CHAPTER 7

Characterization of Particulate Matter with reference to Gross Alpha and Gross Beta Activity

This chapter presents the activity concentrations of gross alpha and gross beta in different size of particulate matter of the study area. Various aspects of activity concentration have been investigated and discussed along with the annual effective dose.

7.1 Introduction

Radioactivity arises from natural radioactive decay, cosmogenic production, nuclear weapons testing, and nuclear accidents in the atmosphere. Some radionuclides come into the atmosphere with meteoroids because the meteorites with the Earth's atmosphere bombard the space with high energy protons for millions of years before the collision. Anthropogenic sources are nuclear explosions in the past, release during normal and accidental (Chernobyl accident) exploitation of nuclear installations, industrial, non–nuclear activities such as black or brown coal burning **[131,206]**.

The existence of radon in the atmosphere comes from rocks and natural sources of radioactivity in the soil. Radon daughters are found to be linked to airborne particulate materials **[197]**. Radon is more substantial than the air, so it will merely be in a sample cabinet or the lowest part of a room. Radon has a small life of 3.8 days, but it will be changed so that this balance will be reached in a closed sample cabinet. Contrary to radon, daughter elements are not gaseous, but there are particles in nature. They attach themselves to dust particles or other particulate matter suspended in the air **[211]**.

Radionuclides present in our environment can provide both internal and external doses. Internal dose is obtained as a result of the intake of radionuclides. For the members of the public, ingestion and inhalation are the main ways of consuming radionuclides. Ingestion involves consuming radionuclide from drinking water and milk and consuming food products. Inhalation involves consuming radionuclides through the respiration of dust particles containing radioactive material. The air's radioactivity level should be controlled because α and β particles are dangerous for humans when the emitting nuclei breathe. The total energy of α particles emitted by air of breath is the amount that is most strongly linked to possible health risks for pulmonary tissue. The radioactivity level in the air can be described in terms of the number of times α and β emissions produced per unit of time and air volume, determined by the atmospheric aerosol specimen **[212]**.

The systematic measurement of gross α and gross β activities enables us to study periodic variations, and apart from allowing the activity to detect peaks, the main weather causes affecting the level of environmental radioactivity. The present study has been conducted for two consecutive years (2016 and 2017) to determine gross α and gross β in particulate matters in the study area.

7.2 Activity concentration of gross alpha and gross beta in particulate matter

The gross α and gross β activity concentration in the area have been monitoring and analyzed twice a week for two consecutive years (2016 and 2017). The results are summarized in **Table 7.1** and provide information (minimum, maximum, average, geometric mean, standard deviation, skewness, and kurtosis values). The values of gross α and gross β activities have given in Bq m^{-3}. The gross α activity is ranging between 0.53 × 10^{-5} and 1.67 × 10^{-3} Bq m^{-3} with an average of 0.90 × 10^{-4} ± 0.31 × 10^{-4} Bq m^{-3} and the geometric mean of 0.86 × 10^{-4} Bq m^{-3} in the $PM_{2.5}$ samples collected in the area.

In the PM_{10} samples, the gross α activities were found to be 0.87 × 10^{-5} – 2.44 × 10^{-3} Bq m^{-3} with an average of 1.65 × 10^{-4} ± 0.51 × 10^{-4} Bq m^{-3} and the geometric mean of 1.56 × 10^{-4} Bq m^{-3}. In SPM samples, the gross α activities were found to be 0.93 × 10^{-5} – 3.62 × 10^{-3} Bq m^{-3} with an average of 2.36 × 10^{-4} ± 0.86 × 10^{-4} Bq m^{-3} and the geometric mean of 2.18 × 10^{-4} Bq m^{-3} **(Table 7.1)**.

