Exploring temporal variation of PM$_{2.5}$ and PM$_{10}$ and their association with meteorological data in Raipur, Chhattisgarh

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Abstract: While significant efforts have been made to mitigate the negative health impacts of particulate matter, there are limited statistics on particle exposure in Raipur. A study was conducted to look at the short-term relationships between particulate matter (PM$_{2.5}$ and PM$_{10}$) and meteorological variables in Raipur. The current research was based on an experimental study conducted at Chhattisgarh's NIT Raipur. During the pre-monsoon, monsoon, post-monsoon, and winter seasons of 2021, a total of 125 air specimens were gathered from the campus. A respirable dust sampler and a fine particulate sampler were used to detect PM$_{10}$ and PM$_{2.5}$ on the building's terrace. To assess the associations between PM$_{2.5}$ and PM$_{10}$ on both dates and site, Pearson's correlation study was used. The monthly mean mass concentrations of PM$_{2.5}$ and PM$_{10}$ in Raipur ranged from 28.0-334.0 µg/m$^3$ to 56.0-448.0 µg/m$^3$, respectively. Post-monsoon PM concentrations were highest, followed by pre-monsoon, winter, and post-monsoon. On more than 92 percent of days, PM$_{2.5}$ concentrations exceeded NAAQS standards, while PM$_{10}$ concentrations exceeded restrictions on 90 percent of days. There were seasonal changes identified in the relationships between PM concentrations and meteorological variables.

Keywords: PM$_{2.5}$, PM$_{10}$, back-trajectory analysis

1. Introduction

Atmospheric aerosol has an impact on local and worldwide climate directly by absorbing and scattering arriving and departing solar radiation, ultimately by affecting cloud microphysical characteristics and semi-directly by reducing cloud covering [1]. Aerosols are the mixture of solid and/or liquid atoms in the environment, which are generated by a variety of natural and anthropogenic activities, including industrial emissions, power stations, burning of biomass, automobile emissions, forest fires, refuse burning, volcanic eruptions, and marine salt sprays, among others. In 2018, 97 percent of cities in low and middle-income nations failed to fulfill WHO air quality guiding principles (www.who.int/airpollution/data/cities/en/), indicating a serious problem [2]. In light of the aforementioned consequence, numerous researchers have investigated the particulate concentration and seasonal deviation of atmospheric aerosols in the India [3,4], specifically in central India, and concluded that PM$_{2.5-10}$ is emitted primarily due to soil particle re-suspension and PM$_{2.5}$ emits majorly from anthropogenic activities [5].
Because PM can enter the body through the respiratory tract, its size has significant toxicological and regulatory implications [6]. Epidemiological studies have shown that exposure to fine as well as coarse particulates causes a growth in lung cancer, mortality to cardiopulmonary diseases and increased respirable morbidity [6, 7]. Outdoor air pollution is responsible for 3.3 million premature deaths globally each year, with the figure expected to double by 2050 if the problem is not addressed [8]. Air pollution has been shown to have a significant influence on lung surfactant structure as well as lung injury. As a result, air pollution increases the risk of respiratory toxicities, asthma, and additional chronic ailments in humans [9].

[10] identified meteorological elements as one of the key factors inducing urban air quality. Temperature, relative humidity, and wind speed and direction are considered major parameters since they can affect the dispersion process, elimination mechanisms of particles and emergence of atmospheric particulates [11,12], thus playing a significant role in limiting the concentrations of air pollutants [12,13]. Furthermore, rainfall may have a varying influence. Several studies have found that climatic variables can have an impact on ambient pollutant levels [8, 12]. The scattering, alteration, and exclusion of air contaminants from the atmosphere are the most essential functions of meteorology in this context [14].

Understanding the relationship between climatic conditions and particle variation is critical for eradicating particulate pollution by taking necessary actions. The objective of this study is to identify the influence of meteorological variables on fine as well coarse aerosols. Back-trajectory study was executed using the Hysplit Single Particle Lagrangian Integrated Trajectory model to better analyze the transboundary migration of particulates from diverse places.

