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Temporal Distribution of AQI and Air Pollutants (PM_{10}, NO_2, SO_2) from 2016-2024, Public Awarness About Air Pollution: A Case-Study in Berhampore, Murshidabad

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Abstract : *Evaluating air quality is vital for safeguarding public health, mitigating environmental degradation, and guiding sustainable urban planning. Monitoring air quality is essential to mitigate chronic health risks, protect local ecosystems, and provide a scientific basis for urban environmental management. This study analyzes temporal distributions of air pollutants, specifically PM_{10}, NO_2, SO_2 and the Air Quality Index (AQI) in Berhampur, Murshidabad, from 2016 to 2024. Using secondary data from the West Bengal Pollution Control Board (WBPCB), the research employs trend analysis, seasonal decomposition, and Exceedance Factor (EF) assessments against National Ambient Air Quality Standards (NAAQS). Findings indicate that PM_{10} consistently exceeded permissible limits, peaking in 2018. Seasonal analysis reveals that winter months experienced maximum pollution due to temperature inversions and biomass burning, whereas monsoon rains significantly reduced concentrations through washout effects. While NO_2 levels declined over time and SO_2 remained within safe thresholds, a household survey of 100 residents identified significant gaps in public awareness. These results highlight an urgent need for targeted educational campaigns and localized emission controls. Strengthening regional monitoring networks and enforcing stricter seasonal controls on agricultural and biomass burning to reduce the regional disease burden and improve public health outcomes in Berhampur.*

Key words: *Air pollutants, WBPCB, NAAQS, Air Quality Index, Temporal distribution.*

Introduction

In today's world, air pollution is a major environmental problem, especially due to rapid industrial growth, urban expansion, and unchecked development (Ghosh et al., 2023). In the last twenty years, deaths related to modern air and chemical pollution have risen by 66%. Air pollution is now linked to over 6.5 million deaths each year. (Fuller et al., 2022). About 90% of these deaths occur in low- and middle-income countries (Fuller et al, 2022). This is caused by unplanned city growth, high fossil fuel use, and weak environmental regulations. Poor air quality poses a serious risk to public health. According to the World Health Organization (WHO), 99% of people worldwide live in areas that exceed its air quality guidelines. In 2019, outdoor air pollution was responsible for 2 million premature deaths globally (Fuller et al, 2022).

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In today's world, air pollution has become a major environmental issue, especially in rapidly developing countries like India (Gurjar et al,.2016). This problem mainly comes from uncontrolled urban growth, vehicle emissions, construction work, and burning fossil fuels. Among the many pollutants, particulate matter (PM_{10}) is a significant cause of worsening air quality. PM_{10} affects visibility and the environment and poses serious health risks because it can penetrate the thoracic region, causing chronic bronchitis, asthma, and reduced lung function. Recent reports link over 6.5 million deaths each year to air pollution, with the burden heavily affecting low- and middle-income areas, including parts of eastern India like Murshidabad (Fuller et al, 2022). Driven by chronic exposure to particulates, leading to ischemic heart disease (IHD), strokes, and lung cancer. Acute exposure during winter peaks triggers sudden cardiac arrests and respiratory failure. To track and evaluate the effects of pollution on public health, the Air Quality Index (AQI) acts as a standard tool that simplifies complex pollutant data into one easy-to-understand value (Bishoiet et al.,.2009). AQI is a tool created to reflect the public point of view of AQI and its associated health risk. Understanding the ''good'' and "bad" air quality is straightforward. The AQI levels depend on various pollutant concentrations. The Central Pollution Control Board (CPCB), India uses eight pollutants to calculate AQI, i.e., particulate matter [PM_{10} (μg/m^3)], particulate matter [$PM_{2.5}$ (μg/m^3)], nitrogen dioxide [NO_2 (μg/m^3)], sulphur dioxide [SO2 (μg/m^3)], carbon monoxide [CO (mg/m^3)], ground-level ozone [O_3 (μg/m^3)], ammonia [NH3 (ìg/m^3)] and lead [Pb (μg/m^3)]. In India, the AQI is calculated based on eight major pollutants, with PM_{10} being one of the most important, especially in semi-urban and developing districts. The levels of PM_{10}, NO_2, SO_2 are heavily influenced by local activities such as road dust, construction, burning biomass, and brick kilns, vehicle emissions which are common in Berhampore and its nearby areas (Ghosh et al, 2023).

Meteorological factors like temperature, wind speed, humidity, and rainfall also play a key role in how PM_{10} spreads or builds up in the air (Ghosh et et.al 2023), **(**Feng et al. 2020). For example, temperature inversions during winter can keep pollutants close to the ground, causing AQI spikes **(**Feng et el, 2020). Seasonal changes often show that PM_{10} levels—and AQI—tend to be higher in the winter and lower during the monsoon because of washout effects (Ghosh et al. 2023), which we can also see in this study, where Berhampore has a higher concentration of PM_{10} in winter seasons.

