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Seasonal Variation of (Benzo[a]Pyrene) in Ambient Air of Urban to Peri-urban Areas of Panvel Municipal Corporation, Raigad with Reference to Particulate Matter

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ABSTRACT

Polyaromatic Hydrocarbons (PAHs) in the environment have been linked to severe health effects. This study aims to assess the atmospheric pollutant and analyze the variation in PAHs, focussed on benzo[a]pyrene [B(a)P]. Among all PAHs, B(a)P is regarded as a marker for human carcinogenicity. This study reflects the B(a)P concentration and its correlation with the particulate matter (PM_{10} and $PM_{2.5}$) in rural, peri-urban, and urban areas of Panvel Municipal Corporation, Maharashtra, India. Samples were collected during the pre & post-monsoon season for two consecutive years (Yr. 2020 and Yr. 2021). B(a)P level was determined using high-performance liquid chromatography coupled with a diode array detector. It was observed that $PM_{2.5}$ and PM_{10} show a strong positive correlation (r=0.8-0.9) with B(a)P. It is observed that B(a)P concentrations were high in pre-monsoon w.r.t. post-monsoon, and this concentration increased spatially as we moved from rural to urban areas. Pre-monsoon B(a)P concentration varies somewhat by 5% between rural to urban areas as compared to post-monsoon. High levels of vehicular emissions and industry were associated with the distribution of B(a)P in urban areas, whereas a combination of local emissions and metropolitan area diffusion was responsible for the presence of B(a)P in peri-urban and rural areas. Also, this study captures the variation of B(a)P levels during the period of COVID-19. In future studies, Artificial Intelligence (AI) can augment the determination of PAHs in soil by improving the accuracy and speed of analysis using predictive modeling based on different input parameters to determine outliers in soil PAH data, building sensor networks for real-time monitoring of PAH levels, leverage robotics for automated sample preparations, and rapid testing of samples to identify hotspots.

INTRODUCTION

Industrialization and urban development, especially in emerging countries, have increased air pollution dispersion in densely populated cities in the past few decades (Buhaug & Urdal 2013, Kermani et al. 2019). These are further augmented by industrial & manufacturing waste, traffic pollution, construction, and burning of biomass that includes Polyaromatic Hydrocarbons (PAHs), particulate matter, and other pollutants.

The PAHs are a category of persistent organic compounds and are one of the most prevalent contaminants in soil, water, and air. It originates from both natural (forest fires, volcanoes, etc.) as well as anthropogenic sources (incomplete combustion of organic matter, like carbon, coke, oil, gas, coal, biomass, vehicular emission, residential heating, asphalt production, etc.) (Wolska et al. 2012, Manoli et al. 2016). Also, the lipophilic nature of PAH makes it easily dissolved and transported by the cell membrane and makes it accumulate in the fatty tissues of living organisms.

Out of sixteen main compounds, Benzo[a]Pyrene, B(a)P is a specific compound that belongs to the group of PAHs. The World Health Organization (WHO) considers B(a)P to be one of the most potent mutagens, frequently employed as a general indicator of PAHs and a marker for carcinogenicity. The Toxic Equivalent Factor (TEF) for all PAHs was determined by comparing the cancer risk of all PAHs relative to the cancer risk of B(a)P (Yu et al. 2008). This can potentially lead to undesirable effects, including cancer, gene mutation (Zhang et al. 2009, Chen et al. 2016), and getting absorbed by fine particulate matter (Baek et al.1991).

Particulate matter (i.e., PM_{10} and $PM_{2.5)}$ has a significant role as a carrier, resulting in air contamination, detrimental health consequences, and global climate changes. They can travel from one area to another for days or even weeks in the air before they gradually get deposited from the atmosphere to the soil. Over the multiple studies done on the size distribution of particulate-bounded PAHs, size is the factor that determines particle deposition, particularly in the respiratory system. Such as $PM_{2.5}$ is more damaging than PM_{10} in terms of its aerodynamic diameter (Oberdorster et al. 2005, Dat & Chang 2017, Kumar et al. 2020). Hence, a significant focus on epidemiological study caters to the measurement of PAHs in $PM_{2.5}$.

In this segment of the study, there are extensive data sets available in developed countries, but the same is not true for developing countries like India. Similar to this there haven't been any studies published about the B(a)P concentrations and their likely sources in the ambient air in Panvel Municipal Corporation (PMC), Panvel (Maharashtra, Inda). PMC is a right-fit study area because it is a fast-developing industrial & residential area, and international airport construction is in progress in the vicinity.

The purpose of this research paper is to study the level of the B(a)P & its impacts on the air in the PMC and its nearby areas over pre and post-monsoon seasons. Hence, the outcome of this study will be utilized to:

(1) assess & predict B(a)P levels using the air samples collected from PMC, Panvel from urban, peri-urban to rural areas, and

(2) identify the factors resulting in seasonal variations, their likely sources of emissions, and their impacts.

In theory, the B(a)P and B(a)P equivalent concentration (BaPeq) can be used to estimate the health risks associated with PAH. The Central Pollution Control Board (CPCB) has set a target value for B(a)P of 1ng.m^{-3} (National Ambient Air Quality Standards).

MATERIALS AND METHODS

Sampling Sites, Atmospheric Conditions, and Their Description

The study was carried out in Panvel Municipal Corporation (PMC), which is located between 18°58′N and 19°70′N latitudes and 73°2′E and 73°9′E longitudes. A node of Navi Mumbai metropolis, PMC is situated in Maharashtra's Raigad district in the Konkan division. Many factors make PMC a right-fit location for such a study, including industrial presence, urban & suburban mix, proximity to Mumbai, ecological diversity, transportation density, land-usage changes, and possible environmental policy implications at local & regional levels. The land-use pattern is mostly residential-cum-industrial, with a total population of 5.09 lakh (2011 census), and this number must have experienced reasonable growth till the year 2023. From 2016 to 2021, the built-up area increases by a factor of two.

