CHAPTER 6

Characterization of Particulate Matter with reference to Natural Radioactivity

The activity concentration of isotopic potassium (^{40}K), lead (^{210}Pb), thorium (^{232}Th), and uranium (^{234}, ^{235}, and ^{238}U) of the atmospheric particulate matter in various sizes in the study area has been investigated and discussed in this chapter.

6.1 Introduction

Natural radioactive materials like Uranium, Thorium can be found everywhere in the earth's crust. Human beings are exposed to radiation coming from non–natural radioisotopes **[194]**. Several serious radioactivity release events are responsible for radionuclide contamination worldwide, such as the decline of atmospheric nuclear weapons testing in the 1950s and 1960s and later from many nuclear accidents. More than half of the total radioactive dose rate available to the world's population is associated with radioactivity using aerosol particles **[195]**. Airborne particulate matter consists of aerosol particles with a diameter on the micrometer scale on the nanometer (nm), suspended and transported by the air. A model based on uranium concentration results shows that particles of about 15 micrometers will travel up to 4 km from their sources **[196]**.

The ^{234}U, ^{238}U, and ^{232}Th procedure utilized a genuine chronometer with applications in paleoclimatology, landscape evolution, and human evolution **[197]**. It is very well known that the radioactive decay series participants make a commendable contribution to the total

exposure dose of the human population. The study on various radioactivity sources provides relevant information in health physics **[198]**. The knowledge about the distribution of the radioisotopes and the radiation levels in the environment allows for the assessment of radiation exposure, and radioisotopes are toxic elements and detrimental to the human **[199]**. Exposure of cells and organisms to radiation may cause DNA damage as alterations that lead to lethality or heritable changes (mutations and chromosomal aberrations) in cells. Natural radioactive aerosols in the air produce an important fraction of the population's radiological exposure to ionizing radiation. After inhalation, the natural radioactive aerosols containing decay products produce a dose rate for the respiratory system, particularly the respiratory epithelium, which seems to be the most irradiated tissue of the whole body **[200]**.

A little work has been done to establishing the concentrations of isotopic potassium (^{40}K), lead (^{210}Pb), thorium (^{232}Th), and uranium (^{234}, ^{235}, and ^{238}U) activity concentrations, particularly in the air of study area. Assessing the magnitude of the accident and radiological doses obtained by the general populations, it is important to evaluate the source term of the radiological discharged into the atmosphere. Consequently, it is important to investigate these radionuclides' activity concentration in air, particularly the breathable fraction as its PM_{10} and $PM_{2.5}$. This particulate matter contributes significantly to the internal radiation dose and may cause unfavourable health and adverse effects. The present study has been conducted during 2016 and 2017 to determine the concentration and activity of potassium (^{40}K), lead (^{210}Pb), thorium (^{232}Th), and uranium (^{234}, ^{235}, and ^{238}U) in the particulate matter at sampling location located in the study area.

6.2 Isotope activity concentration in particulate matter

The statistical description of isotope activity concentration of ^{40}K, ^{210}Pb, ^{232}Th, ^{234}U, ^{235}U, and ^{238}U measured is summarized in **Table 6.1**. The increasing order of the average activity concentration is as follows $^{235}U < ^{238}U < ^{232}Th < ^{234}U < ^{210}Pb < ^{40}K$ in the $PM_{2.5}$ samples and similar orders follow in PM_{10}, and SPM samples, respectively. All the measured activity concentrations of isotopic uranium (^{234}, ^{235}, and ^{238}U), $^{210}Pb < ^{40}K$, and ^{232}Th were in the order of μBq m^{-3}. These values are lower than the found values in PM_{10}, and SPM. In **Table 6.1** shows that the isotopic activity concentration values in PM_{10} and SPM are higher than $PM_{2.5}$. This fact suggests that the presence of uranium, potassium, lead, and thorium in $PM_{2.5}$ do not come from the natural re–suspended surface soil, and these elements have more affinity for adhering to bigger than smaller particles.

