Bq/kg with a mean value of 3.4 Bq/kg in surface and 3.6 Bq/kg in subsurface. Moreover, activity was found to be distributed uniformly in both surface and sub surface soil samples as ratio of surface to sub surface soil samples is found to be 1. Like C-1 soil samples ^{137}Cs in this soil of PINSTECH can also be due to Chernobyl fallout.

5.3. Oil/gas Sites (I & II)

The average activity concentration of ^{232}Th, ^{226}Ra and ^{40}K in soil samples collected from Site I is 28, 29 and 468 Bq/kg respectively whereas in Site II samples the concentration levels are found to be 26, 28 and 441 Bq/kg respectively which are very close to the values of 33, 37 and 513 Bq/kg found in the soil samples collected from outside of the facility.

5.4. Comparison with World Average Value

The measured values of natural radionuclides in C-1, PINSTECH and Oil/gas sites (I and II) are compared with the world average value [7] (Table 4). All these values are less than the world average values in case of PINSTECH and Oil/gas sites (I & II) but in case of C-1 only ^{40}K is slightly higher than world average value.

5.5. Comparison with other locations of Pakistan

A comparison of measured values of activity concentration of natural radionuclides (^{232}Th, ^{226}Ra and ^{40}K) in C-1, PINSTECH and Oil/gas sites (I & II) was made with some other locations in Pakistan (Figures 2, 3 and 4). It is found that the measured values in the present study are comparable with the values of other locations in Pakistan and are also comparable with each other [8-10]. The comparison of ^{137}Cs with different locations of Pakistan (Fig. 5) shows that activity at Chashma location is similar to that of Mianwali but lower than the values reported from other areas in Pakistan [11].

Table 1. Activity concentrations of ^{232}Th, ^{226}Ra, ^{40}K and ^{137}Cs in surface and subsurface soil samples of C-1

No	^{232}Th(Bqkg^{-1})		^{226}Ra(Bqkg^{-1})		^{40}K(Bqkg^{-1})		^{137}Cs(Bqkg^{-1})	
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
1	63 ± 5.5	50 ± 1.4	58 ± 4.4	52 ± 2.5	584 ± 12	567 ± 3.4	0.9 ± 0.4	1.0 ± 0.3
2	53 ± 2.5	40 ± 1.5	50 ± 2	36 ± 2.2	582 ± 12	597 ± 12	3.5 ± 0.5	4.6 ± 0.7
3	33 ± 3.3	39 ± 1.8	33 ± 2.7	45 ± 0.2	457 ± 23	577 ± 6.6	2.2 ± 0.09	1.6 ± 0.1
4	34 ± 3.2	39 ± 1.8	34 ± 2.5	39 ± 1.5	586 ± 13	584 ± 8.4	5.2 ± 0.9	7.1 ± 1.4
5	42 ± 0.7	39 ± 1.9	41 ± 0.5	36 ± 2.2	594 ± 15	576 ± 6.3	0.5 ± 0.4	0.8 ± 0.4
6	27 ± 5	36 ± 2.7	38 ± 1.2	39 ± 1.2	542 ± 0.5	532 ± 6.3	0.7 ± 0.3	1 ± 0.3
7	50 ± 1.4	50 ± 1.3	48 ± 1.3	48 ± 1.1	556 ± 5	546 ± 2.5	1.1 ± 0.2	1.6 ± 0.1
8	52 ± 2	48 ± 0.7	62 ± 5.4	53 ± 2.7	690 ± 43	643 ± 25	6.4 ± 1.3	4.8 ± 0.8
9	52 ± 2	62 ± 4.6	49 ± 1.7	59 ± 4.2	495 ± 12	554 ± 25	0.4 ± 0.4	2.8 ± 0.2
10	46 ± 0.3	52 ± 1.7	39 ± 1.1	44 ± 0.07	516 ± 7	552 ± 25	1.4 ± 0.1	0.6 ± 0.4
11	41 ± 1.1	61 ± 4.3	38 ± 1.4	42 ± 0.6	458 ± 23	487 ± 25	0.9 ± 0.3	0.1 ± 0.5
12	45 ± 0.005	45 ± 0.3	36 ± 2	43 ± 0.4	488 ± 15	519 ± 25	0.9 ± 0.3	0.9 ± 0.3
13	45 ± 0.005	43 ± 0.8	36 ± 2	35 ± 2.7	472 ± 19	481 ± 25	0.7 ± 0.3	0.1 ± 0.6
Mean	44 ± 2	46 ± 1.9	43 ± 2.2	44 ± 1.6	540 ± 15	555 ± 15	1.9 ± 0.4	2 ± 0.5
Max	63 ± 5.5	62 ± 4.6	62 ± 5.4	59 ± 4.2	690 ± 37	643 ± 25	6.4 ± 1.3	7.1 ± 1.4
Min	27 ± 5	36 ± 2.7	37 ± 2.9	36 ± 2.9	293 ± 24	487 ± 25	0.4 ± 0.4	0.1 ± 0.6
Total no of samples measured (C-1): 13								