Additionally, a tropical climate exists in the study area with an average temperature of 37°C and annual rainfall of ~3267 mm, respectively (Environmental Status Report, 2020-21). It is surrounded by offshoots of Sahyadri Ranges in the East, Thane and Dombivali in the North, JNPT port and Uran in the South, and Navi Mumbai in the West. The development in built-up areas throughout the cited areas is seen as primarily responsible for the decline in agriculture, vegetation, barren land, and other land uses. We have identified five different sites in the Panvel Municipal Corporation (PMC) area. It is one of the fully developed industrial areas with businesses engaged in a range of commercial endeavors. Chemical, food and fish processing, dairy products and cold storage, and engineering are the most prevalent industrial activities. Five separate locations were chosen based on the urban, per-urban, and rural areas, and this includes – Panvel, Taloja, Karanjade, Ulwe, and Bhatan. Table 1 and Table 2 show the location-matrix and their respective co-ordinates. Panvel is one of the most populated and advanced cities in this area. Taloja is a popular chemical industrial area created by the Maharashtra Industrial Development Corp. (MIDC). Karanjade is a growing residential area adjoining Panvel town. Ulwe is home to the upcoming Navi Mumbai International Airport (Environmental Status Report, 2020-21). Bhatan is thought

Table 1. Location-matrix view

	Urban	Peri-Urban	Rural
Industrial	Taloja	-	-
Residential	Panvel	Karanjade	-
Agricultural	-	Ulwe	Bhatan

Table 2. Area and co-ordinates

Sr. No.	Area	Latitude	Longitude
1.	Bhatan	18.931531	73.163786
2.	Taloja	19.058538	73.112741
3.	Ulwe	18.982386	73.078349
4.	Karanjade	18.983045	73.091544
5.	Panvel	18.99340	73.116775

of as a control location. The burning of coal and biomass is the main cause of air pollution emissions. Another factor contributing to pollution is the highway network.

Atmospheric conditions are another important criterion since it has a significant impact on the formation of numerous atmospheric pollutants (Zhang 2019, Chen et al. 2020 b). Various combinations and a range of atmospheric data points were considered to perform this study, including maximum temperature, relative humidity, wind speeds, and precipitation for the pre-monsoon and post-monsoon seasons in the years 2020 and 2021. These data were acquired from Power Data Access Viewer, NASA, and the meteorological parameter is depicted in Table 3.

The above data sets constitute nearly 180 units of readings across six months ranging from pre and post-monsoon. The wind is a crucial component for the dispersion and dilution of pollutant plumes. Air pollution is more likely to disperse under high wind conditions than it is to accumulate in low

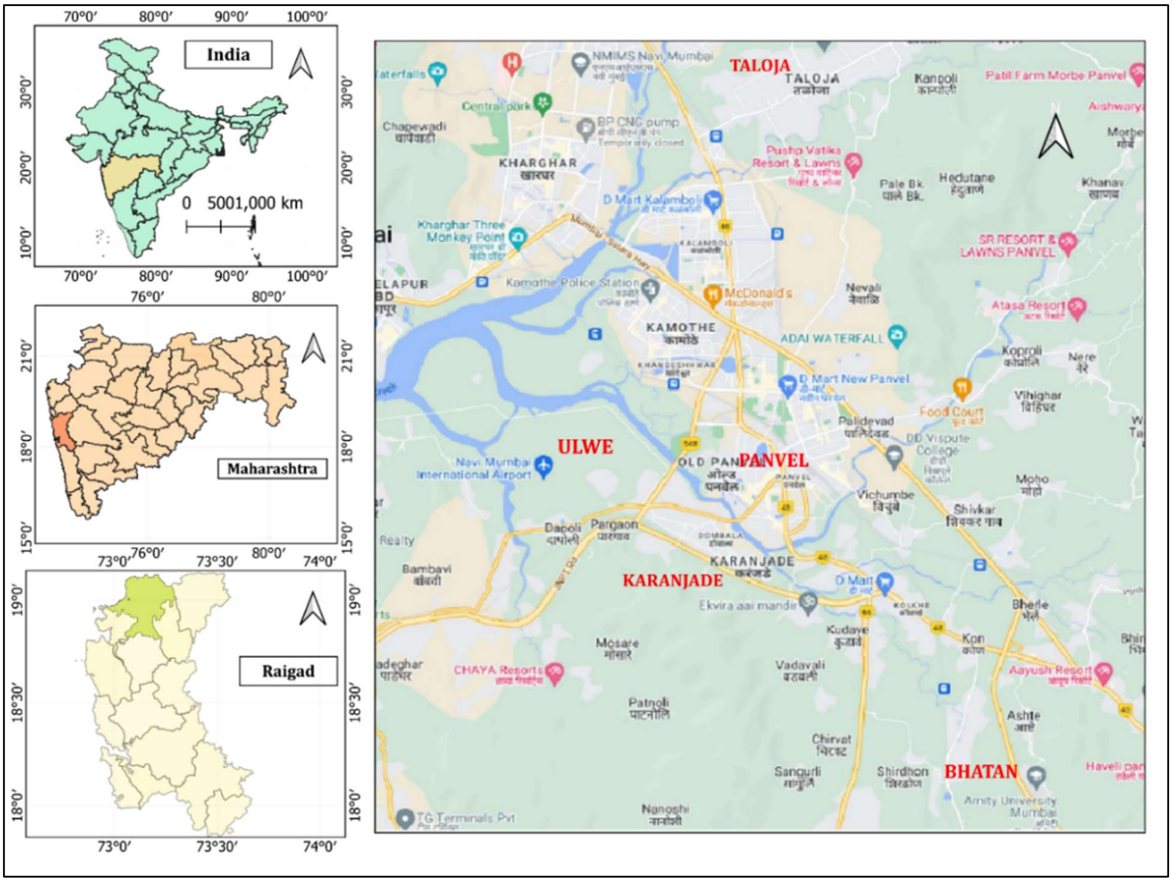

Fig. 1: The study area of the five sites located within the PMC.

