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Unveiling the Relationship betweenBenzo[A] Pyrene, Particulate Matter, and Atmospheric Conditions in PanvelTaluka: An Analytical Study

Namrata Kislay[1], Dr. Geeta Malbhage[2*], Dr. Rahul Kumar[3], Dr. Nilesh D. Wagh[4], Harshala V. Kasalkar[5]

[1]Research Scholar, Amity School of Applied Sciences, Amity University, Maharashtra-410206, India.
[2*]Assistant Professor, Amity School of Applied Sciences, Amity University, Maharashtra, -410206, India.
[3]Associate Professor, SK Somaiya College, SomaiyaVidyavihar University, Maharashtra-400077, India.

Corresponding Email: [2*]gkmalbhage@mum.amity.edu

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ABSTRACT:

This study was conducted in the PanvelTaluka of Raigad district, Maharashtra, to investigate the presence of Benzo[a]pyrene (B[a]P) within Particulate Matter (PM) and its sources. B[a]P is known for its widespread environmental distribution and persistence, posing risks to human health. The research focused on assessing B[a]P concentrations associated with PM emissions in diverse settings such as industrial zones, roadsides, residential areas, and agricultural lands. Sampling was conducted in 2022, both before and after the monsoon seasons, revealing higher average B[a]P concentrations during the pre-monsoon period compared to the post-monsoon period. Specifically, average B[a]P concentrations ranged from 22.88 ng/m^3 to 94.55 ng/m^3 pre-monsoon, and from 18.57 ng/m^3 to 54.58 ng/m^3 post-monsoon. Significant correlations (r=0.7-0.9) were observed between B[a]P levels and PM10 & PM2.5. The study found varying levels of B[a]P among different sampling sites, with concentrations generally highest in industrial areas, followed by roadsides, residential areas, and agricultural regions. Literature reviewed indicated that atmospheric conditions played a crucial role in the deposition of B[a]P. Additionally, backward trajectory analysis demonstrated long-distance transport of B[a]P to the study area, contributing to higher concentrations alongside local emissions.

Keywords: NamrataKislay, Particulate Matter, Atmospheric deposition, Air pollution, Environmental health, Maharashtra

1. Introduction

India, a rapidly developing nation with a population of 1.21 billion plus people (http://censusindia.gov.in/), is experiencing rapid growth due to the implementation of economic reforms. Owing to its vast population, a country like India needs more sources of energy. However, the use of inefficient biofuels in rural areas and poorly maintained automobiles contribute to environmental pollution issues that significantly impact people's health.

This has emerged as a significant issue for researchers because of the rise in urbanization and industrial growth. Out of all pollutants, cancer-causing agents have received the most focus, mainly because of their impact on human health. Polycyclic Aromatic Hydrocarbons (PAHs) are a major group of pollutants that have carcinogenic, teratogenic, and mutagenic characteristics. Many pollutants are categorized as Class-1 carcinogens by the International Agency for Research on Cancer, with other pollutants being deemed probable or potential carcinogens (IARC, 1984). Out of the 16 PAHs, Benzo[a]pyrene (B[a]P), as identified by the Central Pollution Control Board (CPCB), is recognized for its carcinogenic effects in humans.

PAHs are classified into two main groups: Low Molecular Weight (LMW) and High Molecular Weight (HMW) compounds, released through natural and human sources. Forest fires and volcanic eruptions are viewed as natural sources of emissions, in contrast to human-made sources like vehicle emissions, biomass burning, coal and petroleum combustion, and metal production (Kaushik andHaritash, 2006; Zhang and Tao, 2008). They are also released during industrial processes, particularly in energy production where incomplete combustion leads to the release of unburnt carbonaceous material (Xu et al., 2006).

LMW PAHs persist mostly in vapor form, whereas HMW PAHs are primarily associated with fine airborne particles. PAHs attach themselves to airborne particles and undergo dry deposition depending on meteorological conditions (Esen et al., 2010). Nearly 95% of all PAHs are less than 3 µm in size, falling within the aerodynamic diameter limit, which enhances their transportability over long distances (Venkataraman et al., 1994). Due to PAHs' ability for long-distance atmospheric transport and environmental persistence, they are widely distributed worldwide. PAHs can travel considerable distances before being deposited in water, soil, and vegetation under favorable meteorological conditions (Friedman et al., 2013).

B[a] P concentrations in the Mumbai atmosphere

While research on ambient PAHs started in the 1960s in various European countries, most of these studies in India began in the early 1980s (Liu et al., 2015). However, relatively few research works have documented the characterization of particulate-bound PAHs in India. Most studies on B[a] P concentrations in India were conducted in and around Delhi; however, other places, particularly Mumbai, have produced relatively little evidence. Mohan Rao et al. examined B[a] P concentrations at three sampling locations in Mumbai (Matunga, Deonar, and Alibag), corresponding to urban, suburban, and rural areas of the city (Mohan Rao et al., 1982). According to their findings, seven PAH compounds were found to be higher at two sites in Mumbai, IIT and Saki Naka, with observed values ranging from 24.5 ng/m³ to 38.8 ng/m³ (Kulkarni and Venkataraman, 2000).