Table 6.1: Statistical of the activity concentration of measured isotopes and radium equivalent activity (Raeq) index in particulate matter of different sizes

Isotope	Unit		$PM_{2.5}$	PM_{10}	SPM
^{40}K	μBq m^{-3}	**Range**	0.194–18.172	0.749–35.624	0.497–84.395
		Average	2.364±1.728	13.426±5.913	29.939±9.164
^{210}Pb	μBq m^{-3}	**Range**	0.209–17.346	0.278–31.587	0.358–79.376
		Average	2.126±1.095	9.875±4.085	20.737±8.678
^{232}Th	μBq m^{-3}	**Range**	0.013–4.852	0.088–15.211	0.124–34.793
		Average	1.116±0.747	6.121±3.152	11.297±5.817
^{234}U	μBq m^{-3}	**Range**	0.075–5.237	0.472–29.712	0.652–54.125
		Average	1.646±0.746	10.127±5.215	17.215±8.864
^{235}U	μBq m^{-3}	**Range**	0.004–0.189	0.018–0.794	0.028–1.643
		Average	0.025±0.017	0.173±0.089	0.467±0.340
^{238}U	μBq m^{-3}	**Range**	0.064–3.158	0.347–13.834	0.573–28.571
		Average	0.673±0.465	4.384±2.257	10.526±3.420
Raeq	Bq kg^{-1}	**Range**	2.06–242.88	2.02–238.02	1.96–230.74
		Average	51.78±35.20	50.75±34.50	49.19±33.44
Raeq	μBq m^{-3}	**Range**	0.10–11.49	0.53–38.31	0.79–84.79
		Average	2.45±1.67	14.16±7.22	28.97±12.44

± = *Standard deviation*

The average mass concentration of PM_{10} was 196.11 ± 56.20 μg m^{-3} of two consecutive years (2016 and 2017). During the study period, the average activity concentration of ^{40}K, ^{210}Pb, ^{232}Th, ^{234}U, ^{235}U, and ^{238}U was 13.43, 9.88, 6.12, 10.13, 0.173, and 4.38 μBq m^{-3}–PM_{10}, respectively. Furthermore, during the study period, the activity concentrations of the radionuclides ^{40}K, ^{210}Pb, ^{232}Th, ^{234}U, ^{235}U, and ^{238}U were 0.5–84.4 (30.0±9.2 μBq m^{-3}–SPM), 0.4–79.4 (20.7±8.7 μBq m^{-3}–SPM), 0.1–34.8 (11.3±5.8 μBq m^{-3}–SPM), 0.7–54.1 (17.2±8.9 μBq m^{-3}–SPM), and 0.02–1.6 (0.5±0.3 μBq m^{-3}–SPM), respectively.

Table 6.1 also shows that the average isotopic activity concentration of ^{232}Th associated with $PM_{2.5}$ was 0.01–4.9 (1.12±0.75) μBq m^{-3}, within the revised world reference value of 0.5 mBq m^{-3}, which it is worth noting that the world average is based on total suspended particulate matter **[131]**. However, the average isotopic activity concentration of ^{238}U [0.6–3.2 (0.7±0.5) μBq m^{-3} in $PM_{2.5}$)] was lower than the world reference value of 1.0 mBq m^{-3} **[131,201]**.

The monthly average activity concentrations of the radionuclides ^{40}K, ^{210}Pb, ^{232}Th, ^{234}U, ^{235}U, and ^{238}U in particulate matters were found a similar pattern in all sizes of particulate matter i.e., $PM_{2.5}$, PM_{10} and SPM **(Fig. 6.1)**, consistent with the winter season of coal heating in surrounding the study area. Smoke and fly ash, which may be enriched with natural radioactive elements such as uranium and thorium, are released into the environment by coal–burning activity. The highest activity concentrations of isotopes are shown in December and January, and the lowest activity concentration of isotopes is found in all sizes of particulate matter during July and August. There is a rainy season in July and August.

In the rainy seasons, the particulate matter was washed from the atmosphere. A value of 2.5 μm was used as the dividing point for the particle size of between coarse particles and fine particles in this thesis. It may be observed from **Fig. 6.1** that the concentrations of ^{40}K,

^{210}Pb, ^{232}Th, ^{234}U, ^{235}U, and ^{238}U in $PM_{2.5}$, PM_{10}, and SPM in different months are fluctuating significantly. The average activity concentration of isotopes of uranium, potassium, lead, and thorium in $PM_{2.5}$, PM_{10}, and SPM are increased from summer to winter. However, compared with the particles larger than 10 μm, isotopes of uranium, potassium, lead, and thorium contents rose sharply in fine particles.

6.3 Isotopic ratios in particulate matter

To know the relationship between the sizes of particulate matter and the concentration of U and Th in the particulate matters of the study has been conducted. The isotope ratio has been calculated in each size of particulate matter ($PM_{2.5}$, PM_{10}, and SPM). According to this study, $^{235}U/^{238}U$ values of particulate matter samples suggest that uranium is present in the particulate matters of different sizes.