Table 3: Meteorological parameters of the area

Parameters Months	Temperature [°C] Mean ± SD		Relative Humidity [%]Mean ± SD		Wind speed [$m.s^{-1}$] Mean ± SD		Precipitation [mm]	
	2020	2021	2020	2021	2020	2021	2020	2021
March	35.83 ±3.29	39.12 ±1.50	49.34 ±11.8	37.32 ±9.19	6.41±1.12	7.03±0.97	0.13	0.07
April	40.40 ±1.88	39.14 ±1.28	51.15 ±5.18	51.03 ±5.68	7.25±1.03	6.33±0.80	0.171	0.255
May	39.42±1.56	35.93±3.64	57.28±3.47	65.06 ±15.25	6.57±0.74	6.87±3.72	0.23	0.26
October	30.73±1.04	30.79±1.06	82.77±7.09	81.40 ±5.93	4.87±1.44	5.60±1.58	5.81	2.34
November	30.89±0.78	39.14±1.28	75.99±4.44	78.90 ±5.87	7.05±1.50	6.94±1.50	0.015	1.66
December	29.98±0.94	35.93±3.64	69.42±7.78	75.30 ±5.24	7.23±1.96	6.74±1.75	0.39	2.27

wind conditions. Strong winds can concentrate the pollutants by directing a plume to a specific location. Like this, rain can remove particulate matter (PM) from the air. The generation and emissions of air pollutants were influenced by temperature. Also, relative humidity (RH) has a significant impact on atmospheric photochemistry, including the production of O_3 and OH radicals (Lu et al. 2019 b).

Sample Equipment, Collection Frequency, and Sample Size

Sample equipment: Sampling of particulate matter and PAH was conducted during the pre-monsoon (March-April-May) and post-monsoon (October-November-December) seasons for the years 2020 and 2021. Separate samples were collected for $PM_{2.5}$ and $PM_{10.}$ Collecting samples before and after the monsoon helps with better influence assessment of PAH levels in particulate matter. Monsoon changes can have an impact on atmospheric conditions and can affect the transport, deposition, and chemical transformation of particulate matter and PAHs in the environment. Also, it enables a more comprehensive understanding of the dynamics of PAHs in the environment by providing insights into the complex interactions between meteorological conditions, emissions sources, and pollutant levels.

A total number of 350 data samples were collected for PM_{10} over the year 2020 and 2021 from all the sites. For a few of the sites, sample data were collected from Maharashtra Pollution Control Board (MPCB) portals. (https://mpcb.gov.in/). While for $PM_{2.5}$ and B(a)P, 120 data samples each were collected from all the sites. In this study, PM_{10} and B(a)P sampling was carried out using a High-Volume Sampler with Glass Fibre Filter paper. Glass fiber filter papers have a high collection efficiency for fine particles and are designed to effectively capturing and retaining particles, preventing them from passing through the filter and escaping into the environment during sampling. These particles are inhaled deeply into the respiratory system due to their small size and thus pose a health risk to humans. Glass fiber filters are effective at capturing particles in this size range.

Whereas $PM_{2.5}$ sampling was done using Fine Particulate Samplers with Teflon Filter paper. $PM_{2.5}$ sampling is designed to target fine particulate matter with a diameter of 2.5 micrometers or less. Teflon filters are effective at capturing particles in this size range. Teflon filters are chemically inert and do not introduce contaminants or react with the collected particles. This is crucial for accurate measurements of $PM_{2.5}$ composition.

Sample collection frequency: The sampling for particulate matter was carried out for 8 hours with a frequency of twice a week. All the sampling was carried out as per the Central Pollution Control Board (CPCB) guidelines. (https://cpcb.nic.in/).

Sample Processing

In this sampling process, the exposed filter paper was cut into pieces and transferred to a 250 ml beaker. Ultrasonic extraction was carried out using methanol. The bottles were forcefully shaken to suspend the contents after being sealed with screw cap closures packed with polytetrafluoroethylene (PTFE)-faced silicone rubber septum. After that, the bottles were subjected to a high-performance ultrasonic bath that was microprocessor-controlled for precise temperature and time control. This process took place for 60 minutes at 50°C. The samples were periodically re-suspended by shaking and inverting the sample bottles. The supernatant from the centrifuged extraction solutions was then decanted into 4 mL amber vials and kept in the refrigerator until clean-up and analysis were complete (Oluseyi et al. 2011). Sample contaminants may be cleaned out using Solid Phase Extraction (SPE). The residue was then transferred to 1-mL vials and examined using high-performance liquid chromatography (Agilent Technologies, 1260 Infinity).

By comparing the retention times of the samples to those of B(a)P standards, the chromatographic peaks of the samples were detected. The absence of PAH chemicals in the blank samples proved that there was no sample contamination. The chromatographic setups used for the analysis are listed in Table 4.

Data and Result Analysis

Pearson correlation was used in the form of a correlation coefficient to determine the following relationships.

- between B(a)P and particulate matters ($PM_{2.5}$ & PM_{10}), and
- only between particulate matters ($PM_{2.5}$ & PM_{10})

Pearson correlation was used to assess and identify any statistically significant association between the concentrations of B(a)P and particulate matter. This helps determine the relationship between B(a)P and particulate matter, which is essential for understanding their potential co-occurrence and interdependence, if any.

Table 4: Conditions for B(a)P analysis in HPLC.