Previous research has been conducted on the distribution of PAHs in cigarette smoke and the potential dangers of inhaling them (Tiwari et al., 2017). Their research involved utilizing the single-box method for modeling PAHs linked to aerosol burning in indoor settings and the risks associated with inhaling PAHs generated by household fuels (Tiwari et al., 2015, 2016). In 2019, research was conducted on PM2.5 and related PAHs in two distinct locations: Mumbai Central, an urban region, and Kalyan, a suburban region. Dhananjayan et al. (2012) investigated PAH levels in sediment and water samples taken from the Mumbai harbor-line and found concentrations ranging from 8.66 ng/l to 46.74 ng/l.

PanvelTaluka is a suitable research region due to its rapid industrial and residential development, alongside the ongoing construction of an international airport nearby. The research objective is to monitor and interpret the results of particulate matter (PM10 and PM2.5) and B[a] P concentrations at various sampling locations. Therefore, the findings of this study will be used:

1. To evaluate and forecast B[a]P and particulate matter concentration levels using air samples taken from PanvelTaluka's industrial, residential, roadside, and agricultural areas,
2. To identify the causes of seasonal variations in B[a]P and particulate matter concentrations, their probable emission sources, and their effects, and
3. To establish correlations between particulate matter, B[a] P, and different meteorological attributes.

2. Material and Methods

2.1 Study area

Agricultural areas of PanvelTaluka in the Raigad district of Maharashtra, India. According to the Census of India (2011), the population was around 5.09 lakh, with a population density of 4636 people/km². Entities such as the Panvel Municipal Council, City and Industrial Development Corporation (CIDCO), Maharashtra Industrial Development Corporation (MIDC), Mumbai Metropolitan Region Development Authority (MMRDA), Raigad District Panchayat, and gram panchayats are included in this area. Panvel is encircled on the north by Dombivali& Thane, on the south by Uran and JNPT port, on the east by the Sahyadri Ranges offshoots, and on the west by Navi Mumbai (Maharashtra). The functional economy of the city has markedly changed from agricultural to industrial and business sectors, establishing a strong economic base for the research area, thereby boosting population growth. Alongside industrial development, structural changes are a driving force behind migration in the city, significantly impacting land use and land cover. The study sites include Taloja, Ulwe, Panvel, and Bhatan. Table 1 shows the location matrix and their respective coordinates. Figure 1 shows the sample collection sites.

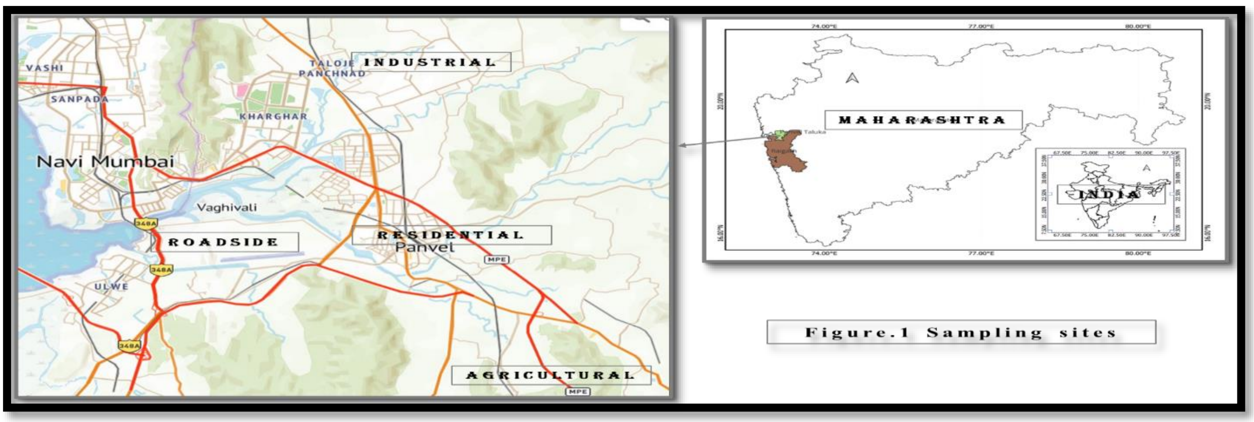

Figure.1 Sample collection sities

Table 1.Area coordinates and Location

S.No.	Area	Latitude	Longitude	Location
1	Bhatan	18.931531	73.163786	Agricultural
2	Taloja	19.058539	73.112742	Industrial
3	Ulwe	18.982386	73.078349	Roadside
4	Panvel	18.99340	73.116775	Residential

Sampling took place during the pre-monsoon period (March, April, and May) and post-monsoon period (October, November, and December). The pre-monsoon period has high temperatures and a high rate of evaporation, resulting in the production of moisture-laden clouds over the Arabian Sea. October saw the highest relative humidity and the lowest temperature throughout the sampling period. The highest wind speed was recorded in November. The meteorological parameters shown in Table 2 were obtained from the Power Data Access Viewer, NASA.