The activity concentration ratios of $^{234}U/^{238}U$ range from 1.3 to 2.2 (1.8 ± 0.8) in PM_{10} and similar in $PM_{2.5}$, and SPM were found to 0.1 to 1.7 (1.4 ± 0.7), and 1.1 to 2.0 (1.3 ± 0.8), respectively. There were no significant differences in this activity concentration ratio between the collected samples of particulate matter of different sizes. All $^{234}U/^{238}U$ values were not in the best equilibrium between these isotopes. This phenomenon is not expected in atmospheric particles **[202]**.

However, these activity ratios are according to the EPA **[203]**, who has reported typical values between 0.5 and 5 in the environment, establishing that in the environmental samples, the $^{234}U/^{238}U$ ratio differs significantly from the equal proportions found in crystalline rock ($^{234}U/^{238}U \sim 1$) due to the alpha–recoil effects of uranium atoms in natural environments **[204]**.

The $^{232}Th/^{238}U$ activity ratio in particulate matter was found between 0.20 to 1.54 with an average value of 0.9 ± 0.5, 0.25 to 1.10 (0.8 ± 0.7), and 0.22 1.22 with an average value of

0.8 ± 0.8 in the $PM_{2.5}$, PM_{10}, and SPM, respectively. This range is so far from the average crust ratio of 3.5, indicating that ^{232}Th activity concentration has not increased by coal combustion **[205]**.

These events are the main factors in the increase of the activity concentration of ^{232}Th. The lower $^{232}Th/^{238}U$ ratio is a potential indicator of the source, and relative elevation of U concentrations, due to none of the above-mentioned factors, has altered the level of ^{232}Th. The hypothesis is strengthened that the origin of uranium increases in particulate matters of different sizes comes from the atmospheric fallout.

Two shreds of evidence can prove that the uranium found in these particles is mainly for anthropogenic sources' contribution. One is the high ratio of $^{234}U/^{238}U$ indicates that these are not in balance in the radioisotope particulate matter of different sizes, and another is the high proportion of the $^{235}U/^{238}U$, in this fact, includes some ^{235}U contributions that can come from atmospheric degradation with nuclear weapons testing or atomic accidents rather than contribute to some uranium processing facilities.

As a result of analyzing the particulate matter, the activity concentration ratio of $^{232}Th/^{40}K$ was 0.42, 0.38, and 0.033, and $^{238}U/^{40}K$ was 0.28, 0.32, and 0.36 in $PM_{2.5}$, PM_{10}, and SPM, respectively. The activity concentration ratio of $^{40}K/^{210}Pb$, $^{232}Th/^{210}Pb$, and $^{38}U/^{210}Pb$ in $PM_{2.5}$ was measured as 0.91, 0.48, and 0.27, respectively. For PM_{10}, $^{40}K/^{210}Pb$, $^{232}Th/^{210}Pb$, and $^{238}U/^{210}Pb$ were found to be 1.02, 0.54, and 0.38, respectively. Similarly, in SPM, the activity concentration of $^{40}K/^{210}Pb$, $^{232}Th/^{210}Pb$, and $^{238}U/^{210}Pb$ was 1.13, 0.54, and 0.42, respectively.

6.4 Correlation among the activity concentrations of isotopes with meteorological factors

The correlations among the studied isotopes of potassium (^{40}K), lead (^{210}Pb), thorium (^{232}Th), and uranium (^{234}, ^{235}, and ^{238}U) with meteorological factors are given in **Table 6.2**. There is a good positive correlation between ^{232}Th and ^{238}U (0.60–0.70, p–value < 0.001), supporting the conclusion that they originated from the same source, mostly the crust, not as a result of coal mining.