Column	Poroshell C18, 4.6x 250 mm
Column temperature	40°C
Eluent	Acetonitrile: water (60%:40%)
Detector	UV-Visible detector
Run time	10 mins
Flow rate	$1mL.min^{-1}$
Injection volume	10 µL

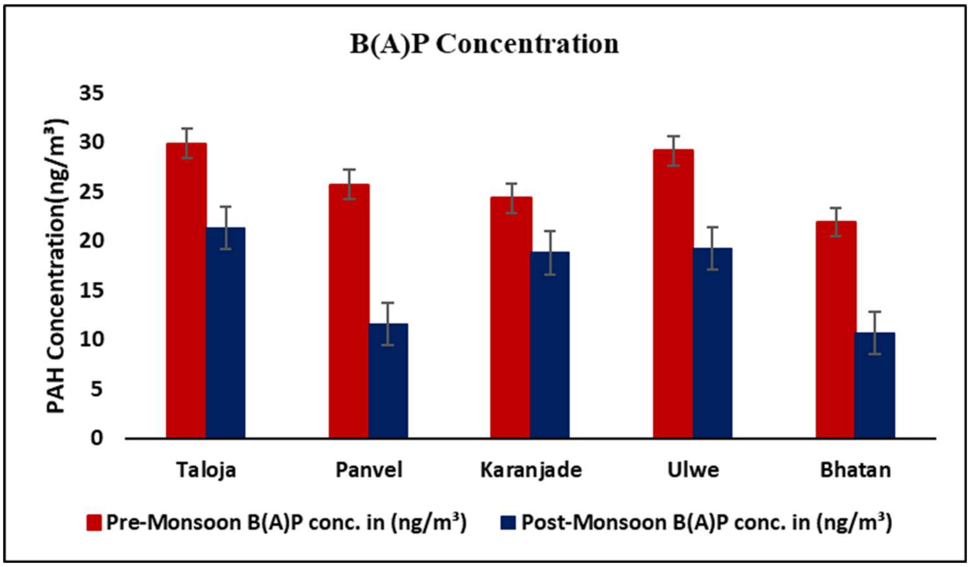

Fig. 2: B(a)P concentrations at five different locations during the pre-monsoon and post-monsoon.

A relationship or correlation analysis can provide insights into potential sources of pollution. Suppose there is a strong positive correlation between B(a)P and PM. In that case, it may indicate that B(a)P is originating from sources that also emit particulate matter, such as combustion processes. Additionally, a positive correlation between B(a)P and PM can influence regulatory decisions and policies. It may prompt stricter regulations on sources that emit pollutants to reduce overall environmental and health impacts.

RESULTS AND DISCUSSION

Pre-Monsoon and Post-Monsoon Variation of B(a)P at Different Sampling Sites

It was observed in the study that the concentrations of B(a) P at the urban, peri-urban, and rural sites were in the ranges of 10.41-29.90 ng.m^{-3}, 15.4-29.17 ng.m$^{-3,}$ and 10.69-21.93 ng.m^{-3}, respectively. In general, concentrations of B(a)P were observed to be on the higher side for all the sampling sites. The B(a)P levels and trends varied significantly between sampling sites and over seasons (i.e., pre-monsoon and post-monsoon).

In pre-monsoon, the concentration pattern showed the following trend (highest to lowest), i.e., Taloja > Ulwe > Panvel > Karanjade > Bhatan.

While there is slight variation observed in the post-monsoon pattern, i.e., Taloja > Ulwe > Karanjade > Panvel > Bhatan.

As per the National Ambient Air Quality Standards (NAAQS), the annual concentration of B(a)P in ambient air is 1ng.m^{-3} in industrial, residential, rural, and other areas.

In general, the B(a)P was more abundant in pre-monsoon season samples. The maximum B(a)P concentration (29.90 ng.m^{-3}) was found at the urban site in the pre-monsoon season, and the minimum (10.69 ng.m^{-3}) at the rural site in the post-monsoon season. Fig. 2 shows the pre and post-monsoon concentration of the B(a)P across the five different sites within Panvel Municipal Corporation. Details of the Pre-monsoon and Post-Monsoon for the year 2021.

There are multiple reasons behind the different concentrations of B(a)P for all the sites over different seasons are highlighted below. Firstly, the urban sites (i.e., Taloja and Panvel) are located near an industrial area and may receive more pollutants from vehicular movement and other sources. Secondly, the B(a)P concentration gap between the urban and peri-urban areas has narrowed down because of growth & development activities that include new construction and a rise in vehicular ownership. Additionally, B(a)P was found in rural area samples (i.e., Bhatan) that potentially could be a result of local emissions, which include improper disposal of solid waste, burning of fossil fuels, and diffusion from metropolitan areas.

Source-Identification and Long-Range Transport of Air-Borne Particulate Matter

During the study period, 'Backward Trajectory' computations were used to forecast the air parcel trajectories of atmospheric contaminants, B(a)P, over PMC, Panvel. This computation gives an indicative picture of the pollution brought on by airborne particles that are carried by the wind or released by local origin sources.