Table2. Meteorological parameters of the study area

Month(s)	Temperature(°C) Mean± SD	Relative Humidity(%) Mean± SD	Wind-speed(m/s) Mean± SD	Precipitation (mm)
March,2022	39.37±1.58	41.68±8.78	4.33±1.15	0.2
April,2022	40.40±1.67	50.68±6.84	3.49±0.65	0.127
May,2022	37.4±1.40	61.80±2.61	4.95±1.01	0.26
October, 2022	29.80±1.02	82.64±7.77	4.51±1.18	6.08
November, 2022	30.00±1.12	72.31±3.72	5.34±1.02	0.02
December, 2022	30.14±1.14	71.31±7.07	4.44±0.89	0.41

Meteorology, along with gaseous pollutants, has a significant impact on the fluctuation of particulate matter concentration. Research has indicated that various elements such as temperature, humidity, wind speed, and precipitation can impact the levels of particulate matter in the air (Singh et al., 2022). Furthermore, Saha et al. (2019) mentioned that pollutants are dispersed and diluted by stronger winds, which move them away from the source area. Safiur Rahman et al. (2019) and Afrin et al. (2021) have conducted research that demonstrates the close relationship between ambient air quality and atmospheric attributes. In fact, it is possible to utilize air quality to anticipate PM concentration, even with minor changes in emissions.The along-shore region weather is also impacted by variations in season and sea-land breezes. Sea breezes have a significant impact on boundary layer stability and wind structure in coastal regions (Tsai et al., 2011). Depicting the relationships among various attributes and PM is not an easy task in this area.

2.2 Sample equipment,sample size, and collection frequency

In the current study, B[a] P and PM were sampled during the pre-monsoon (March, April, and May) and post-monsoon (October, November, and December) seasons of 2022. Sample collection before and after the monsoon aids in a more accurate assessment of the impact of particulate matter and B[a] P levels. Furthermore, it facilitates a more thorough comprehension of the dynamics of B[a] P in the environment by offering perspectives on the intricate relationships among climatic factors, emission sources, and pollutant concentrations.

At the selected study sites, a high-volume air sampler was used to monitor ambient air. Glass fiber filter sheets were used for the collection of PM10 and B[a]P samples. These sheets efficiently trap and hold particles, preventing their escape through the filter and into the surrounding area during sampling. They have high collection efficiency for tiny particles, which are particularly concerning for human health as they can be deeply inhaled into the pulmonary system.
For PM2.5, Teflon filter paper was used with fine particulate samplers. Teflon filters capture PM with a diameter of not more than 2.5 micrometers effectively, without reacting with the particles due to their chemical inertness. This property is essential for precise measurements of PM2.5 composition. Samples were collected once every 15 days for eight hours each time. Every sampling event adhered to regulations set forth by the Central Pollution Control Board (CPCB) (https://cpcb.nic.in/).

2.3 Sample extraction and analysis
Using a 250 ml conical flask, one-fourth of the filter paper was cut into tiny sections, and 100 ml of toluene solution was added to extract B[a]P. Following securely sealing the flask with a stopper, the samples were immersed in an ultrasonic bath for a period of 30 minutes. Following the ultrasonic extraction procedure, the filtered the extracts with Whatman filter paper. The toluene extractions were concentrated with a rotary evaporator. The extracts were then subjected to a cleanup procedure involving loading onto a 200 mm column packed with slurry of silica gel (60–100 mesh size). Cyclohexane was used to elute the toluene through the column. Subsequently, 5 ml of cyclohexane was used to collect the sample extract.

The ambient air's B[a] P concentration was measured using a standard solution from Supelco (Bellefonte, USA), containing 1000 µg/mL of B[a] P in acetone. Acetone and methylene dichloride, both analytical grade solvents, were used in the sample preparation and analysis. Deionized water from the Milli-Q system was utilized to prevent any impurities and facilitate accurate measurements that uphold the integrity and dependability of the findings. Gas Chromatography-Mass Spectrometry (GC-MS) was used to analyze B[a] P, utilizing an Agilent 7890B/7000C system with a DB-5MS capillary column (15 m length, 0.25 µm film thickness, 250 µm inner diameter).

Injector	**320°C**
FID Temperature	320°C
Oven	140°C →3 min hold→ Ramp A- 6°C/min→250°C→6 min hold Ramp B- 10°C/min→300°C→5 min hold
Run-time	36mins
H_2 - Gases for FID	30 ml/min, Air flow- 300ml/min
N_2 - Carrier gas flow	30 ml/min
Sample Injected	2 µL

2.4 Quality control
The Quality Assurance and Control (QA/QC) technique for the study analysis was adapted from earlier research that had been published (Cao et al., 2011; Ho et al., 2011). To check for background contamination, field blank samples (unexposed filters) were utilized for quality assurance and control. Method blank and sample blank solvents were examined. There was no B[a] P found in any of the QA/QC samples.

2.5 Data Analysis

The Pearson correlation coefficient was utilized to ascertain the following correlations:

1. Between particulate matters (PM10 & PM2.5) and B[a]P
2. Between particulate matters (PM10 & PM2.5)
3. Between particulate matters (PM10) and meteorological conditions.

Any statistically significant correlation between B[a] P and PM concentration was evaluated and found using Pearson correlation. This analysis was performed using JASP 0.18.3, an open-source statistical software.

A wind direction trajectory analysis lasting 5 days was carried out with the NOAA HYSPLIT4 model, created by Draxler and Rolph in 2003. Furthermore, NASA's Fire Information and Resource Management System detected current fire locations(https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/). QGIS was used for spatial interpolation.