Table 7.1: Descriptive analysis of gross alpha and beta activity in the airborne particulate matter of Singrauli coalfield during two consecutive areas (2016–2017)

	Gross α activity (Bq m^{-3})		
	$PM_{2.5}$	**PM_{10}**	**SPM**
No. of samples[a]	203	201	205
Min	0.53 × 10^{-5}	0.87 × 10^{-5}	0.93 × 10^{-5}
Max	1.67 × 10^{-3}	2.44 × 10^{-3}	3.62 × 10^{-3}
Average	0.90 × 10^{-4} ± 0.31 × 10^{-4}	1.65 × 10^{-4} ±0.51 × 10^{-4}	2.36 × 10^{-4} ±0.86 × 10^{-4}
Geo–mean	0.86 × 10^{-4}	1.56 × 10^{-4}	2.18 × 10^{-4}
Skewness	1.32	–0.29	–0.42
Kurtosis	0.86	–1.20	–1.06
	Gross β activity (Bq m^{-3})		
	$PM_{2.5}$	**PM_{10}**	**SPM**
No. of samples[a]	203	201	205
Min	0.86 × 10^{-5}	1.38 × 10^{-5}	1.41 × 10^{-5}
Max	2.29 × 10^{-3}	3.18 × 10^{-3}	4.07 × 10^{-3}
Average	1.42 × 10^{-4} ±0.37 × 10^{-4}	2.23 × 10^{-4} ±0.56 × 10^{-4}	2.58 × 10^{-4} ±0.83 × 10^{-4}
Geo–mean	1.37 × 10^{-4}	2.16 × 10^{-4}	2.44 × 10^{-4}
Skewness	0.45	0.05	0.12
Kurtosis	–0.21	–1.17	–1.08

[a]Number of detection samples above the limit of detection; ± Standard deviation;
Geo = Geometric; All the activities are given in Bq m^{-3}

The activity concentration of gross β in $PM_{2.5}$, PM_{10}, and SPM samples were found to be in the range of 0.86 × 10^{-5} – 2.29 × 10^{-3} Bq m^{-3}, 1.38 × 10^{-5} – 3.18 × 10^{-3} Bq m^{-3}, and 1.41 × 10^{-5} – 4.07 × 10^{-3} Bq m^{-3} with an average of 1.42 × 10^{-4} ± 0.37 × 10^{-4} Bq m^{-3}, 2.23 × 10^{-4} ± 0.56 × 10^{-4} Bq m^{-3}, and 2.58 × 10^{-4} ± 0.83 × 10^{-4} Bq m^{-3} and the geometric mean of

1.37×10^{-4}, 2.16×10^{-4} Bq m^{-3}, and 2.44×10^{-4} Bq m^{-3}, respectively in the study area **(Table 7.1)**.

The variation of gross α and gross β are similar in both years, and it may be a cyclical variability repeated every year with nominal fluctuation. The gross α and gross β and activity concentration are slightly higher in 2017 than in 2016. This condition may be related to a low amount of anthropogenic activities and meteorological conditions. The average gross beta activity concentration is higher than the respective average gross alpha activity concentration in particulate matter. The primary source of gross beta activity can be ^{210}Pb, a long–lasting descendant of gaseous ^{222}Rn. This result can be justified in isotopic radioactivity, which is naturally known as the dominant reduction of particulate matter particles of gaseous radon. However, other secondary sources of radioactivity, such as breeding soil particles or mangrove activities, should be considered. Several anthropogenic sources, such as fossil fuel burning, cement, fertilizer, and other metal production **[213]**.

The histograms of gross α and gross β show that the frequency distribution of gross α and gross β activities are shown in **Fig. 7.1**. It may be observed from **Fig. 7.1** that the daily gross α and gross β activity in $PM_{2.5}$, PM_{10}, and SPM samples have been divided into seven ranges. In the distribution of gross α in $PM_{2.5}$, PM_{10}, and SPM samples activity, a peak is observed between $10.01 \times 10^{-6} - 100 \times 10^{-6}$ Bq m^{-3}, $100.01\times 10^{-6} - 500 \times 10^{-6}$ Bq m^{-3}, and $500.01 \times 10^{-6} - 1000 \times 10^{-6}$ Bq m^{-3} at the study area.