Table 6.2: Correlation among the activity concentration of isotope of potassium, lead, thorium, and uranium with meteorological factors

	^{40}K	^{210}Pb	^{232}Th	^{234}U	^{235}U	^{238}U	$PM_{2.5}$	RH	T	WS
^{40}K	1									
^{210}Pb	0.692	1								
^{232}Th	0.461	0.622	1							
^{234}U	0.306	0.555	0.475	1						
^{235}U	0.555	0.379	0.338	0.841	1					
^{238}U	0.265	0.635	0.609	0.841	0.981	1				
$PM_{2.5}$	0.256	0.563	0.505	0.332	0.289	0.256	1			
RH	0.342	0.093	–0.260	–0.066	–0.132	0.492	0.432	1		
T	0.293	0.356	0.283	0.288	0.483	–0.181	0.551	0.041	1	
WS	0.143	0.363	0.503	–0.084	–0.095	0.072	–0.272	–0.623	–0.374	1
	^{40}K	^{210}Pb	^{232}Th	^{234}U	^{235}U	^{238}U	PM_{10}	RH	T	WS
^{40}K	1									
^{210}Pb	0.642	1								
^{232}Th	0.483	0.628	1							
^{234}U	0.352	0.310	0.329	1						
^{235}U	0.462	0.458	0.352	0.879	1					
^{238}U	0.325	0.227	0.619	0.879	0.948	1				
PM_{10}	0.273	0.263	0.324	0.233	0.292	0.205	1			
RH	0.314	0.129	–0.202	–0.022	–0.121	0.422	0.472	1		
T	0.279	0.336	0.271	0.218	0.423	–0.181	0.074	0.041	1	
WS	0.164	0.233	0.393	–0.042	–0.153	–0.021	–0.431	–0.624	–0.372	1
	^{40}K	^{210}Pb	^{232}Th	^{234}U	^{235}U	^{238}U	SPM	RH	T	WS
^{40}K	1									
^{210}Pb	0.612	1								
^{232}Th	0.468	0.654	1							
^{234}U	0.408	0.265	0.558	1						
^{235}U	0.158	0.073	0.565	0.242	1					
^{238}U	0.382	0.566	0.698	0.722	0.706	1				
SPM	0.383	0.383	0.391	0.332	0.429	0.325	1			
RH	0.381	0.213	0.420	0.122	0.312	0.221	0.423	1		
T	0.288	0.364	0.327	0.283	0.342	–0.218	–0.154	0.041	1	
WS	0.151	0.323	0.243	–0.022	–0.053	–0.001	–0.472	–0.623	–0.374	1

SPM=Suspended Particulate Matter; RH=Relative Humidity;
T=Temperature; WS=Wind Speed

The average calculated $^{232}Th/^{238}U$ ratio was 0.9 ± 0.5, 0.8 ± 0.7, and 0.8 ± 0.8 in the $PM_{2.5}$, PM_{10}, and SPM, respectively, close to the world average of unity **[131]**. On the other hand, weak positive correlations between ^{40}K and ^{232}Th (0.48, p–value < 0.001) in $PM_{2.5}$ and other sizes of particulate matters have been similar to the $PM_{2.5}$, and between ^{238}U and ^{40}K (0.26–0.38) were found in different sizes of particulate matter, supporting the conclusion that ^{40}K originated from other sources besides the crust, as discussed earlier. Similar correlations were observed for particulate matter samples in other studies **[125]**.

It may be revealed from **Table 6.2** that contains the data concerning to correlation coefficients between the specific radioactivity concentration of the ^{234}U, ^{235}U, and ^{238}U in all sizes of particulate matter, where the highest correlation coefficient is between ^{238}U, and ^{235}U was found to be 0.98 in $PM_{2.5}$. The results show a noticeable correlation between activity concentration ^{40}K and ^{210}Pb (0.61 – 0.69 in the $PM_{2.5}$, PM_{10}, and SPM), suggesting that the origin of these isotopes may be the same. It may also be observed from **Table 6.2**, that a positive correlation was observed between the concentrations of ^{210}Pb and ^{232}Th were found to be 0.62, 0.63, and 0.65 in the $PM_{2.5}$, PM_{10}, and SPM, whereas a negative correlation was noted between wind speed and ^{234}U, ^{235}U, ^{238}U, particulate matters, relative humidity, and temperature.

It may also be revealed from **Table 6.2** that the correlation analysis between specific radioactivity concentration and some meteorological factors, varying to a temperature of 03–46°C, relative humidity of 5–100 % with no rain, and wind speed of 0.1 to 20 km h^{-1}. The results showed a low correlation between concentrations of specific radioactivity concentrations of uranium and temperature in $PM_{2.5}$ (–0.181 to 0.483) and high in $PM_{2.5}$ of specific radioactivity concentrations potassium, lead, and thorium with temperature (0.28 to 0.36), suggesting that the temperature is the one of the atmospheric factor affecting

removal of the specific radioactivity concentration, while the analysis of other parameters in this study reveals that there is low influence on the particular radioactivity concentration of isotope and similar temporal behavior and fluctuation were found in the specific radioactivity concentration in PM_{10}, and SPM samples, respectively.