3. Results and Discussion

3.1 Seasonal Variations in PM Concentrations and B[a] P

This study observed distinct patterns of PM and B[a] P concentrations throughout the year (Figure 2a and 2b). In the pre-monsoon season, B[a] P levels were typically higher, ranging from 22.88 to 95.55 ng/m³, while in the post-monsoon season, levels were lower, ranging from 18.57 to 54.58 ng/m³. It is clear that the PM concentration was higher in the pre-monsoon season than in the post-monsoon season. The pre-monsoon average concentrations for PM10 and PM2.5 are in the range of 75.23–52.85 µg/m³ and 39.15–29 µg/m³, respectively. However, the post-monsoon average concentrations for PM10 and PM2.5 are in the range of 66.87–50.47 µg/m³ and 36.5–25.18 µg/m³, respectively. The recorded levels exceed the annual means of 40 µg/m³ for PM2.5 and 60 µg/m³ for PM10 as established by the National Ambient Air Quality Standards (NAAQS).

In the pre-monsoon season, the concentrations of PM and B[a] P were higher, indicating that high emissions and low precipitation during the pre-monsoon season result in high aerosol loads. Nevertheless, steady atmospheric conditions and reduced pollution dispersion result in conditions that encourage the buildup of air pollutants and atmospheric boundary layer heights (Ram and Sarin, 2015).

During the post-monsoon season, there is burning of wood and crop residues in northern India (Ram and Sarin, 2015). Pollutants released during burning may be transported upwind over considerable distances from their source regions, which would increase the concentration of particulate matter. The next section uses satellite data, fire locations, and air-mass back trajectories to further explain and verify this. Even though the concentrations are diluted by the monsoon's heavy precipitation, which washes away pollutants released into the atmosphere.