As part of this study, a 5-day isentropic back trajectory was calculated for a total run time of 120 Hours at an altitude of 500m using Hybrid-Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model developed by the National Oceanic and Atmospheric Administration's (NOAA) Air Resources Laboratory (ARL) for the pre-monsoon and post-monsoon season for the year 2020 and 2021. The HYSPLIT model (Draxler et al. 2012, http://ready.arl.noaa.gov/HYSPLIT.php) was used in conjunction with the Global Data Assimilation System (GDAS1) metrological database as input. The backward trajectory was created as an indicative cause of PMC's elevated PAH concentration. The study was carried out at the control spot, i.e., a rural site (Bhatan), and it is similar to all the other sites because of its proximity. It is shown in Fig. 3 (a, b, c, and d) for all the possible flow combinations:

- Pre-Monsoon, Year 2020
- Post-Monsoon, Year 2020
- Pre-Monsoon, Year 2021
- Post-Monsoon, Year 2021

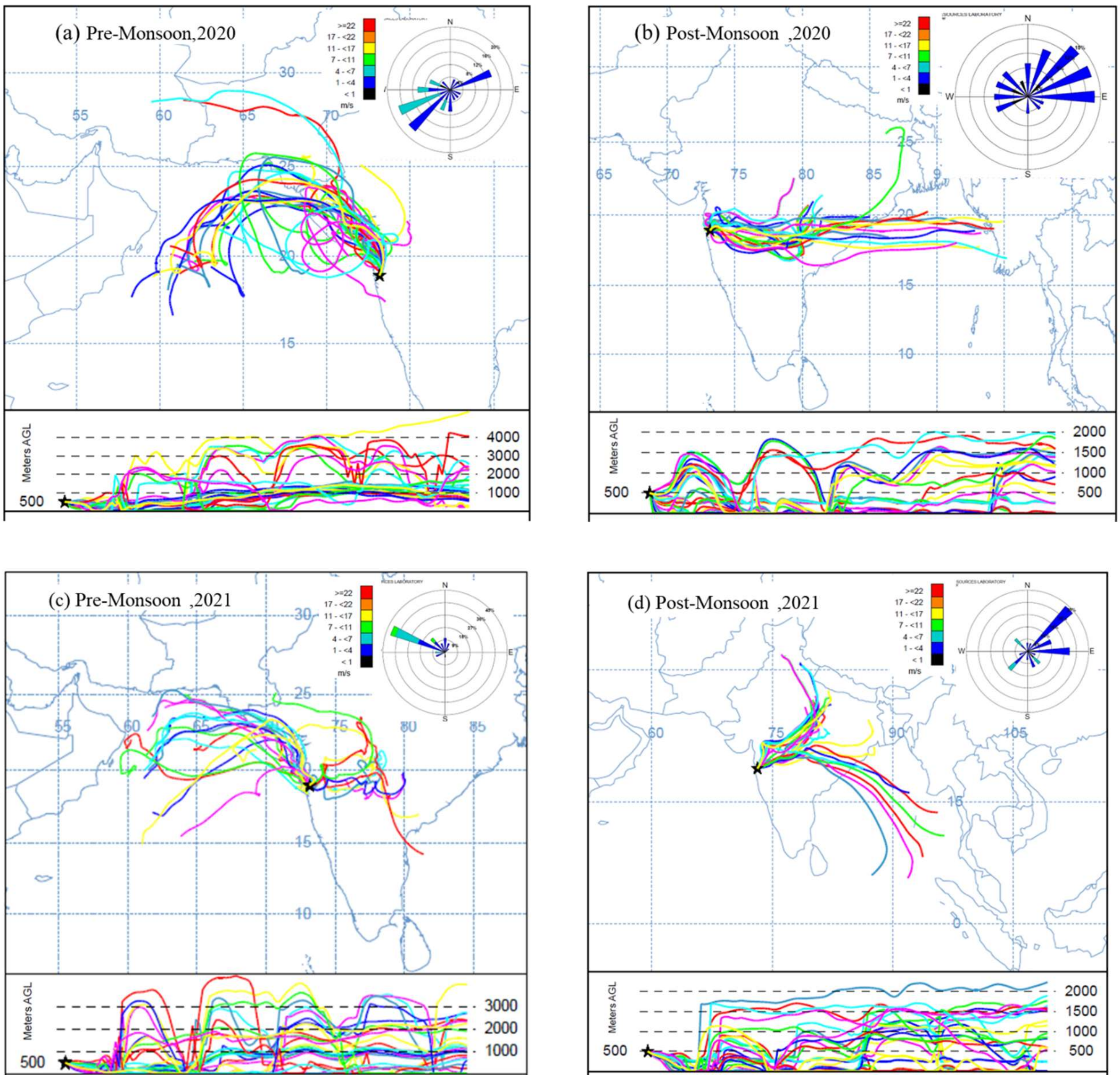

Fig. 3: (a, b, c, d and d) 5-day HYSPLIT air mass backward trajectories at 500 m AGL at PMC, Panvel for the pre and post-monsoon. The color scale represents the traveling altitude by the air mass before reaching the observation site.

The back-trajectory research study revealed that the air mass came from various sources depending on the season. Most of the back trajectories that were analyzed suggested that the air mass may have originated and transported from outside India. The trajectories during the pre-monsoon season indicate a long-distance transit of the filthy air flowing towards PMC, Panvel, over the Arab nations and continents of the Middle East. Due to frequent dust storms and relatively strong winds, the pre-monsoon season's high concentration of $PM_{2.5}$ is typically impacted by wind-blown dust (Panicker et al. 2013). In the post-monsoon, the trajectories originated from the northern and northeastern parts of India. The nearby industrial operations and agricultural activities also contributed to the large mass concentration of pollution over the research site.

Particulate Matter Concentration in PMC, Panvel (Maharashtra, India)

This section reflects the analysis around the seasonal variation and depiction of satellite study via the Giovanni NASA portal.

Table 4: The average concentration of PM_{10} and $PM_{2.5}$ of all five sampling sites over pre & post-monsoon seasons.