As far as gross β in $PM_{2.5}$, PM_{10} and SPM samples activity is concerned, the peak was observed 100.01×10^{-6} to 200×10^{-6} Bq m^{-3}, 100.01×10^{-6} to 500×10^{-6} Bq m^{-3}, and 500.01×10^{-6} to 1000×10^{-6} Bq m^{-3}, interval, respectively; 62%, 67%, and 61.0% of gross β in $PM_{2.5}$, PM_{10} and SPM samples, respectively. The activity was below the observed peak values and approximately 35% of gross β in particulate matter samples. The activity concentration was above the measured peak values in the area. About 42% of gross α activity in $PM_{2.5}$ samples were below 10^{-4} Bq m^{-3}, 34% in the range of 10^{-5} to 10^{-4} Bq m^{-3}, and around 58% of gross α activity in $PM_{2.5}$ samples were exceeded the measured peak value of 10^{-4} Bq m^{-3}.

It may also be observed from **Fig. 7.1** that in the gross α activity in PM_{10} samples, the peak was observed 1.0×10^{-4} to 5.0×10^{-4} Bq m^{-3}, interval; 70% of gross α activity in PM_{10} samples were below 5.0×10^{-4} Bq m^{-3} which is the measured peak values interval, and 30% of gross α in PM_{10} samples were above–observed peak values of 5.0×10^{-4} Bq m^{-3}. As far as gross α activity in SPM is concerned, the peak was observed between 5.0×10^{-4} to 10^{-3}, interval; 64% of gross α activity in SPM were below 10^{-3} Bq m^{-3}, and 36% of gross α activity in SPM was above 10^{-3} Bq m^{-3}. However, only 2% of gross α activity in SPM has been observed above the 3.0×0^{-3} Bq m^{-3}. In accordance with other published studies **[213,214]**.

The frequency distribution plot of gross alpha and gross alpha activities in particulate matter samples reveals that particulate matter activities are shown in the skewed condition **(Fig. 7.1)**. Therefore, the results of gross alpha and gross beta activities have been compared with other reported values from the urban sources, and it has been seen that the results of the present study were well within the other reported study, and it is presented in **Table 7.2**.

Table 7.2: Comparison of gross α and gross β concentration in airborne particulate matters reported previously

Sl. No.	Country		Concentration (Bq m^{-3})		References
			Gross α	**Gross β**	
1	Oceanic Island		1.41×10^{-4}	1.00×10^{-3}	**[214]**
2	Valencia, Spain		5.30×10^{-5}	5.77×10^{-4}	**[215]**
3	Malaga, Spain		3.78×10^{-5}	5.69×10^{-4}	**[216]**
4	Ankara		2.02×10^{-3}	2.85×10^{-3}	**[217]**
5	Malaga, Spain		5.90×10^{-5}	6.08×10^{-4}	**[213]**
6	Singrauli Coalfield	$PM_{2.5}$	0.90×10^{-4}	1.42×10^{-4}	***Present Study***
		PM_{10}	1.65×10^{-4}	2.23×10^{-4}	
		SPM	2.36×10^{-4}	2.58×10^{-4}	

7.3 Monthly and seasonal variation of gross α and gross β activity concentration in particulate matter

The monthly average gross α and gross β activities in the area in ambient particulate matters ($PM_{2.5}$, PM_{10}, and SPM) samples for two consecutive years (2016–2017) were shown in **Fig. 7.2**. It may be observed from **Fig. 7.2** that the variations of the gross α and gross β activity concentrations are similar, and the gross β activity concentration is slightly higher concerning the gross α activity concentration in $PM_{2.5}$, PM_{10}, and SPM samples. It may be observed that there is a mismatch between the gross α and gross β activity concentrations in January, February, April, and December. This may be because both the effects of the environment are affecting the gross alpha and beta properties. The gross α and gross β sampling and measurement were performed twice a week, and the monthly concentrations are the average of the twice a week sample.

By keeping both of them in a similar pattern, it is difficult to understand the deviation. The remaining contribution in gross alpha and beta is probably generated from undisclosed short–lived ancestors emitted in ^{222}Rn, ^{40}K, ^{228}Ra (and its progenies) and other natural or artificial gross alpha and beta aerosol particles, but more detailed support evidence will be required, which will be presented in our further research.