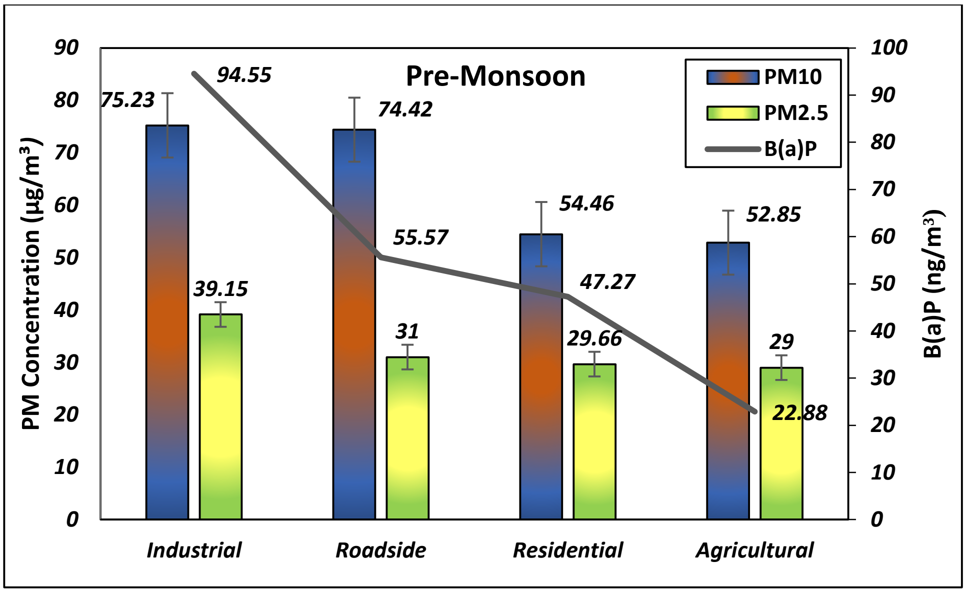

Figure 2(a).B[a] P and PM concentrations in the pre-monsoon

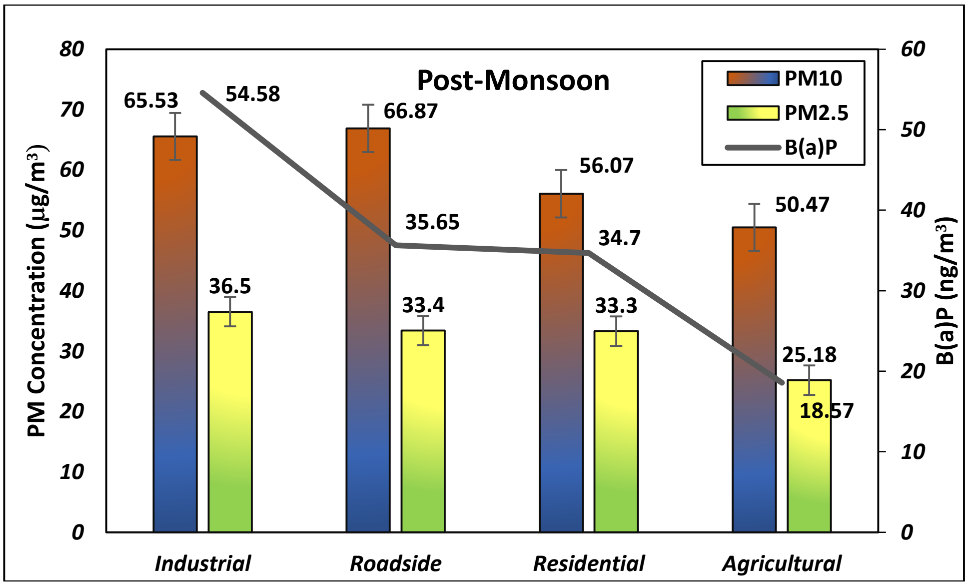

Figure 2(b).B[a] P and PM concentrations in the post-monsoon

The concentration pattern for B[a]P and PMs tracks the same trend for both pre- and post-monsoon seasons: Industrial > Roadside > Residential > Agricultural. Several factors contribute to the variations in particulate matter and B (a) P concentrations at each site during the two seasons. The primary source of emissions in agricultural areas is the burning of biomass. Vehicular transport along the Mumbai-Pune highway near Panvel is another significant contributor to pollution. Panvel, a highly populated city in Maharashtra, characterizes the Residential area. The Roadside site in Ulwe will soon house the Navi Mumbai International Airport (Status report for Environment, 2020–21). This area is currently expanding with numerous buildings under development. The once-productive and diverse ecosystems of wetlands and mangrove forests, spanning thousands of hectares, have been destroyed due to airport construction activities. Over the past decade, significant urbanization has occurred here due to development initiatives like the New Mumbai International Airport and the Multi-Corridor Project. ONGC, Reliance, L&T, and other major industries are involved in various ongoing reconstruction projects. Lastly, the Industrial area serves as the base for businesses and corporates engaged in extensive commercial activities, spanning food processing, dyes, heavy engineering, chemicals, and steel, among others. Figure 3 displays the spatial distribution map of B (a) P for the year 2022. The concentration gradient ranges from blue to red indicating increasing levels: Industrial (Taloja, T) > Roadside (Ulwe, U) > Residential (Panvel, P) > Agricultural (Bhatan, B).

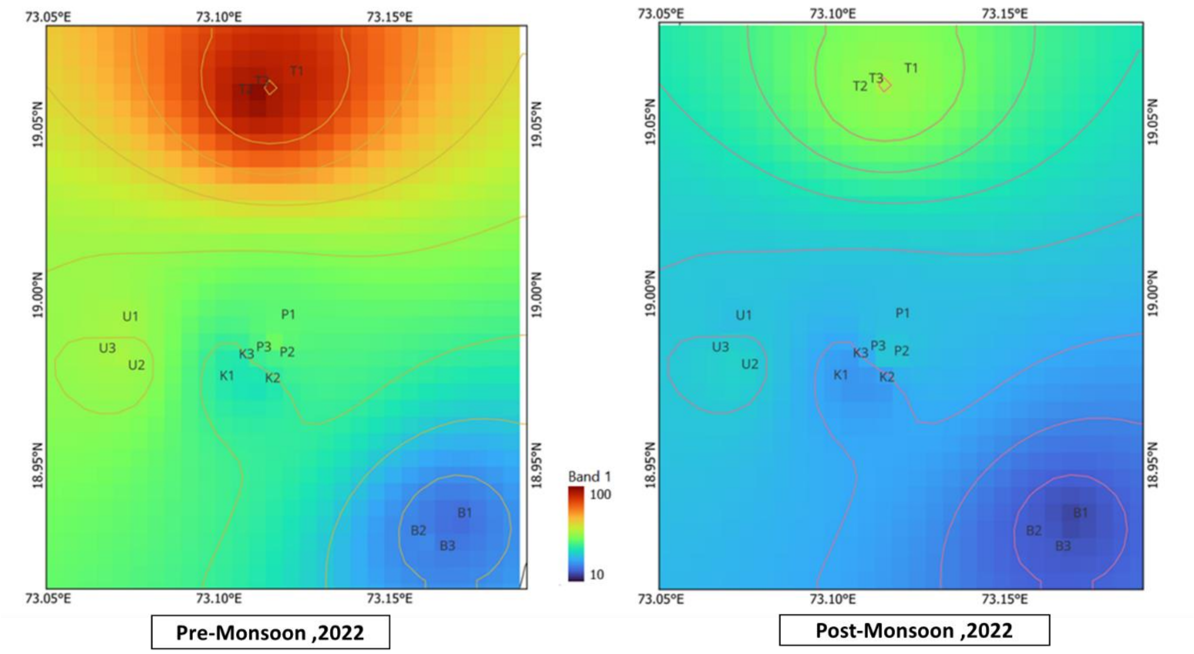

Figure 3. Map for spatial distribution across pre-monsoon and post-monsoon

3.2 Backward trajectory, fire spots and possible transport pathways

The movement of air masses from different areas is a factor that adds to PM levels in different locations. Local activities and weather patterns also play a role in this influence (Yadav et al., 2017). During both the pre- and post-monsoon seasons of 2022, a 5-day isentropic backward trajectory was computed using the NOAA HYSPLIT4 model created by the Air Resources Laboratory of NOAA. It took 120 hours for this model to operate at an altitude of 500 meters. The HYSPLIT model was combined with the GDAS1 meteorological database from Figure 4 for analysis. In addition to the reverse path, NASA MODIS was utilized to produce an active fire map during two distinct periods. These maps were leveraged to understand the possible sources, atmospheric conditions, and pathways of pollutant transport during the sampling seasons. Due to its proximity to all other sampling sites, the study was conducted at the control point, which is the rural and agricultural site.