	Pre-Monsoon, 2020		Post-Monsoon, 2020		Pre-Monsoon, 2021		Post-Monsoon, 2021	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Taloja	62.66 ±11.45	32.8 ± 3.81	65.42 ± 7.85	39.3 ± 1.49	66.78 ± 4.74	39.81 ± 1.30	67.35 ± 11.21	41.71 ± 3.69
Panvel	40.7 ±7.02	32.5 ± 3.67	50.96 ±4.40	37.15 ± 1.44	54.08 ±5.70	36.5 ± 2.28	54.62 ±10.79	37.36 ± 1.02
Karanjade	47.9 8.59±	30.8 ± 2.96	58.5±8.42	35.6 ± 1.11	57.33±2.65	37.2 ± 2.68	60.14±7.51	38.78 ± 1.63
Ulwe	41.28 6.26±	33.1 ± 5.09	62±4.23	38.4 ± 1.33	65.76±3.46	40.67 ± 1.52	65.5±8.42	40.31 ± 1.58
Bhatan	53.4 4.79±	27.5 ± 1.27	44.4±2.83	34.3 ± 1.08	48.67±3.95	33.41 ± 1.06	47.9±5.25	34.51 ± 2.60

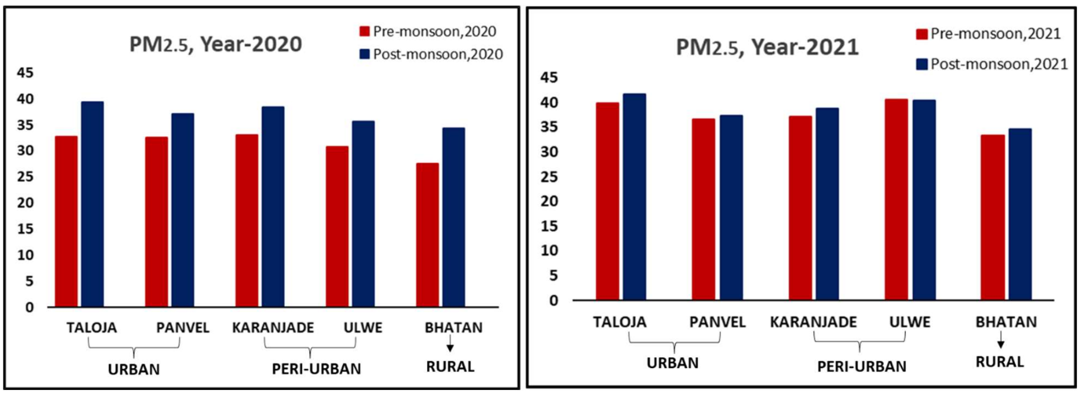

Fig. 4: $PM_{2.5}$ concentration pattern during pre-monsoon and post-monsoon.

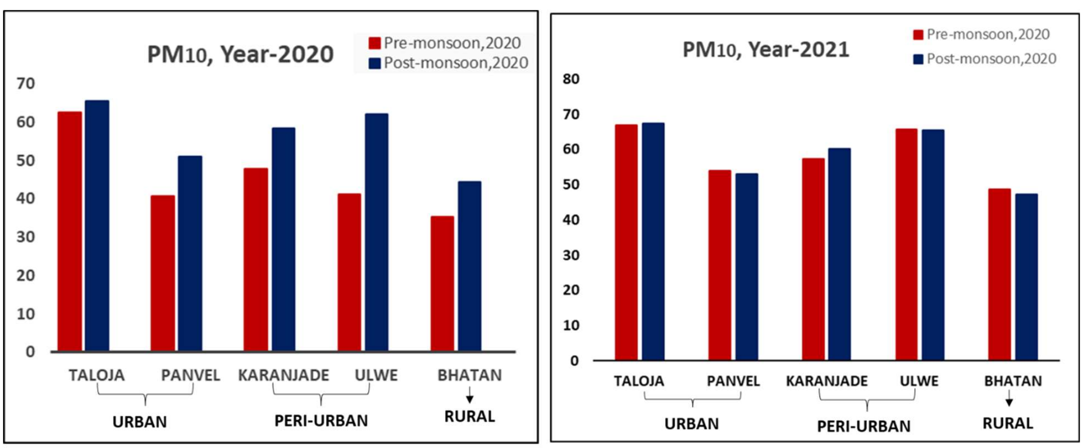

Fig. 5: PM_{10} concentration pattern during pre-monsoon and post-monsoon.

Seasonal variations of $PM_{2.5}$ and PM_{10} value across pre and post-monsoon seasons: Basis the study, seasonal variation can be observed for $PM_{2.5}$ and PM_{10} values (shown in Table 4).

For $PM_{2.5}$,

- Pre-monsoon average concentrations are in the range of 27.5-33.1 $\mu g.m^{-3}$ and 33.41-40.67 $\mu g.m^{-3}$ for the years 2020 and 2021, respectively,
- Post-monsoon average concentrations are in the range of 34.3-39.3 $\mu g.m^{-3}$ and 34.51-41.71 $\mu g.m^{-3}$ for the years 2020 and 2021, respectively.

For PM_{10},

- Pre-monsoon average concentrations are in the range of 40.7-62.66 $\mu g.m^{-3}$ and 48.67-66.78 $\mu g.m^{-3}$ for the years 2020 and 2021, respectively.
- Post-monsoon average concentrations are in the range of 44.4-65.42 $\mu g.m^{-3}$ and 47.9-67.35 $\mu g.m^{-3}$ for the years 2020 and 2021, respectively.

All the measured concentrations exceed the NAAQS standards of annual averages of 40 $\mu g.m^{-3}$ for $PM_{2.5}$ and 60 $mg.m^{-3}$ for $PM_{10.}$ High concentration of PM in the atmosphere can be attributed to several variables, including high