2. Methodology

i. Site description

Raipur, the state capital of Chhattisgarh, is one of central India's most important industrial and commercial centres. Raipur district is industrially developed, with room for innovative companies and up-grading of prevailing ones [1]. Raipur has a tropical wet and dry climate with mild temperatures excluding pre-monsoon, when the peak temperature might reach 39 degrees Celsius. The winter season lasts from December-January, with lowest mean temperature. The samples were collected on the terrace of NIT Raipur institution at a height of 303.36 metres above sea level, far from concentrated pollutant emissions. The study site is cautiously chosen on a rooftop with no substantial vehicle or additional pollution within a 200-meter radius.

ii. Particulate sampling

PM$_{10}$ specimens were acquired using a respirable dust sampler and PM$_{2.5}$ samples were collected using a fine particulate sampler (APM 550) (Envirotech instruments Pvt. Ltd., New Delhi, India) on 8” x 10” Whatman glass fibre tissues and a 47mm diameter PTFE tissue at the National Institute of Technology in Raipur, Chhattisgarh respectively. PM$_{2.5}$ and PM$_{10}$ samples were acquired from 1st January 2021 to 15th December 2021. The sampling location was chosen to be distant from every direct concentrated pollutants within a 200-meter radius of the instruments. Prior to and following sampling, the filter tissues were kept in desiccators for 24 hours to remove any available moisture. A balance (Precisa-92SM-202A) with 0.01mg resolution was used to weigh the dehydrated filter papers. PM$_{2.5}$ and PM$_{10}$ were calculated gravimetrically by dividing the variation between the filter paper's initial and final weights prior to and after experimenting by the sampled air volume. When moving the paper from the lab to the field, precautions were made by keeping it in covers to elude infection, and coding was done on top of it. The filter papers were collected and kept in the freezer until they were analyzed chemically in the lab. During the sampling period, meteorological elements such as temperature, wind speed, precipitation, and relative humidity were gathered using worldweatheronline.com's most recent weather forecasts.
3. Results and Discussions

i. Seasonal variation of particulates

The entire study period was divided into categories based on the many types of human activities and associated possible influence on aerosol mass concentrations and chemical compositions, as well as meteorological changes. PM$_{2.5}$ and PM$_{10}$ mass concentrations ranged from 28.0-334.0 µg/m$^3$ to 56.0-448.0 µg/m$^3$ on a daily basis (Figure. 1). The mean yearly range of PM$_{2.5}$ and PM$_{10}$ was around 135.04±79.4 µg/m$^3$ to 225.37±104.6 µg/m$^3$, which is much greater in comparison to the National Ambient Air Quality Guidelines set by the Central Pollution Control Board being three and four times higher than the USEPA's standards. The elevated particulate concentration in the Raipur area can be attributed to a cluster of industrial sectors that create significant particulates and have high pollution levels. PM$_{2.5}$ concentrations surpassed NAAQS limits on more than 92 percent of days and PM$_{10}$ surpassed limits on 90 percent of days, posing a threat to human health, animal life, the climate, and historical sites [15]. Both the PM$_{2.5}$ and PM$_{10}$ concentrations were observed to be minimum in the post monsoon season. PM$_{2.5}$ concentrations were reported to be 196.2 µg/m$^3$ during the post-monsoon season, higher than 117.5 µg/m$^3$ reported during the monsoon. PM$_{2.5}$ concentrations averaged 131.5 µg/m$^3$ during the pre-monsoon season. During the post-monsoon, pre-monsoon, and winter seasons, PM$_{2.5}$ concentrations are 1.7 times, 1.5 times, and 1.6 times greater than that reported in the monsoon season. During post-monsoon PM$_{10}$ concentrations was observed to be 325.7 µg/m$^3$ whereas in monsoon the average particulate level was 182.2 µg/m$^3$. The average concentrations of PM$_{10}$ for the pre-monsoon season were 239.7 µg/m$^3$. PM$_{10}$ concentration is 1.4 times during post-monsoon and pre-monsoon and 1.6 times during winter time concentrations than the concentration observed during monsoon.