The seasonal variation of gross α show that it has the maximum average values (1.67 Bq m^{-3}–$PM_{2.5}$, 2.44 Bq m^{-3}–PM_{10}, and 3.62 Bq m^{-3}–SPM) in winter, minimum average values (0.53 Bq m^{-3}–$PM_{2.5}$, 0.87 Bq m^{-3}–PM_{10}, 0.93 Bq m^{-3}–SPM) in rainfall **(Fig. 7.3)**. The main differences are between winter and rain, and summer can be analyzed because they overlap. The difference observed in the seasons can be explained mainly by atmospheric factors. Gross α and gross β activity concentrations are seen more in the winter months than in other months. Seasonal variations can be explained in terms of radioactive air levels in different weather.

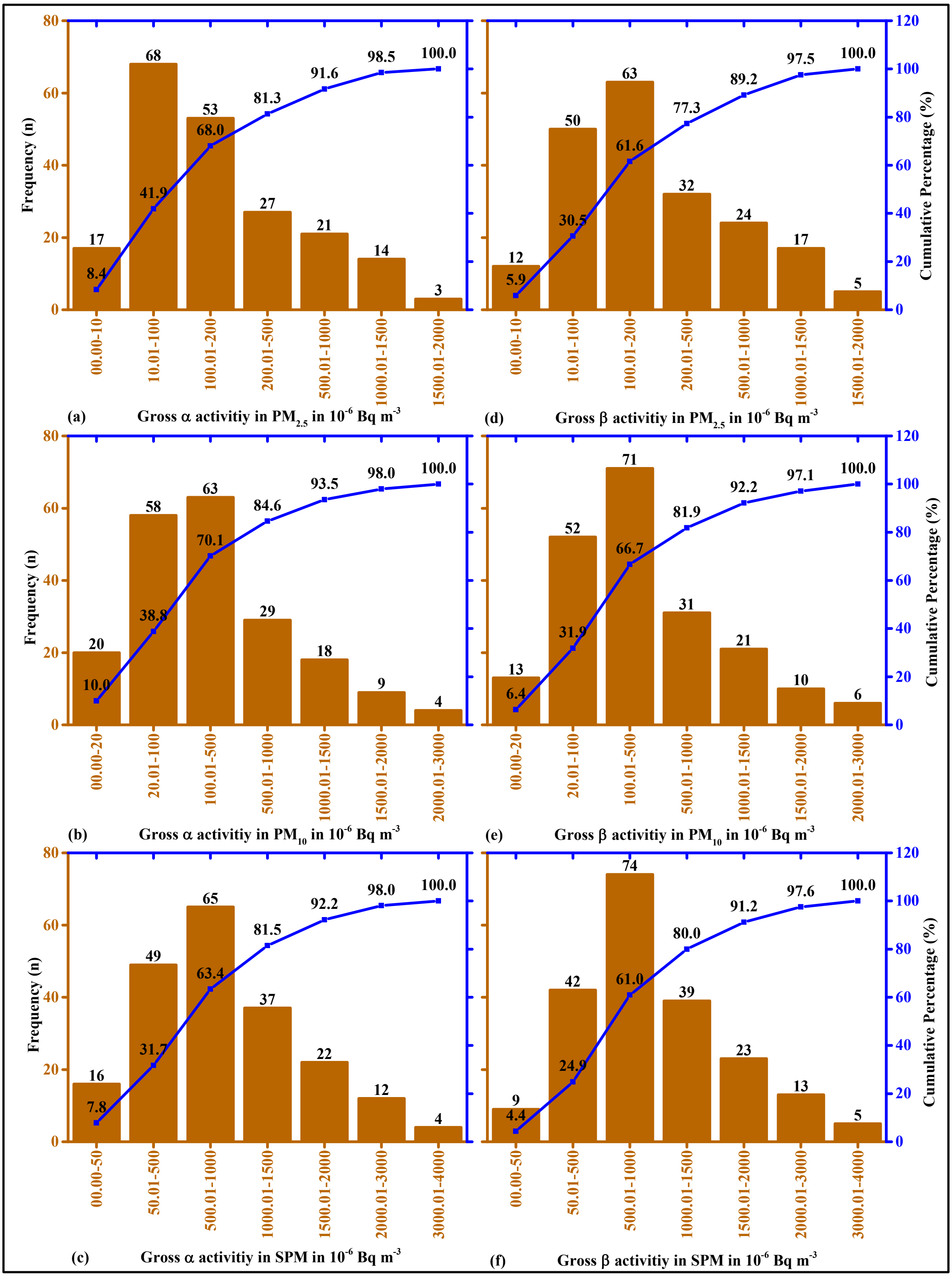

Fig. 7.1: Frequency distribution of: (a) gross α activity in $PM_{2.5}$, (b) gross α activity in PM_{10}, (c) gross α activity in SPM, (d) gross β activity in $PM_{2.5}$, (e) gross β activity in PM_{10} and (f) gross β activity in SPM for the collected during two consecutive years (2016–2017) in the area. All the activities concentration is given in 10^{-6} Bq m^{-3}

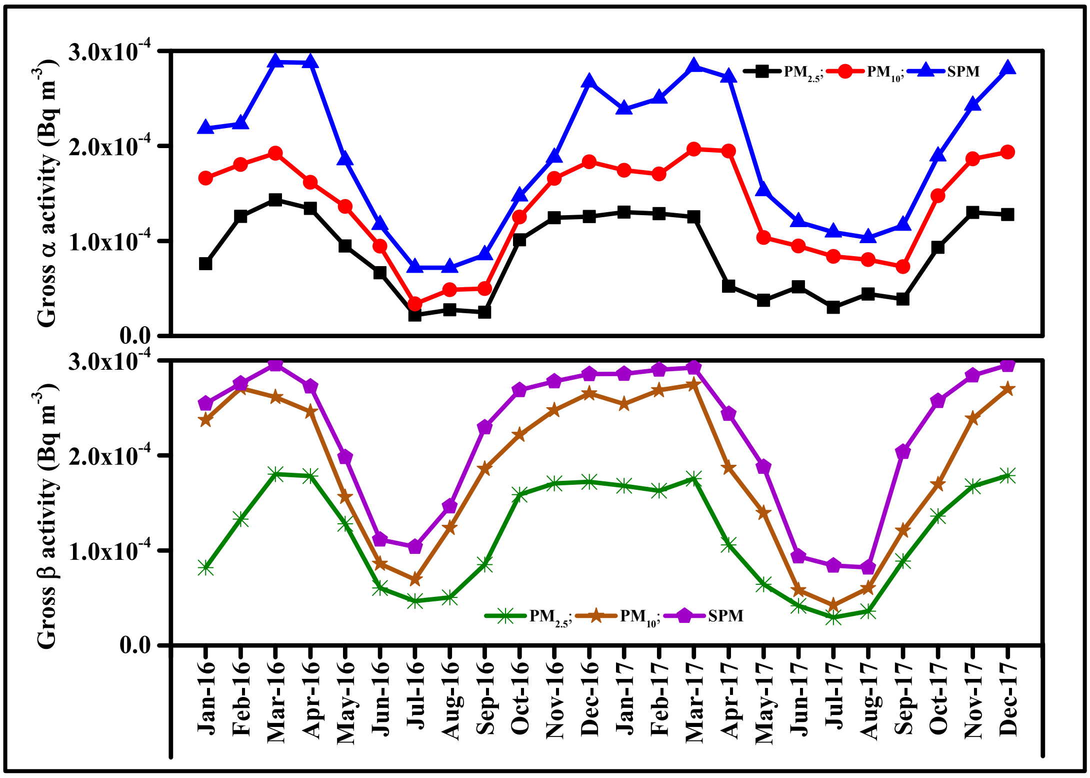

Fig. 7.2: Monthly variation of gross alpha (α) and gross beta (β) activity concentration in particulate matters