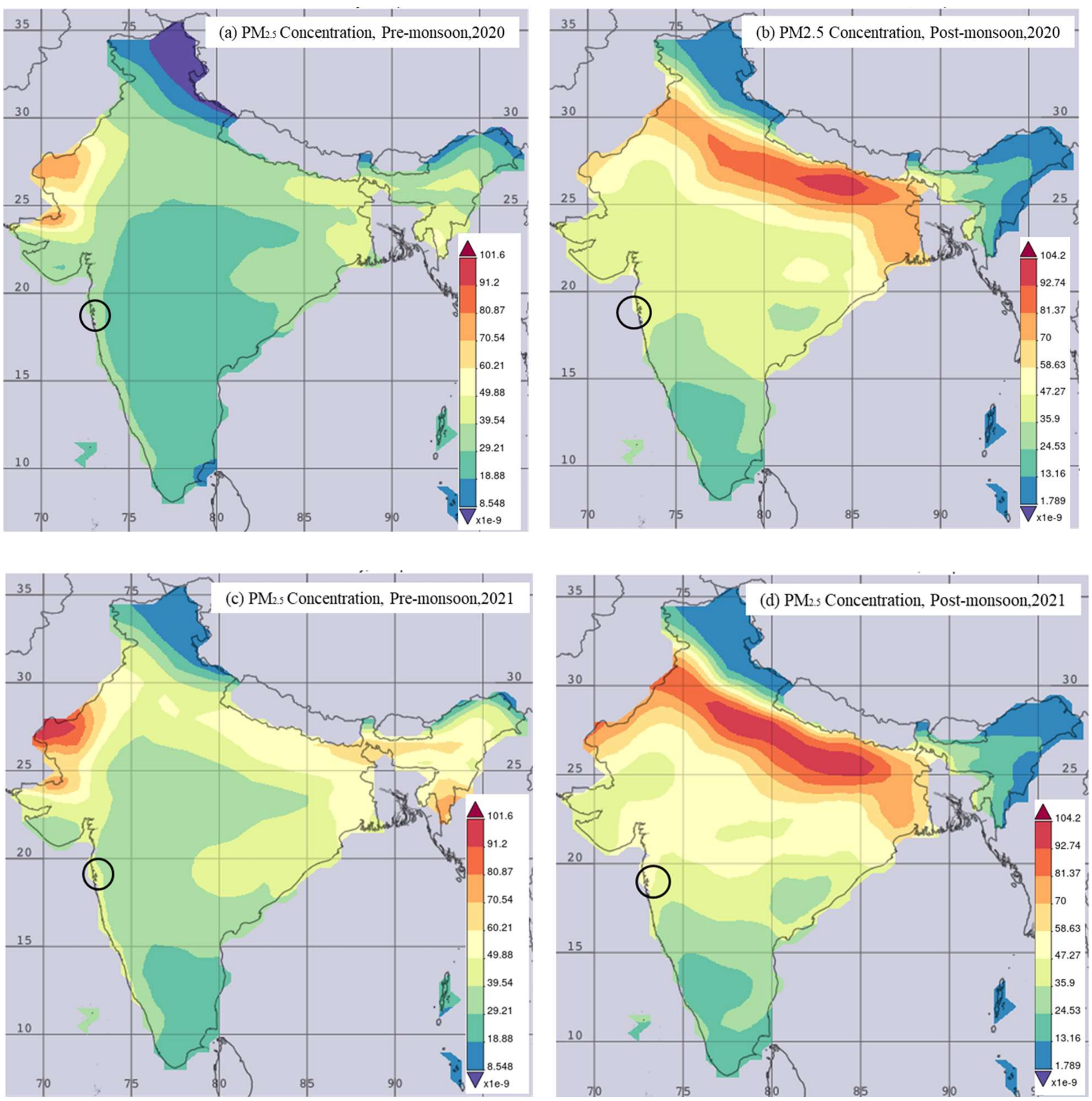

Fig. 6: (a, b, c, and d) Time average map of $PM_{2.5}$ surface mass concentration monthly 0.5 × 0.625 deg. (MERRA-2 Model M2TMNXAER v 5.12.4) $Kg.m^{-3}$ at the two different seasons (Pre-Monsoon and Post-Monsoon).

energy consumption, rapid economic growth, etc. Details of the Pre-monsoon and Post-Monsoon for the year 2020-21.

Fig. 4 and 5 illustrate the distinct seasonal fluctuations in PM levels at all 5 sampling sites. From the figures, both PM_{10} and $PM_{2.5}$ are slightly higher in post-monsoon than in pre-monsoon.

All the sampling sites in Table 4 are distinguished into three functional areas: urban, peri-urban, and rural (including industrial, residential, and agricultural sites). Additionally, it was found that, as compared to rural areas, particulate concentrations are higher in urban and peri-urban areas. Differences in the kinds and intensities of emissions primarily caused the geographic variations in particulate matter between sampling locations. The study data indicates that residential firewood burning has an impact on rural areas, while automotive emissions are the main source of particulate matter in urban and peri-urban areas, with a large contribution from industries.

$PM_{2.5}$ satellite study via the Giovanni NASA portal: $PM_{2.5}$ measurements were also observed from the satellite study via the Giovanni NASA website for the years 2020 and 2021. This helps analyze various data sets collected by NASA's Earth-observing satellites.

The pictorial representation (Fig. 6) is the result of the time average map of $PM_{2.5}$ surface mass concentration monthly 0.5 × 0.625 deg. (MERRA-2 Model M2TMNXAER v 5.12.4) $Kg.m^{-3}$ at the two different monsoon seasons.

Key takeaways from the above representation include the burning of biomass, coal, waste incineration, and stubble as the major sources of particulate matter in post-monsoon. It should be noted that as biomass and coal are utilized for heating in these regions during the winter, a significant portion of the contribution from burning these fuels came from the north and north-eastern states, including Haryana, Uttar Pradesh, Bihar, and West Bengal states in India (Guo et al. 2018). This may help to partially explain the large contributions from biomass burning, which is also India's main source of particulate matter. The higher concentration of particulate matter in the study area is directly or indirectly linked with the long-range transport of pollutants from other states, as shown in the backward trajectory. However, it cannot be concluded that the particulate matter getting carried by the air is resulting in increased benzo[a]pyrene concentration. So, the gap that is identified as part of this study can be further studied in future research activities.