The low correlation between wind speed and the particular radioactivity concentration in all sizes of particulate matter to a resuspension process because there is no local radionuclide source in the study area. However, the direction of wind indicates that the variation of the $^{238}U/^{235}U$ ratio can be due to the transport and dispersion of faster sources.

6.5 Radium equivalent activity, Inhalation exposure, and lifetime cancer risk

The average radium equivalent activity (Raeq) index in the study area with different sizes of particulate matter was found to be 2.06–242.88 Bq Kg^{-1} with an average value of 51.78±35.20 Bq Kg^{-1}, 2.02–238.02 Bq Kg^{-1} with an average value of 50.75±34.50 Bq Kg^{-1}, and 1.96–230.74 Bq Kg^{-1} with an average value of 49.19±33.44 Bq Kg^{-1} in the $PM_{2.5}$, PM_{10} and SPM, respectively, which is lower than the world average of 89.0 Bq Kg^{-1} in soils **[201]** and much lower than the acceptable level in soil of 370 Bq Kg^{-1} set by Organization for Economic Cooperation and Development **[206]** as given in **Table 6.2** on the previous page. Isotopes activity concentrations in air (μBq m^{-3}) were used in the calculation of inhalation annual effective radiation dose to various age groups of the public with $PM_{2.5}$, and PM_{10}. The SPM particles could not inhale the human body through the inhalation route. The variations in the air–breathing rate, the total annual dose due to the natural radioactivity in airborne $PM_{2.5}$, and PM_{10} increases for the older age groups. The average values of dose for the different age groups in the study area were found in the range from 0.26 to 42.36 pSv $year^{-1}$ in $PM_{2.5}$ and from 0.62 to 100.85 pSv $year^{-1}$ in PM_{10}, respectively. These annual

effective doses are lower than the yearly limit of 1 mSv $year^{-1}$, as suggested by the ICRP **[128]**. But it is not average that people living in the study areas are safe. These dosage values present the risk of inhalation associated with the $PM_{2.5}$, and PM_{10} fraction of atmospheric particles. The total annual effective dosage available to the general public includes external gamma radiation, inhalation, and ingestion risk of all radioactive nuclides [207]. The present study results are slightly higher than the inhaling radiation dose in Mexico City **[194]**. This indicates a potentially high risk of ^{40}K exposure in both sizes of particulate matter in Singrauli coalfield regions.

UNSCEAR estimated that the average annual effective dose worldwide is 6×10^3 nSv from uranium and thorium series of radionuclide, excluding radon. It may be observed from **Table 6.3** shows that the estimated dosage due to inhalation of potassium, lead, thorium, and uranium in $PM_{2.5}$ and PM_{10} for six different exposed public groups. This **Table 6.3** shows the annual dose estimation to six different groups, ^{232}Th, and ^{234}U are the isotopes in $PM_{2.5}$, and PM_{10} that most contribute to the yearly dose, the worldwide average annual effective dose from uranium and thorium is 6.0 μSv, excluding radon **[128]**, several orders of magnitude higher than those found in this work.

Although the risk of low activity concentration, dose, and lifetime cancer have been found in the $PM_{2.5}$ and PM_{10} for isotopic potassium, lead, thorium, and uranium, it does not average that these elements are not a hazardous risk to people. Even though the dose and lifetime cancer was calculated, with those results, the populations were not able to know the real hazard, due to the results must be standardized to mortality statistics, and this data are not available, but these first results can establish the preliminary levels of activity concentration of isotopic potassium, lead, thorium, and uranium in $PM_{2.5}$, and PM_{10} being the first analysis of this kind in the area.

Table 6.3: The average inhalation annual effective radiation dose due to inhalation of $PM_{2.5}$ and PM_{10}