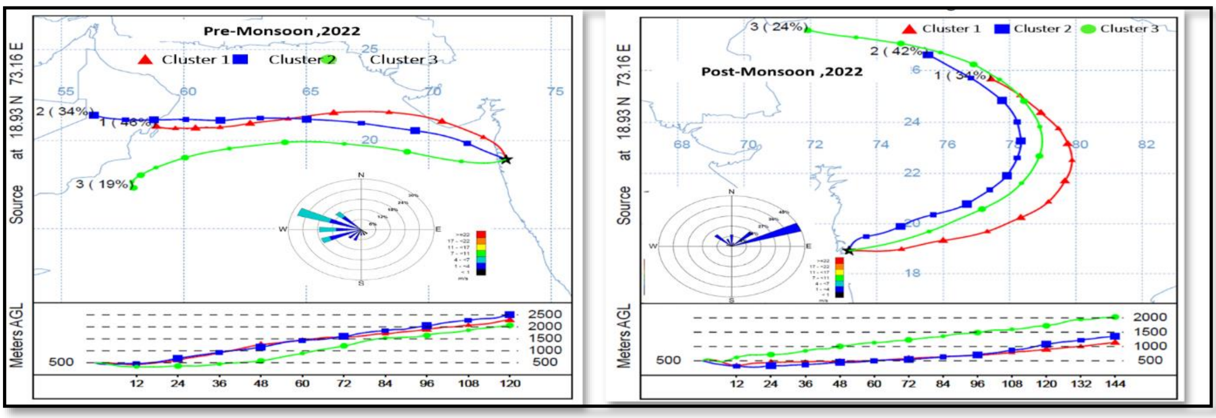

Figure4. Backward trajectories at PanvelTaluka for the pre-monsoon and post-monsoon

The back-trajectory analysis reflects that, depending on the season, the air mass originates from various sources. During the pre-monsoon period, the majority of the air mass comes from the Arabian Sea, with a fraction also originating from land areas. These land areas primarily include arid regions in the states of Gujarat and Rajasthan, abundant in dust and sand particles. It is also evident that the sources for post-monsoon season trajectories are primarily land areas. The majority of land areas that play a role in moving air masses are located in inland cities in Maharashtra state, as well as in parts of central India such as Rajasthan and Madhya Pradesh. This air mass is made up of naturally occurring aerosols as well as pollutants from industry and vehicles (Guttikunda et al., 2014). Increased concentration occurs in PanvelTaluka during the post-monsoon period due to shifts in trajectories, in comparison to the pre-monsoon period. Barudgar et al. (2022) conducted a study at the coastal station of Mumbai in a similar manner. Additionally, significant fire spots were identified on the sampling site in both seasons. It is also noted that backward trajectories can ascend to a maximum height of about 3,000 meters, meaning they are limited to the lower troposphere.
The active fire sites in the sampling seasons are represented by red dots, as shown in Figure 5, collected from FIRMS (https://firms.modaps.eosdis.nasa.gov/).