Table 2. Activity concentrations of ^{232}Th, ^{226}Ra, ^{40}K and ^{137}Cs in surface and subsurface soil samples of PINSTECH

No	^{232}Th(Bqkg^{-1})		^{226}Ra(Bqkg^{-1})		^{40}K(Bqkg^{-1})		^{137}Cs(Bqkg^{-1})	
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
1	47 ± 3	75 ± 10	60 ± 4	95 ± 13	486 ± 26	744 ± 82	6 ± 0.7	6.7 ± 0.8
2	50 ± 4	48 ± 3	48 ± 1	62 ± 4	516 ± 34	471 ± 12	5.9 ± 0.6	2.6 ± 0.2
3	39 ± 1	43 ± 2	48 ± 1	53 ± 2	418 ± 8	473 ± 12	6.3 ± 0.7	8.9 ± 1.4
4	44 ± 2	41 ± 1	54 ± 3	50 ± 1	435 ± 13	435 ± 2	2.9 ± 0.1	1.9 ± 0.4
5	39 ± 1	42 ± 1	51 ± 2	51 ± 1	391 ± 2	424 ± 0.5	8.4 ± 1.3	9.1 ± 1.4
6	36 ± 0.1	34 ± 0.7	46 ± 1	38 ±2	388 ± 1	517 ± 23	4.4 ± 0.3	1.6 ± 0.5
7	36 ± 0.1	34 ± 0.7	49 ± 1	38 ±2	396 ± 3	515 ± 23	0.03 ± 0.9	0.1 ± 0.9
8	31 ± 1	43 ± 2	36 ± 2	45 ± 0.1	472 ± 24	606 ± 46	0.3 ± 0.8	0.8 ± 0.7
9	35 ± 0.1	36 ± 0.2	48 ± 1	46 ±0.1	359 ± 7	329 ± 25	4.3 ± 0.2	2.6 ± 0.2
10	36 ± 0.1	35 ± 0.4	48 ± 1	42 ± 1	353 ± 8	333 ± 24	3.6 ± 0.1	3 ± 0.1
11	28 ± 2	31 ± 1	36 ± 2	38 ± 2	293 ± 24	384 ± 11	4.3 ± 0.2	9 ± 1.4
12	31 ± 1	31 ± 1	38 ± 2	38 ± 2	405 ± 5	383 ± 11	1 ± 0.6	0.2 ± 0.9
13	25 ± 3	28 ± 2	30 ± 4	31 ± 4	383 ± 1	375 ± 13	4.6 ± 0.3	5.7 ± 0.5
14	28 ± 2	25 ± 3	32 ± 3	27 ± 5	355 ± 8	292 ± 35	0.2 ± 0.8	0.1 ± 0.9
15	33 ± 1	33 ± 1	40 ± 1	41 ± 1	512 ± 33	397 ± 7	1.5 ± 0.5	5.4 ± 0.5
16	32 ± 1	33 ± 1	39 ± 1	34 ± 3	405 ± 5	521 ± 25	0.7 ± 0.7	0.2 ± 0.9
Mean	36 ± 1.2	38 ± 1.9	44 ± 1.8	46 ± 2.6	410 ± 12.4	450 ± 22	3.4 ± 0.5	3.6 ± 0.7
Max	50 ± 4	75 ± 10	60 ± 4	95 ± 13	516 ± 34	744 ± 82	8.4 ± 1.3	9.1 ± 1.4
Min	25 ± 3	25 ± 3	30 ± 4	27 ± 5	293 ± 24	292 ± 35	0.03 ± 0.9	0.1 ± 1.8
Total no of samples measured (PINSTECH): 16								

Table 3. Activity concentrations of ^{232}Th, ^{226}Ra, ^{40}K and ^{137}Cs in surface and subsurface soil samples of Oil/gas Sites (I and II)

S. No	Sample Name	^{232}Th(Bq/kg)		^{226}Ra(Bq/kg)		^{40}K(Bq/kg)		^{137}Cs(Bq/kg)	
		Site-I	Site-II	Site-I	Site-II	Site-I	Site-II	Site-I	Site-II
1	SS1	33 ± 6	27± 5	40 ± 6	29 ± 5	490 ± 22	469 ± 21	<LLD	2.5 ± 0.4
2	SS2	27± 5	25 ± 5	25 ± 5	29 ± 5	467± 21	472 ± 21	<LLD	1.3 ± 0.3
3	SSS1	26 ± 5	20 ± 4	25 ± 5	24 ± 4	471± 21	357 ± 18	<LLD	2.2 ± 0.2
4	SSS2	25 ± 5	31 ± 5	24 ± 4	28 ± 5	445 ± 21	468 ± 21	<LLD	1.2 ± 0.3
Average		28	26	29	28	468	441	-	1.8
5	BKG	33 ± 6	32 ± 5	36 ± 6	38 ± 6	573 ± 24	513 ± 22	<LLD	<LLD

Surface Sample (SS), Subsurface Sample (SSS), Background Soil Sample (BKG), Lower Limit of Detection (LLD)

Table 4. Comparison of activity concentration of ^{232}Th, ^{226}Ra and ^{40}K with world average value.