Age group	Unit	3 months	1 year	5 year	10 year	15 year	Adult
Particulate matter size less than 2.5 μ ($PM_{2.5}$)							
^{40}K	nSv year^{-1}	0.03±0.02	0.04±0.03	0.04±0.02	0.04±0.03	0.03±0.02	0.02±0.02
^{210}Pb		20.45±9.29	40.33±18.33	48.77±22.16	56.01±25.45	58.09±26.40	58.60±26.63
^{232}Th		32.20±19.01	58.81±34.72	86.11±50.84	106.16±62.68	129.22±76.29	137.32±81.07
^{234}U		13.19±5.27	19.08±7.63	24.03±9.61	28.91±11.56	32.02±12.80	28.35±11.34
^{235}U		0.17±0.11	0.26±0.16	0.33±0.20	0.39±0.24	0.43±0.26	0.38±0.23
^{238}U		4.32±2.63	6.67±4.07	8.28±5.05	9.85±6.01	10.60±6.47	9.61±5.86
Particulate matter size less than 10 μ (PM_{10})							
^{40}K	nSv year^{-1}	0.07±0.02	0.10±0.03	0.09±0.02	0.09±0.03	0.07±0.02	0.06±0.02
^{210}Pb		48.68±9.29	96.03±18.33	116.11±22.16	133.35±25.45	138.32±26.40	139.51±26.63
^{232}Th		76.67±19.01	140.03±34.72	205.01±50.84	252.77±62.68	307.66±76.29	326.94±81.07
^{234}U		31.41±5.27	45.44±7.63	57.21±9.61	68.83±11.56	76.23±12.80	67.51±11.34
^{235}U		0.41±0.11	0.63±0.16	0.78±0.20	0.94±0.24	1.02±0.26	0.91±0.23
^{238}U		10.27±2.63	15.88±4.07	19.71±5.05	23.45±6.01	25.23±6.47	22.87±5.86

± = *Standard deviation*

The annual inhalation exposure of isotopic uranium and thorium did not show significant differences between the six groups; the highest dose (around 137.32 nSv year^{-1}) is lower than the annual limit 2 mSv year^{-1} as suggested by the ICRP **[129]**. For instance, E_{Total} was 70.36 nSv year^{-1} to the infants (3 month), while it was 234.28 nSv year^{-1} to the adults in $PM_{2.5}$, and similar for PM_{10}, 167.52 nSv year^{-1} to the infants (3 months), while it was 557.80 nSv year^{-1} to the adults, depending on the age group. The variations in the air–breathing rate, the total annual dose due to the natural radioactivity in airborne $PM_{2.5}$, and PM_{10} increases for the older age groups. These values are lower than the corresponding values calculated from the data presented in UNSCEAR **[126]**.

The ^{232}Th, ^{210}Pb, and ^{234}U are the main contributor to the inhalation annual effective dose. ^{232}Th, ^{210}Pb, and ^{234}U were found to be responsible for the total dose. On the other hand, ^{40}K, ^{235}U, and ^{238}U, where were found to contribute slightly to the total dose. Biological effects of ionizing radiation that establish that every additional 100 mSv of radiation dose received correspond to a 1% increase in cancer (solid cancer or leukemia) incidence **[208]**, none of these exposed personal is increasing this percentage due to the inhalation of $PM_{2.5}$, and PM_{10} in the area. The highest annual effective dose was found in adults, and those are more exposed.

Based on these results, life cancer risk was calculated and presented in **Fig. 6.2**, being 9.41E–11±6.07E–11, 2.26E–07±1.03E–07, 5.29E–07±3.12E–07, 1.09E–07±4.36E–08, 1.47E–09±8.98E–10, and 3.70E–08±2.26E–08 to ^{40}K, ^{210}Pb, ^{232}Th, ^{234}U, ^{235}U, and ^{238}U, respectively in $PM_{2.5}$. A similar trend was found in the PM_{10}, 2.24E–10±1.49E–10, 5.37E–07±2.52E–07, 1.26E–06±7.68E–07, 2.60E–07±1.07E–07, 3.50E–09±2.21E–09, and 8.81E–08±5.55E–08 to ^{40}K, ^{210}Pb, ^{232}Th, ^{234}U, ^{235}U, and ^{238}U, respectively.