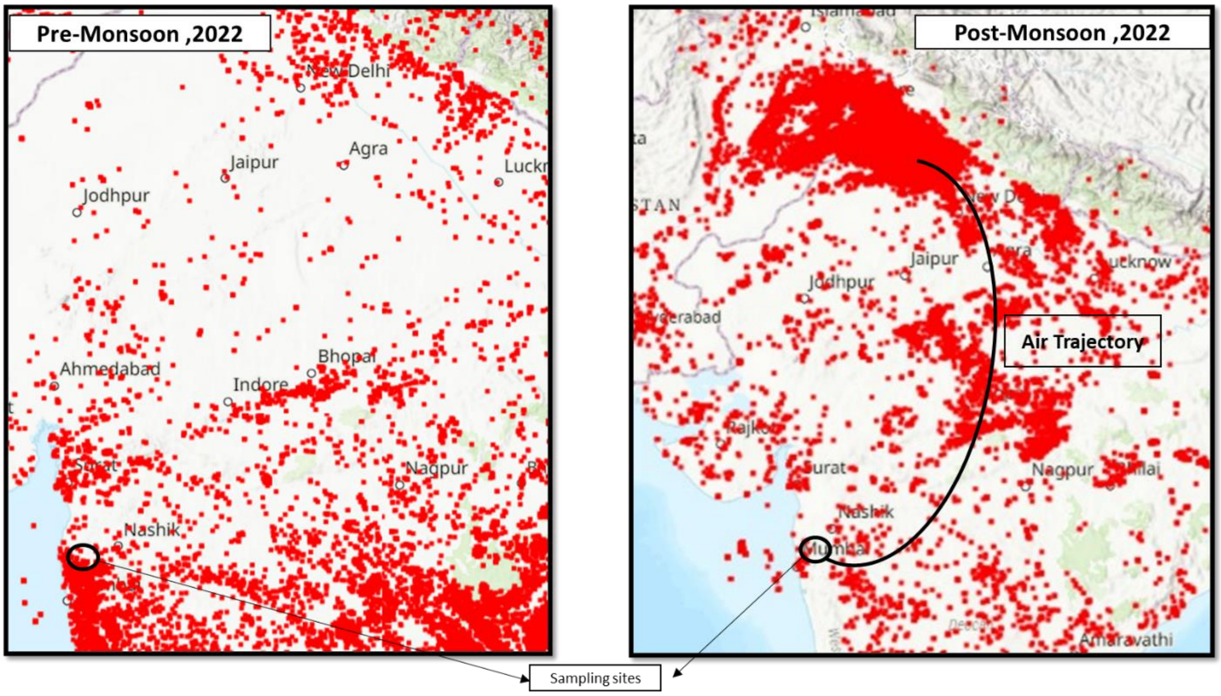

Figure 5. The active fireplaces are indicated by red-dots

3.3 Correlation of $PM_{2.5}$ and PM_{10} and B[a] P

During the Pre-monsoon season, B[a] P was utilized to evaluate air quality for PM2.5 and PM10. Figure 6 displays the Pearson's correlation coefficients computed among B[a] P, PM2.5, and PM10. B[a] P exhibited strong positive relationships with PM10 ($r = 0.80$) and PM2.5 ($r = 0.84$). Meanwhile, PM10 demonstrated a highly robust positive correlation with PM2.5 ($r = 0.90$; $P < 0.05$). For the Post-monsoon season, Pearson's correlation coefficients among B[a] P, PM2.5, and PM10 are also shown in Figure 6. B[a] P showed a correlation coefficient of ($r = 0.77$) with both PM10 and PM2.5. Similarly, PM10 exhibited a very strong positive relationship with PM2.5 ($r = 0.93$; $P < 0.05$).

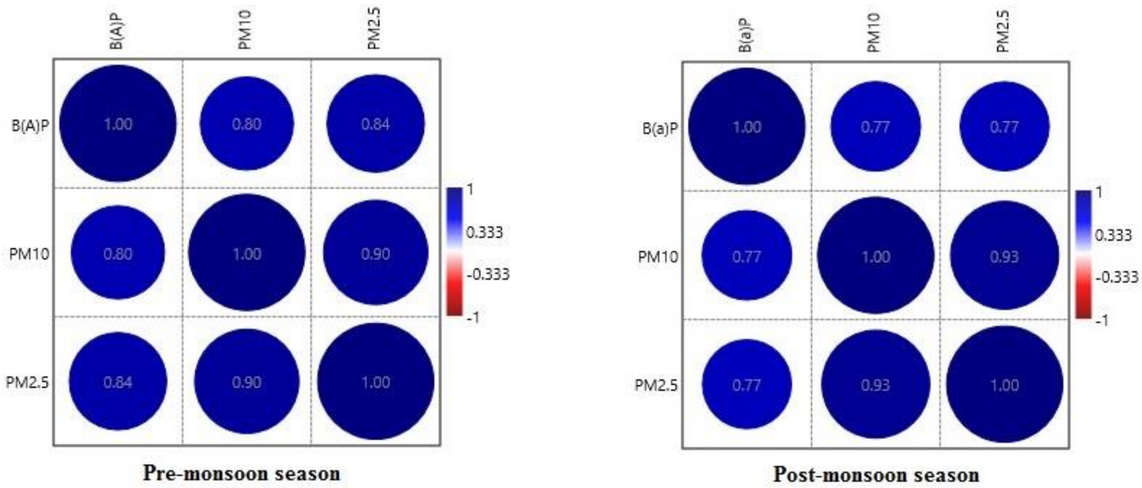

Figure 6. Pearson correlations of PM_{10} and $PM_{2.5}$ and B[a] P concentrations in pre-monsoon and post-monsoon periods.

A strong association was detected between PM and B[a] P, suggesting that they share very similar emission sources. High levels of B[a] P in fine particulate matter are generated by high-temperature activities like combustion. Their compact dimensions, elevated levels, and comparatively extensive surface area per mass unit make them effective adsorbents (Sheu et al., 1997).

3.4 Correlationbetween PM Concentrations and Atmospheric Attributes

Atmospheric attributes such as air temperature, wind speed, precipitation, atmospheric boundary layer, relative humidity, and others are the primary determinants of ambient pollution distribution and seasonal variations in the atmosphere (Trivedi et al., 2014). By studying the correlation between PM concentration and atmospheric factors, we can determine the primary factors impacting PM mass concentration in the atmosphere.

Pearson correlation coefficients between PM10 concentrations and atmospheric attributes show that relative humidity (RH) ranged between 42% and 62% during the pre-monsoon season and 72% to 83% during the post-monsoon season, as mentioned in Table 3 below. PM10 was negatively correlated with RH, producing correlation coefficients of -0.57 to -0.63 for all sites (p-value < 0.001) during the post-monsoon season. This negative association is due to relative humidity affecting particle movement and potentially causing particulate matter to settle on the ground. However, due to the narrower range of humidity in the pre-monsoon season, its impact on PM may be minimal. According to Jayaraman's studies (2007), a negative correlation exists between suspended PM concentration and relative humidity in Delhi across all seasons. Figures 7(a) and 7(b) show scatter plots of relative humidity (RH) and PM10.

However, no significant correlation was found between temperature, wind speed, precipitation, and PM10 for both the pre-monsoon and post-monsoon seasons. The wind was a light breeze with speeds ranging from 3.49 to 5.34 m/s, capable of dispersing pollutants within a specific region while limiting turbulence. Hence, the relationship between PM10 concentration and wind speed is insignificant.