B(a)P Level During the Period of COVID-19

We all experienced the effects of COVID-19 and the blackouts it resulted in. All companies, industrial complexes, educational institutions, and local marketplaces were required to shut down completely, per an order from the Indian government during the COVID-19 lockdown. It had the biggest impact in reducing traffic emissions in 2020, which may have caused the B(a)P level to fall significantly across all sites. At the same time, industrial activity was also affected by the pandemic. Even though many nations saw human casualties, on the contrary, environmental conditions improved, leading to a decrease in particulate matter, black carbon, and PAH emissions, thus resulting in an improved air quality level (Agarwal et al. 2020, Gautam 2020, Panda et al. 2020, Sharma et al. 2020, Singh & Chauhan 2020, Ambade et al. 2021). Due to this, air pollution emission sources altered substantially throughout the lockdown period.

This is to note that B(a)P was not present in a detectable amount during this period at the sites in consideration. While in the research, Phenanthrene and Pyrene were the most abundant PAH detected during the lockdown period in both pre-monsoon and post-monsoon samples. Prior research has identified some PAHs, such as pyrene and phenanthrene, as markers for different types of air pollution in metropolitan areas, such as coal combustion, incineration, and wood burning. Low molecular weight PAH, like Pyrene, is more prevalent in emissions from the burning of dried cow dung (Harrison et al. 1996, Khalili et al. 1995, Li & Kamens 1993). The concentration of pyrene in the ambient samples in Mumbai is due to the combustion of cooking fuel, i.e., animal manure, Liquid Petroleum Gas, and Kerosene (Raiyani et al. 1993).

While short-term reductions in air pollution were observed during COVID-19 lockdowns, long-term trends in B(a)P levels may require more data points and continuous monitoring. Long-term impact on B(a)P levels depends on factors, including ongoing emission reduction efforts and required future policy amendments related to air quality and environmental sustainability.

Correlation of Particulate Matter ($PM_{2.5}$ and PM_{10}) and B(a)P Using Statistical Approach

The quality of the air was examined with respect to B(a)P in particle size fractions $PM_{2.5}$ and PM_{10}. The relationship between B(a)P and particulate matter was analyzed using Pearson correlation. The study showed a significant positive correlation between the levels of $PM_{2.5}$ and PM_{10} with B(a)P in the air (i.e., r = 0.8-0.9).

The strong correlation between particulate matter and B(a)P showed that B(a)P concentrations increased effectively with increasing particulate matter mass concentrations. Table 5 shows the correlation for particulate matter. This correlation is established using 30 data sets distributed over

Table 5: Pearson correlations of particulate matter (PM_{10} and $PM_{2.5}$) and B(a)P concentrations in pre-monsoon and post-monsoon period.

Pre-monsoon period, 2021(n=30)				Post-monsoon period, 2021(n=30)			
	$PM_{2.5}$	PM_{10}	B(a)P		$PM_{2.5}$	PM_{10}	B(a)P
$PM_{2.5}$	1.000			$PM_{2.5}$	1.000		
PM_{10}	0.856**	1.000		PM_{10}	0.859**	1.000	
B(a)P	0.928**	0.900**	1.000	B(a)P	0.871**	0.949**	1.000

**Correlation is significant at the 0.01 level (2-tailed).

pre-monsoon and post-monsoon samples.

Concentrations of $PM_{2.5}$ and PM_{10} were also highly correlated because the primary sources of emissions are almost similar for both particulate matters. Smaller particulates typically contain more B(a)P. This is because high-temperature sources, such as combustion, mainly produce fine particulates with a high B(a)P content. They are an excellent adsorbent due to a high number of concentrations, small size, and comparatively large surface area per unit of mass (Sheu et al. 1997). These results indicated that the sources of particulate matter and B(a)P in the air were mainly comparable. Hence, reducing particulate matter levels reflects an efficient strategy to lower the B(a) P level in the air.

CONCLUSION

This is the first study carried out on the particulate matter and B(a)P in urban, peri-urban, and rural areas of PMC in pre-monsoon and post-monsoon periods, and it has presented valuable insights. The result showed that the concentration of particulate matter and B(a)P was quite concerning when compared to NAAQS benchmarks. The B(a)P concentration was thirty times higher than the standard limit of NAAQS ($1 ng.m^{-3}$).

The concentration of B(a)P and particulate matter were higher at urban sites, i.e., the maximum concentration of B(a) P was recorded in Taloja in both periods, i.e. 29.9 $ng.m^{-3}$ and 21.32 $ng.m^{-3,}$ respectively. When compared to post-monsoon, the seasonal variation pattern of B(a)P reveals a considerable increase in concentration. Thus, the increased B(a)P load in the PMC (i.e., 5 sites) is attributed to increased industrial activities, vehicular emissions, and population density. This requires proper corrective intervention to reduce the adverse effects of prolonged exposure on the surrounding population. And thus, help realize the importance of sustainable urban planning and pollution control measures to mitigate adverse health and environmental effects. The study also reflects the importance of implementing air quality management policies tailored to the larger requirements of urban, peri-urban, and rural areas. These measures should include stricter emissions controls, green infrastructure development, and public awareness campaigns.

Nonetheless, it is critical to start leveraging Artificial Intelligence (AI) in the study of particulate matter and B(a) P that significantly enhances and enables fast turnaround in research processes. AI can be used to develop predictive models for PM and B(a)P basis historical data and air circulation patterns can help devise pro-active pollution control measures. Additionally, AI combined with GIS will help create faster and more detailed maps for PM and B(a) P in areas like PMC and can be a potential next step of this research. A holistic integration of data sets – collected from satellite imagery, weather data, and ground-based sample results – can also provide a view of air quality and pollution sources. By harnessing the power of AI, institutions can work toward effective pollution control mechanisms and public health protection strategies in Panvel Municipal Corporation, Maharashtra.

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