Locations	^{232}Th ($Bqkg^{-1}$)	^{226}Ra ($Bqkg^{-1}$)	^{40}K ($Bqkg^{-1}$)
C-1	45	43	547
PINSTECH	37	45	430
Site-I	28	29	468
Site-II	26	28	441
World Average	50	50	500

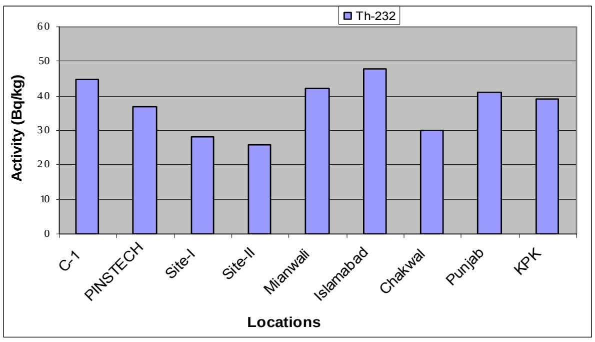

Figure 2. Comparison of activity of ^{232}Th in present study with other locations in Pakistan

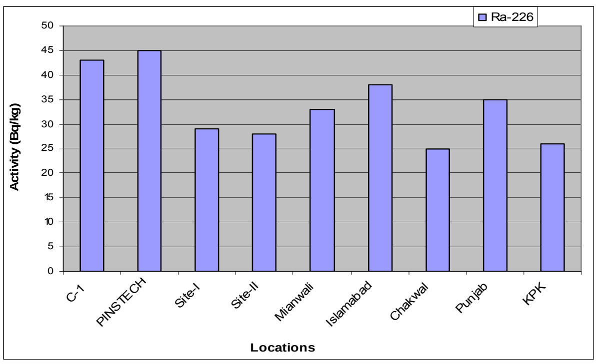

Figure 3. Comparison of activity of ^{226}Ra in present study with other locations in Pakistan

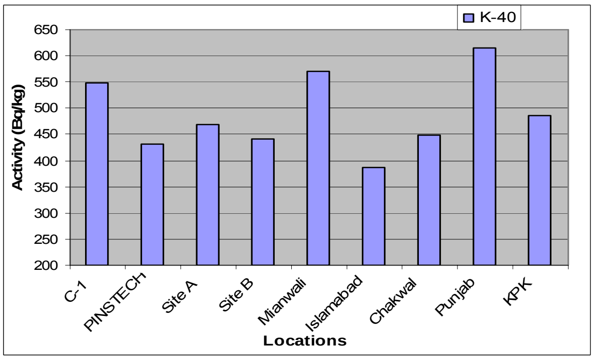

Figure 4. Comparison of activity of ^{40}K in present study with other locations in Pakistan

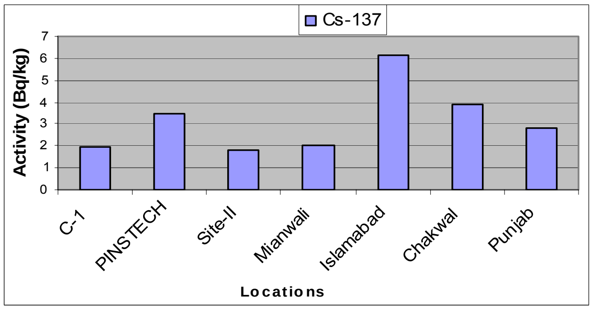

Figure 5. Comparison of activity of ^{137}Cs in present study with other locations in Pakistan.

5.6. Comparison with other Countries

Comparison of activity concentration levels of ^{232}Th, ^{226}Ra and ^{40}K of C-1, PINSTECH and Oil/gas sites (I & II) with the reported values for different countries of East and West Asia [12] is shown in Table 5. The average values of ^{40}K in our study are less than the Hong Kong & Iran; slightly higher than Thailand, Malaysia, Japan, Kazakhstan and Bangladesh and almost similar to India & China. The average values of ^{226}Ra in our study are less than Hong Kong & Malaysia and similar to all other countries. The average values of ^{232}Th in our study are less than Hong Kong, Malaysia, India & Kazakhstan and almost similar to other countries.