![Figure 1: Seasonal variation of PM$_{2.5}$ and PM$_{10}$ concentrations during January 2021 to December 2021](image)

ii. Impact of meteorological criteria on particulate variation

Figure. 2 shows the variation in the daily concentration of PM$_{10}$ at the sampling site with changes in the meteorological environment including temperature, wind speed, relative humidity and precipitation. Considerable seasonal changes have been observed in earlier studies also [16, 17, 18]. Seasonal PM$_{2.5}$ and PM$_{10}$ correlation shows significant relationship among them in all the seasons. The gravimetric concentration level of PM$_{2.5}$ and PM$_{10}$ changed in a similar way throughout time. During the study period, four and three different peaks in daily PM$_{2.5}$ and PM$_{10}$ levels were identified. The average wind
speed during monsoon and pre-monsoon is lower (15 km/h and 12 km/h) resulting in lower average PM$_{2.5}$ and PM$_{10}$ concentrations (117.5 and 131.5 µg/m$^3$). The average wind speed observed during monsoon is 15 km/h, which is the highest of the year, with precipitation significantly lowering particulate levels in the city via a wet removal mechanism. After the post-monsoon period in October, when biomass/wood burning/combustion activities begin in the city as the temperature lowers, PM$_{10}$ concentrations begin to rise, peaking in November and December.

Seasonal differences in climatic circumstances, as well as varying potential particulate sources, are the main causes of this discrepancy [19]. Maximum PM$_{10}$ concentrations during the post-monsoon period may come from combustion combined with favourable meteorological circumstances that result in a lower boundary layer height, slower diffusion due to which pollutants remain in the atmosphere for extended periods of time. During monsoon, days during higher rainfall exhibited lowest particulate concentrations.
All the peak values of PM$_{2.5}$ and PM$_{10}$ were observed in January month. Through winter and post-monsoon, the wind speed (8 km/h) was lowest when the particulate concentrations were observed to be highest. Diwali is one of India's most significant religious festivals, and it is observed for several days in October and November each year across the country, with illuminations and the lighting of firecrackers. High levels of respirable PM are caused by firework show emissions and Diwali festivities are associated through the greatest levels [20]. Also, during the months of October through January, when temperatures and wind speeds are lower, higher PM$_{2.5}$ and PM$_{10}$ concentrations are seen [21]. During the monsoon season, heavy rain washes away pollutants, lowering particle concentrations in the area [22]. Temperature inversions occur during the summer, resulting in pollutant accumulation. Temperature, wind speed, precipitation, and relative humidity all play a role in PM$_{10}$ fluctuations.

![Figure 2](image_url)  
**Figure:** 2 PM$_{2.5}$ and PM$_{10}$ variation with meteorological factors during (a) Pre-monsoon (b) Monsoon (c) Post-monsoon (d) Winter

Table 1 shows the findings of a Pearson correlation analysis of PM$_{2.5}$ and PM$_{10}$ with other environmental variables such as meteorological parameters. PM$_{2.5}$ and PM$_{10}$ shows a significant correlation. PM$_{2.5}$ concentrations were shown to have no correlation (0.04 and 0.01) with ambient temperature and wind speed for the yearly values. However, lower wind speeds showed a negative relationship with coarse particle concentrations (-0.32), indicating extended standstill periods at lower wind speeds [19]. Relative humidity exhibited negative correlation with both fine and coarse aerosols as humidity...
suppress the particulates minimizing their concentrations during monsoon. The temperature ranged from 6 to 41 degrees Celsius, with a relative humidity of 8 to 96 percent. The wind rose diagrams plotted throughout different seasons of the study period are shown in Figure 3. Throughout the three seasons, the overall wind speed fluctuated between 4 and 26 km/h. During post-monsoon and winter seasons, the wind blew from the northeast, in pre-monsoon the wind blows from southwest whereas in the monsoon, it blew from the southeast.