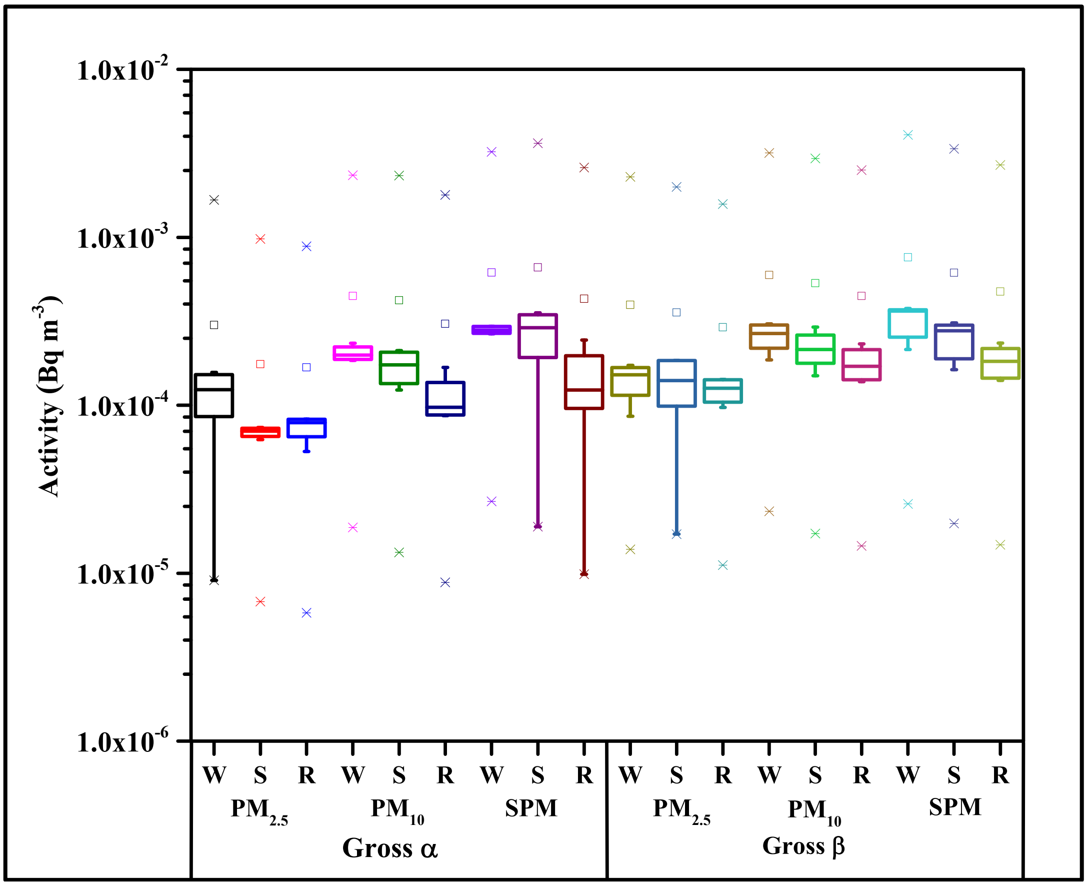

Fig. 7.3: Box–Whisker plot for the logarithm of gross alpha and beta in particulate matters in Bq m^{-3} considering the seasonal factor

It may be observed that the weather–related variables affecting gross α and gross β activities in the seasons are in the form of temperature, humidity, and direction of a wind, as well as the effect of the less often terrestrial electrostatic area. Apart from this, during the summer months, due to the increase in solar insulation, the surface gets heated and goes up and down for the active vertical movements of the mass of the particulate matter **[212]**.

Other authors have previously reported such seasonal patterns **[212,213]**. Since ^{222}Rn progeny, which has a crustal origin, has been suggested to be the primary source of gross alpha and beta activities **[212]**, the observed seasonal fluctuation may be explained in terms of particulate dust variations, i.e., particulate matter. The opposite behavior has observed by Gillen, the changes related to the wind–related activity change **[218]**.

7.4 Correlation studies among the gross α and gross β, particulate matter, and meteorological factors

Correlation among gross α and gross β, and the particulate matter, and meteorological factors considered in the study were calculated to evaluate linear relations between them. A non–parametric technique was used for analysis because there was a lack of generality in gross α and gross β activities. This is a descriptive and personalized analysis done by pairs of variables results shown in **Table 7.3**.