Table 5. Range of activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in different countries of East Asia and Pakistan

Country	^{40}K ($Bqkg^{-1}$)		^{226}Ra ($Bqkg^{-1}$)		^{232}Th ($Bqkg^{-1}$)	
	Mean	Range	Mean	Range	Mean	Range
Bangladesh	350	130-610	34	21-43	---	---
China	440	9-1800	32	2-440	41	1-360
Hong Kong	530	80-1100	59	20-110	95	16-160
India	400	38-760	29	7-81	64	14-160
Iran	640	250 -980	28	8 -55	22	5-42
Japan	310	15-990	33	6-98	28	2-88
Kazakhstan	300	100-1200	35	12-120	60	10-220
Malaysia	310	170-430	67	38-94	82	63-110
Thailand	230	7-712	48	11-78	51	7-120
Pakistan (C-1)	547	457-690	43	36-62	45	27-63
Pakistan (PINSTECH)	430	292-744	45	30-95	37	25-75
Pakistan (Oil/gas Site-I)	468	445-490	29	24-40	28	25-33
Pakistan (Oil/gas Site-II)	441	357-472	28	24-49	26	20-31

Table 6. Range of activity concentration of ^{137}Cs in soil samples reported for different countries of the world

Country	Activity Concentration ($Bqkg^{-1}$)	Reference
Majorca (Spain)	10-60	Gomez *et al.*
Inshass, Cairo (Egypt)	1.6-19.1	Higgy and Pimple
Algeria	15-35	Noureddin *et al.*
Kocaeli basin (Turkey)	2-25	Karakella *et al.*
Savart (Bangladesh)	2-3	Karakella *et al.*
Louisiana (USA)	5-58	Karakella *et al.*
Bay of Cadiz (Spain)	0.5-5	Lerate *et al.*
Montenegrin coast(Yugoslavia)	1.5-28.4	Vukotic *et al.*
Sudan	0-18.5	Sam *et al.*
North-western Libya	0.9-1.7	Shenber
Riyadh (Saudi Arabia)	0.2	Al-Kahtani *et al.*
Northern Taiwan	1.48-27	Wang *et al.*
Pakistan (C-1)	2	Present study
Pakistan (PINSTECH)	3.5	Present study
Pakistan (Oil/gas Sites)	2	Present study

5.7. Comparison of Activity Concentration of ^{137}Cs with other Countries

Table 6 shows that activity concentration levels of ^{137}Cs reported in different countries of the world [13, 14] the values in many countries are much higher than the values found around the investigated sites in the present study.

5.8. Radium Equivalent (Ra_{eq})

For determining the radiological effects or radiation hazards due to ^{232}Th, ^{226}Ra and ^{40}K, a single quantity is used which is called radium equivalent activity [Ra_{eq}], and is calculated by using the following relation [15].

$$Ra_{eq} = A_{Ra} + 1.43\ A_{Th} + 0.077\ A_k$$

Where A_{Ra}, A_{Th} and A_k are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in $BqKg^{-1}$. The annual effective dose for Ra_{eq} of 370 $BqKg^{-1}$corresponds to the dose limit of 1.0mSv for the general population [16]. Earth surface materials for which radium equivalent activity concentration exceeds

370 $BqKg^{-1}$may cause radiation hazards [15]. The average values of radium equivalent (Ra_{eq}) activity in soil samples of C-1, PINSTECH and Oil/gas sites (I & II) are given in Table 7. All these values are much lower than the value of 370 $BqKg^{-1}$.

Table 7. Radium Equivalent (Ra_{eq}) value at C-1, PINSTECH and Oil/gas sites.

Ra_{eq}	C-1	PINSTECH	Oil/gas Sites	
			I	II
Mean Value	149 ± 6	131 ± 6	108 ± 14	103 ± 13
Max Value	200 ± 14	260 ± 34	127 ± 13	123 ± 11
Min Value	116 ± 10	85 ± 12	94± 16	80 ± 5

5.9. *External Effective Dose Rate Due to ^{137}Cs*

An additional gamma dose on account of ^{137}Cs activity concentration in soil around the NPP site was estimated [11] and presented in Table 8. The dose rates varied from 0.006 to 0.43 nSv/h with mean value around 0.12 nSv/h The average external gamma ray dose rate of 0.12 nSv/h measured in this study is very small as compared with the dose rate limit of 1.0 mSv/y [3] as well as the average gamma dose of 0.5 mSv/y received from natural radiation sources assessed by UNSCEAR [17].

Table 8. External effective dose rate for ^{137}Cs at C-1, PINSTECH and Oil/gas sites (I & II)

Location	Effective dose (nSv/h)		
	Mean	Min	Max
C-I	0.12	0.006	0.426
PINSTECH	0.21	0.002	0.546
Oil/gas Site-I	-	-	-
Oil/gas Site-II	0.11	0.072	0.150

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