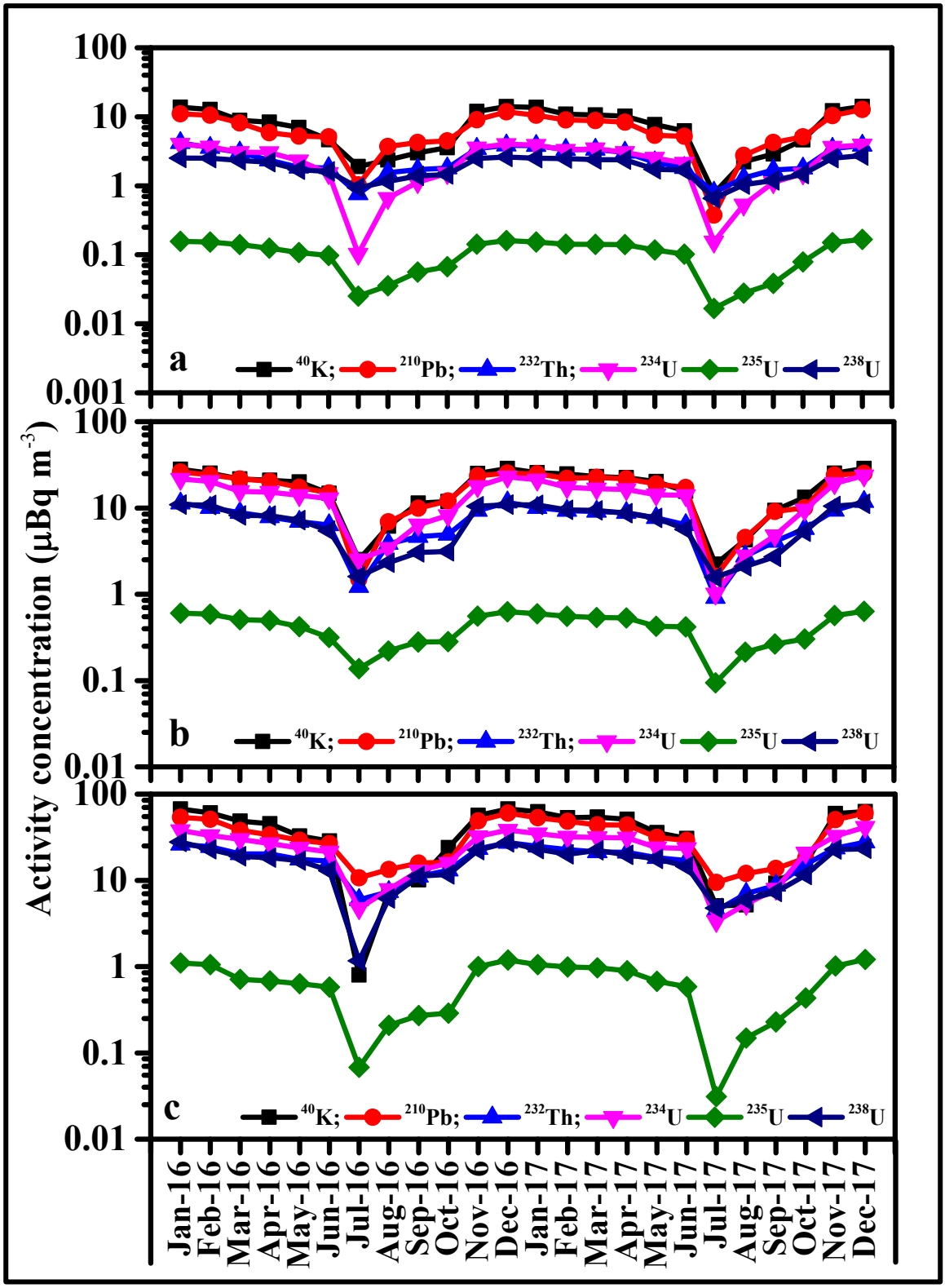

Fig. 6.1: Monthly variation of (a) isotope activity in $PM_{2.5}$, (b) isotope activity in PM_{10}, (c) isotope activity in SPM, collected during two consecutive years (2016 and 2017) in Singrauli coalfield. All the activities are given in μBq m^{-3}