Table 7.3: Correlation studies among gross α, gross β, particulate matter and meteorological factors

	Gross α	*Gross β*	*$PM_{2.5}$*	*RH*	*T*	*WS*
Gross α	1.00					
Gross β	0.93	1.00				
$PM_{2.5}$	0.84	0.73	1.00			
RH	0.71	0.61	0.43	1.00		
T	0.44	0.55	0.55	0.04	1.00	
WS	–0.56	–0.59	–0.27	–0.62	–0.37	1.00
	Gross α	*Gross β*	*PM_{10}*	*RH*	*T*	*WS*
Gross α	1.00					
Gross β	0.88	1.00				
PM_{10}	0.81	0.71	1.00			
RH	0.68	0.56	0.47	1.00		
T	0.57	0.35	0.07	0.04	1.00	
WS	–0.41	–0.39	–0.43	–0.62	–0.37	1.00
	Gross α	*Gross β*	*SPM*	*RH*	*T*	*WS*
Gross α	1.00					
Gross β	0.81	1.00				
SPM	0.74	0.67	1.00			
RH	0.62	0.48	0.42	1.00		
T	0.64	0.24	–0.15	0.04	1.00	
WS	–0.37	–0.09	–0.47	–0.62	–0.37	1.00

SPM=Suspended particulate matter; RH=Relative humidity; T=Temperature; WS=Wind speed

A strong positive correlation exists between gross α and gross β activity in the airborne particulate matters ($PM_{2.5}$, PM_{10}, and SPM) of the area. The gross α and gross β activity correlation were 0.81 to 0.93 (r = 0.81–0.93). This correlation states that gross α and gross β are similar in origin, and there is no evidence to suggest that there is no anthropogenic contribution in gross α or gross β activities. Other studies follow the same correlations, between 0.72 and 0.88 **[214,215]**. Particulate matter ($PM_{2.5}$, PM_{10}, and SPM) content in µg m^{-3} also has a high linear correlation with α and β. Correlation is positive because of the greater particulate matter content, the higher the gross α, and gross β activity. However, particulate matter of different sizes is radioactive, and the correlation is above 0.6 **(Table 7.3)**. This correlation is more important for α than β.

The study area found a positive correlation between relative humidity and gross α and gross β (0.48 and 0.71) in particulate matters ($PM_{2.5}$, PM_{10}, and SPM) samples was established. The temporal variations of gross α and gross β did not indicate any favourable correlation when the concentration was too high, or there was no linear relationship with meteorological data. The annual average calculated values for gross α and gross β activities were very stable. Correlations with temperature and gross α and gross β are positive and in the range presented in other studies with values between 0.44 to 0.64, alpha correlation, and 0.24 to 0.55, for beta correlation. With the increase of temperature, radon is easily removed from the soil **[212,214]**.

Correlation of gross α and gross β activity concentration in particulate matters ($PM_{2.5}$, PM_{10}, and SPM) samples with wind speed were also studied. Results show that wind speed highly influences gross α and gross β activity but negatively, like in other cities **[214,215]**. This could be explained because wind removes aerosols from ambient air (atmosphere). There is a poor (negative) correlation between activity and wind speed.

7.5 Total annual effective dose of gross α and gross β in particulate matter

The annual effective dose equivalents were assessed for adults that breathe 6.7 m^{-3} of airs per 8h every day outside of the houses. Keeping this work in view, the total annual indicative dose was calculated for two classes of particulate matters, i.e., $PM_{2.5}$ and PM_{10} using the following approach. The annual effective dose was calculated, and annual indicative dose values are given in **Table 7.4**.