**Table 1:** Pearson correlation analysis of PM$_{2.5}$ and PM$_{10}$ with meteorological factors during 2021

|        | PM$_{2.5}$ | PM$_{10}$ | Temp | WS  | RH  |
|--------|------------|-----------|------|-----|-----|
| PM$_{2.5}$ | 1          |           |      |     |     |
| PM$_{10}$ | 0.88       | 1         |      |     |     |
| Temp    | 0.04       | 0.18      | 1    |     |     |
| WS      | 0.01       | -0.03     | 0.14 | 1   |     |
| RH      | -0.16      | -0.32     | -0.69| 0.13| 1   |

**Figure 3:** Wind rose diagrams plotted during (a) pre-monsoon (b) monsoon (c) post-monsoon and (d) winter seasons
iii. PM$_{2.5}$-PM$_{10}$ relation

The relationship between PM$_{10}$ and PM$_{2.5}$ concentrations was studied using coincident daily averages. For the studied year, PM$_{2.5}$ concentrations follow the same pattern as PM$_{10}$, however their means are clearly lower. Figure 4 displays a concentration scatterplot of PM$_{10}$ vs. PM$_{2.5}$ concentrations measured in Raipur in 2021. The concentrations of PM$_{10}$ and PM$_{2.5}$ are highly linked ($r = 0.76$). The PM ratio (PM = PM$_{2.5}$ / PM$_{10}$) was calculated and found to be 0.65, indicating that fine aerosols are present in significant quantities at our site.

Figure 4: Scatter plot of PM$_{10}$ vs. PM$_{2.5}$ concentrations measured at Raipur

iv. Back-trajectory analysis

Figure 5: Back-trajectory plots using HYSPLIT NOAA
Stable air masses at the lower boundary level denoted local sources, whereas air masses at the upper boundary level with strong wind speeds denoted air masses from beyond. As illustrated in Figure 5, back-trajectories were computed at (21°15'00" N and 81°37'48"E) in the study region Raipur during periods of greatest concentration. Backward trajectories were computed for 120 hours at 500m, 1000m, and 1500m above ground level. During phases of maximum concentration detected in the winter season, the local sources were associated with NE winds with air masses at lower levels. According to the trajectory study, higher amounts of pollutants develop at lower levels, which could be attributed to anthropogenic activities during festivals. The highest PM$_{2.5}$ and PM$_{10}$ concentration was reported on May 10th (448 µg/m$^3$ and 304 µg/m$^3$) during pre-monsoon period when the wind route was observed from west. In winter, highest PM$_{2.5}$ concentrations were noticed on December 1st and highest PM$_{10}$ concentrations were observed on December 15th 2021 when the wind direction was observed from east. This suggests that, despite the greater wind speeds, the pollutant concentration was substantially higher, indicating the presence of powerful polluting sources, which could be local wood/coal burning sources used for heating and cooking during the winter.

4. Conclusion

Based on daily PM levels reported at the sampling station and concurrent estimation of surface meteorological factors, this paper examined the temporal variation of PM$_{2.5}$ and PM$_{10}$ values in Raipur from January 2021 to December 2021, along with their interactions with different meteorological factors. From January to December 2021, the monthly mean mass concentrations of PM$_{2.5}$ and PM$_{10}$ in Raipur ranged from 28.0-334.0 µg/m$^3$ to 56.0-448.0 µg/m$^3$, respectively. Post-monsoon PM concentrations were highest, followed by pre-monsoon, winter, and post-monsoon. Due to the inoculation of coarse particulates into the environment from earth crust in the area by heavy winds, PM$_{10}$ levels were at their extreme in the zone in pre-monsoon. PM$_{2.5}$ concentrations were higher in the pre-monsoon season although the wind speed was higher as the region is surrounded by industrial areas. PM$_{2.5}$ showed no significant correlation with temperature (0.5) and wind speed (0.01) whereas PM$_{10}$ showed no relation with temperature (0.04) and was negatively associated with wind speed (-0.03). Relative humidity was negatively associated with both PM$_{2.5}$ (-0.16) and PM$_{10}$ (-0.32) indicating that moisture helps in the wet removal of both coarse and fine aerosols. The back-trajectory analysis depicts the local polluting sources throughout higher concentrations both during the pre-monsoon and post-monsoon season indicating the presence of regional polluting sources in the area. PM$_{2.5}$/PM$_{10}$ ratio concluded the presence of significant fine aerosols at the location. Overall, the PM$_{2.5}$ concentrations surpassed NAAQS limits on more than 92 percent of days and PM$_{10}$ surpassed limits on 90 percent of days, posing a threat to human health. Seasonal differences in the correlations among PM concentrations and meteorological factors were discovered. The impacts of radiation, planetary boundary layer height, air temperature, relative humidity and wind speed must all be considered while studying PM pollution.

5. References

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