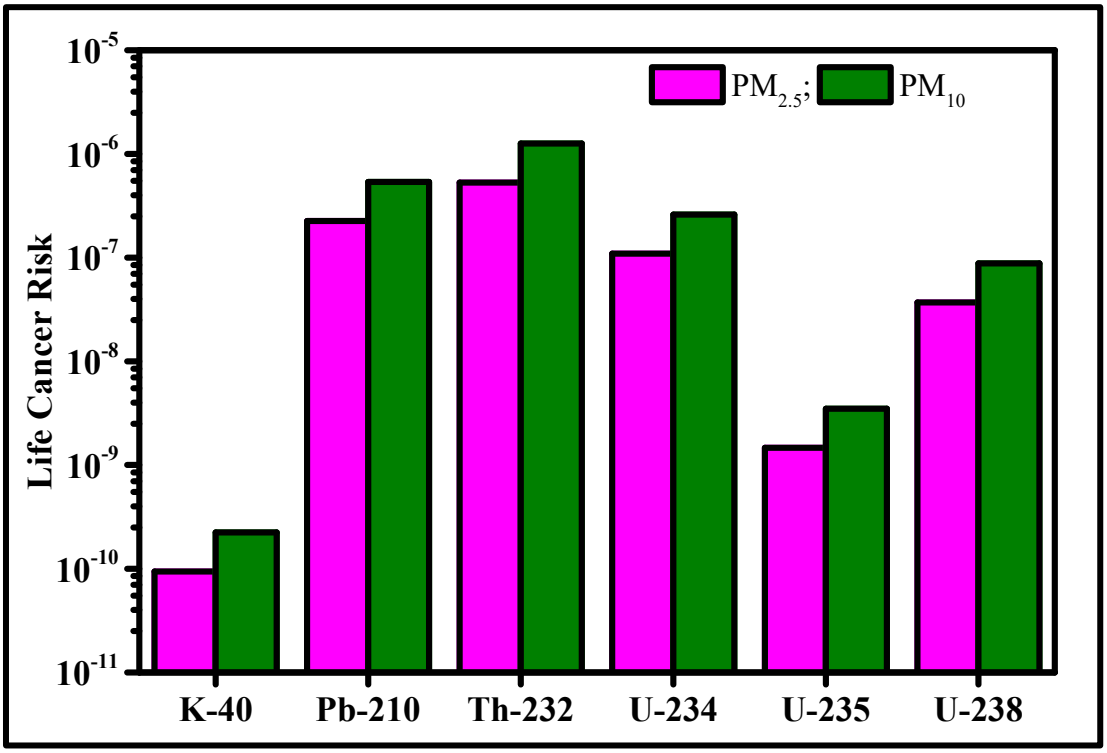

Fig. 6.2: Lifetime cancer risk in $PM_{2.5}$, and PM_{10}

So far that found in Pinarhisar district from Kirklareli, Turkey, with a high average gamma dose rate, around 283 nGy h^{-1} **[209]**, the lifetime cancer risk proposed by **[210]** is 2.9E–04, several orders of magnitude higher than found in $PM_{2.5}$, and PM_{10} particles in the area.

6.6 Conclusion

This study has analyzed the activity concentration of potassium, lead, uranium, and thorium isotopes in different sizes of particulate matter in the study area. The average activity concentration of ^{40}K, ^{210}Pb, ^{232}Th, ^{234}U, ^{235}U, and ^{238}U was 13.43, 9.88, 6.12, 10.13, 0.173, and 4.38 µBq m^{-3} in PM_{10}, respectively.

The activity concentrations of the radionuclides of ^{40}K, ^{210}Pb, ^{232}Th, ^{234}U, ^{235}U, and ^{238}U were 30.0±9.2 µBq m^{-3}, 20.7±8.7 µBq m^{-3}, 11.3±5.8 µBq m^{-3}, 17.2±8.9 µBq m^{-3}, and 0.5±0.3 µBq m^{-3} in SPM, respectively. The average activity concentration of ^{232}Th associated with $PM_{2.5}$ was 1.12±0.75 µBq m^{-3}, within the revised world reference value of

0.5 mBq m^{-3}, which the world average is based on total suspended particulate. However, the average activity concentration of ^{238}U [0.6–3.2 (0.7±0.5) μBq m^{-3}–$PM_{2.5}$)] was lower than the world reference value of 1.0 mBq m^{-3}. The average activity concentration ^{40}K, ^{210}Pb, ^{232}Th, ^{234}U, ^{235}U, ^{238}U in the present study are lower than the world average values. The activity concentration ratios of $^{234}U/^{238}U$ range from 1.3 to 2.2 (1.8±0.8) in PM_{10} and similar in $PM_{2.5}$, and SPM were found to 0.1 to 1.7 (1.4±0.7), and 1.1 to 2.0 (1.3±0.8), respectively. There were no significant differences in this activity concentration ratio between the collected samples of particulate matter of different sizes.

The lifetime cancer risk proposed is 2.9E–04, several higher orders than found in $PM_{2.5}$, and PM_{10} particles. The doses and lifetime cancer risk were assessed based on the highest concentrations of isotopic uranium and thorium, founding several orders of magnitude lower than established by UNSCEAR. This study's results will form baseline data for the activity concentration of potassium, lead, uranium, and thorium isotopes in different sizes of particulate matter and estimate population exposure by inhalation of particulate matter.