Table 7.4: Calculated total indicative doses from radionuclides for adults [μSv $annual^{-1}$ (8h every day)]

Total indicative doses from	**$PM_{2.5}$**	**PM_{10}**
^{234}U	$16.2 \times 10^{-2} \pm 5.6 \times 10^{-2}$	$25.5 \times 10^{-2} \pm 6.6 \times 10^{-2}$
^{235}U	$15.1 \times 10^{-2} \pm 5.2 \times 10^{-2}$	$23.7 \times 10^{-2} \pm 6.1 \times 10^{-2}$
^{238}U	$14.6 \times 10^{-2} \pm 5.1 \times 10^{-2}$	$22.9 \times 10^{-2} \pm 6.0 \times 10^{-2}$
^{226}Ra	$51.1 \times 10^{0} \pm 1.8 \times 10^{1}$	$80.3 \times 10^{0} \pm 2.1 \times 10^{1}$
^{232}Th	$97.6 \times 10^{0} \pm 3.4 \times 10^{1}$	$15.3 \times 10^{1} \pm 4.0 \times 10^{1}$
^{210}Po	$51.5 \times 10^{0} \pm 1.8 \times 10^{1}$	$81.0 \times 10^{0} \pm 2.1 \times 10^{1}$
^{224}Ra	$18.8 \times 10^{-2} \pm 6.5 \times 10^{-2}$	$29.5 \times 10^{-2} \pm 7.7 \times 10^{-2}$
^{137}Cs	$60.4 \times 10^{-7} \pm 2.1 \times 10^{-6}$	$94.9 \times 10^{-7} \pm 2.5 \times 10^{-6}$
^{210}Pb	$80.8 \times 10^{0} \pm 2.8 \times 10^{1}$	$12.7 \times 10^{1} \pm 3.3 \times 10^{1}$
^{210}Bi	$92.1 \times 10^{-5} \pm 3.2 \times 10^{-4}$	$14.5 \times 10^{-4} \pm 3.8 \times 10^{-4}$

The gross α and gross β activities were assumed to be from ^{234}U, ^{235}U, ^{238}U, ^{226}Ra, ^{232}Th, ^{210}Po, ^{224}Ra, ^{137}Cs, ^{210}Pb, and ^{210}Bi, respectively.

For our calculations, we used the following dose conversion factors: 7.37×10^{-7} Sv Bq^{-1} for ^{234}U, 6.85×10^{-7} Sv Bq^{-1} for ^{235}U, 6.62×10^{-7} Sv Bq^{-1} for ^{238}U, 2.32×10^{-4} Sv Bq^{-1} for ^{226}Ra, 4.43×10^{-4} Sv Bq^{-1} for ^{232}Th, $\times 10^{-4}$ Sv Bq^{-1} for ^{210}Po, 8.53×10^{-7} Sv Bq^{-1} for ^{224}Ra, 2.74×10^{-11} Sv Bq^{-1} for ^{137}Cs, 3.67×10^{-4} Sv Bq^{-1} for ^{210}Pb, and 4.18×10^{-9} Sv Bq^{-1} for ^{210}Bi **[124]**.

The minimum and maximum total annual indicative doses of particulate matter per eight hours every day throughout the two years are caused by ^{137}Cs and ^{232}Th, respectively. It may also be seen that there is no long difference between the measured particulate matters, i.e., $PM_{2.5}$ and PM_{10} **(Table 7.4)**. Therefore, these outcomes indicate that the slightly high levels for 8h every day within the two years. As far as the simplest of our knowledge, the study may be, also, valuable in the future to use atmospheric activity studies to investigate the influence of the origin of the particulate matter masses on concentrations of the gross alpha and beta levels and different radionuclides, and the total annual indicative doses from inhalation in the area.

7.6 Conclusion

In this work, analysis and behavior of gross alpha and gross alpha activity concentration in airborne particulate matter of the Singrauli coalfield of two consecutive years (2017–2017), focussing on the descriptive analysis of the data influence of the climatic factors in both indexes, was done.

This work results do not show any significant difference in gross α and gross β for two consecutive years, but there are seasonal variations. Higher gross alpha and gross beta activities were obtained in the winter season and lowest in the rainy season, followed by the summer season.

A strong positive correlation exists between gross α and gross β activity in the airborne particulate matter. The temporal variations of gross α and gross β did not indicate any favourable weather when the concentration was too high, or there was no linear relationship with meteorological data. In addition to the above, meteorology plays an essential role in the spread and transport of radioactivity.

Finally, this study's outcomes may also be useful in isotopic activity studies to investigate the influence of the origin of the particulate matter masses on concentrations of the gross alpha and beta levels and different radionuclides, and the total annual indicative doses from inhalation in the area.