Table3. Pearson correlations of PM_{10} and meteorological parameters in pre-monsoon and post-monsoon seasons

	Pre-Monsoon (PM_{10})	**Post-Monsoon (PM_{10})**

Correlation Coefficient	Industrial	Roadside	Residential	Agricultural	Industrial	Roadside	Residential	Agricultural
Temperature	0.049	-0.078	0.096	0.195	0.357	0.476*	0.189	0.297
RH	0.153	0.336	0.274	-0.082	-0.610***	-0.635**	-0.577**	-0.574**
Wind Speed	-0.069	-0.192	-0.389*	0.109	0.157	0.411	0.185	-0.140
Precipitation	0.158	0.405	0.237	0.040	0.414*	0.468*	-0.304	-0.195

* p< .05, ** p < .01, *** p < .001

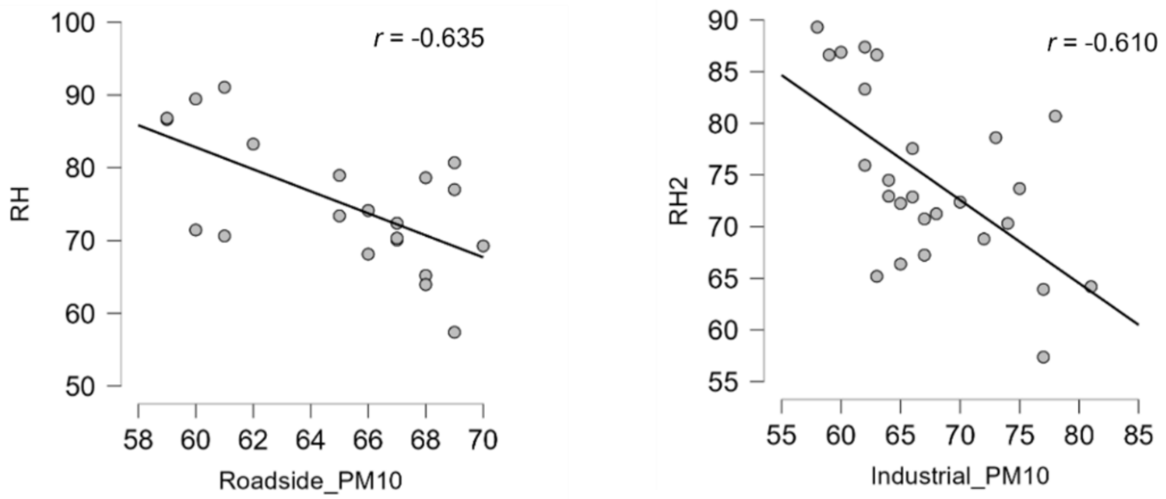

Figure7(a). Scatter plot of RH vs. PM_{10} concentrations

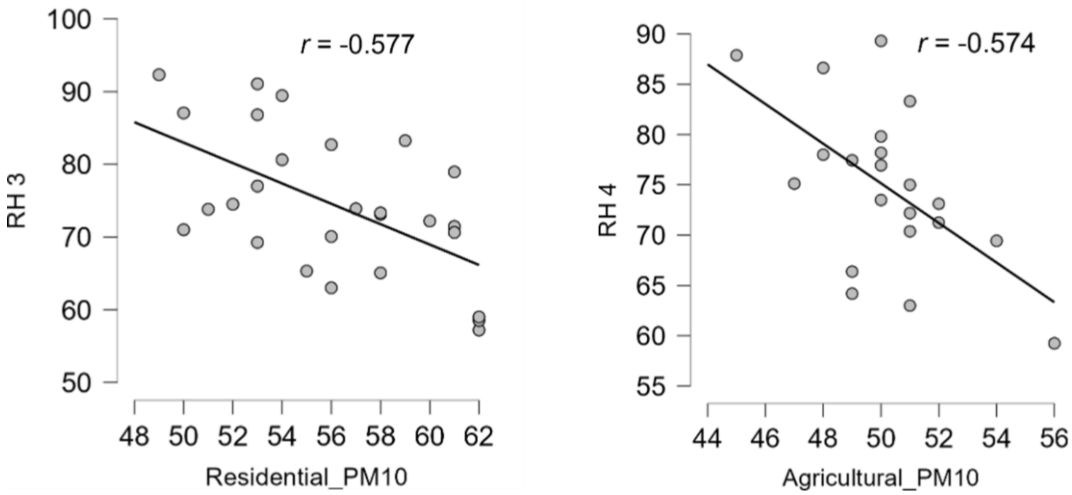

Figure7(b). Scatter plot of Relative Humidity, RH vs. PM_{10} concentrations

4. Conclusion

This study analyzed PM and B[a]P concentrations in industrial, residential, roadside, and agricultural areas of PanvelTaluka during the pre-monsoon and post-monsoon seasons of 2022 and has provided valuable insights. The results can be summarized as follows:

1. Comparing the particulate matter and B[a]P concentrations to NAAQS criteria revealed extremely alarming results. Concentrations were higher during the pre-monsoon season. Growing industrialization, urbanization, and related traffic are factors contributing to the rising levels of particulate matter in PanvelTaluka.
2. Additionally, a study was conducted to analyze possible sources of emission. Backward trajectory analysis of the air mass indicates that more pollutants are transported during the post-monsoon season. Conversely, before the monsoon season, pollutants originate from nearby sources.
3. A noteworthy correlation exists between PM10, PM2.5, and B[a] P.
4. During the post-monsoon season, statistically significant negative correlations existed between PM10 and relative humidity (p-value < 0.001). PM10 showed no correlation with temperature, wind speed, and precipitation. This study presents a preliminary analysis of PM10 and other meteorological factors.

The findings support the implementation of swift, stringent regulations to reduce elevated pollution levels and protect residents of PanvelTaluka.

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