This study aims to look at the distribution of AQI, focusing on PM_{10}, NO_2, SO_2 in Berhampore, Murshidabad, from 2016 to 2024 from the manually operated WBPCB station in Berhampore, as data from 2016 are available. The analysis covers monthly, seasonal, and annual patterns to grasp long-term trends and changes. Despite being a high-density administrative hub, there is a systemic lack of longitudinal air quality research for Berhampore. This study fills a critical data void, providing a scientific baseline for the West Bengal Pollution Control Board (WBPCB) to design localized "Clean Air Action Plans". This research offers valuable insights into how PM_{10} pollution patterns shift over time in a smaller urban area like Berhampore, and the need to educate people about the risks of air pollution-related health risks, as the awareness is very poor among the residents of the study area.

Objectives

To analyze the temporal variation of Air Quality Index (AQI) and PM_{10}, NO_2, SO_2 in Berhampore, Murshidabad, from 2016 to 2024, across annual, monthly, and seasonal timeframes. Study the trends and fluctuations of PM_{10}, NO_2, and SO_2 concentrations during the study period and identify periods of critical exceedances. Assess the long-term trend of AQI and the seasonal and monthly trend throughout the years of PM_{10} in Berhampore. To find out the awareness about Air pollution among the residents of Berhampore, the need to educate people about the health risks related to it and the need for regulation to control air pollution in smaller cities like Berhampore from the government and local communities to ensure the sources of air pollutants.

Study Area

The current research takes place in Berhampore, the administrative center of the Murshidabad district in West Bengal, India. Berhampore is located between 24°05' N and 24°10' N latitude and 88°15' E and 88°20' E longitude, with an average elevation of about 18 meters above sea level. The Murshidabad district is strategically positioned in the north-central part of West Bengal. It is bordered by Malda district to the north, Nadia district to the south, Birbhum district to the west, and Bangladesh to the east. This location is important both geopolitically and environmentally. Berhampore serves as the administrative and commercial hub of Murshidabad, and its air quality is a direct byproduct of its unique physical geography and rapid urbanization. The town's flat topography (average elevation of 18m) and its location within the Ganga-Bhagirathi basin influence local wind patterns. While the Bhagirathi River acts as a natural corridor for air movement, the town suffers from a declining green belt due to horizontal urban expansion. The existing vegetation is fragmented, providing limited "carbon sinking" capacity to offset the particulate matter generated by high-density residential zones. Furthermore, the region's susceptibility to thermal inversions during winter traps ground-level pollutants, exacerbating the concentrations of $PM_{10.}$

Unlike heavy industrial zones, Berhampore's pollution profile is dominated by small-to-medium enterprises. Key contributors include:

- Brick Kilns: Numerous kilns in the peri-urban fringes contribute significantly to SO_2 and PM_{10} levels.
- Construction Activity: Unregulated real estate development across the town is a primary source of fugitive dust.
- Biomass Usage: A significant portion of the suburban population still relies on solid fuels for cooking and heating, contributing to localized "smoke pockets."

The most critical human factor is the dramatic shift in transport dynamics. Berhampore is a transit point for North-South Bengal connectivity, leading to:

- Vehicle Density: There has been a steady increase in registered Internal Combustion Engine vehicles, particularly heavy-duty trucks and diesel-operated buses.
- The *"Toto"* Revolution: While the town has seen a massive surge in electric three-wheelers (locally known as *Toto*), they primarily replace non-motorized transport (cycles/ rickshaws) rather than heavy emitters. The proportion of electric vehicles to private cars and commercial freight remains negligible.
- Traffic Congestion: Narrow, historical road networks lead to frequent idling at major intersections like Panchanantala and Mohan, resulting in high localized NO_2 emissions.

Materials and Methods

1. **Primary Data:** A household survey was done in Berhampore to collect the data about Air Pollution awareness and its Health impact among the residents.

2. **Secondary Data:** The air pollutant data (PM_{10}, NO_2, and SO_2) were collected from the West Bengal Pollution Control Board (WBPCB), which is controlled by the Central Pollution Control Board (CPCB), New Delhi. Three criteria pollutants, particulate matter (PM10), nitrogen dioxide (NO2), and sulphur dioxide (SO_2), were used to calculate the air quality index (AQI) as per the Central Pollution Control Board (CPCB) guideline. Over the course of the study period from 2016 to 2024, as data before it was not available, the data on the selected pollutants were collected from the Berhampur monitoring stations situated in the Murshidabad district of West Bengal, India (Ghosh et al,.2024).AOD was collected from Giovanni (NASA EARTH) over the period from 2016 to 2024 to measure the quantification of the amount of aerosols in the atmosphere.

3. Sample Design: The primary data collection followed a Simple Random Sampling framework to evaluate the environmental literacy and health awareness of Berhampore's residents. By utilizing a random selection process, every household within the municipal boundaries was afforded an equal probability of inclusion, thereby mitigating selection bias and ensuring a representative cross-section of the town's demographic. A total of 100 respondents were interviewed using a structured questionnaire that targeted three core areas: their personal observation of seasonal pollution fluctuations, their history of respiratory ailments, and their awareness of the Air Quality Index (AQI). The sample size of 100 residents was determined using Cochran's Formula (1977) for large populations.

4. Air quality index (AQI) analysis: The Air Quality Index (AQI) is a mechanism for clearly explaining the air quality status to the general public. It simplifies the complicated information about the air quality caused by different contaminants into a single number (index value), nomenclature, and colour (Bishoi et al,.2009). The CPCB guidelines for computing AQI state that

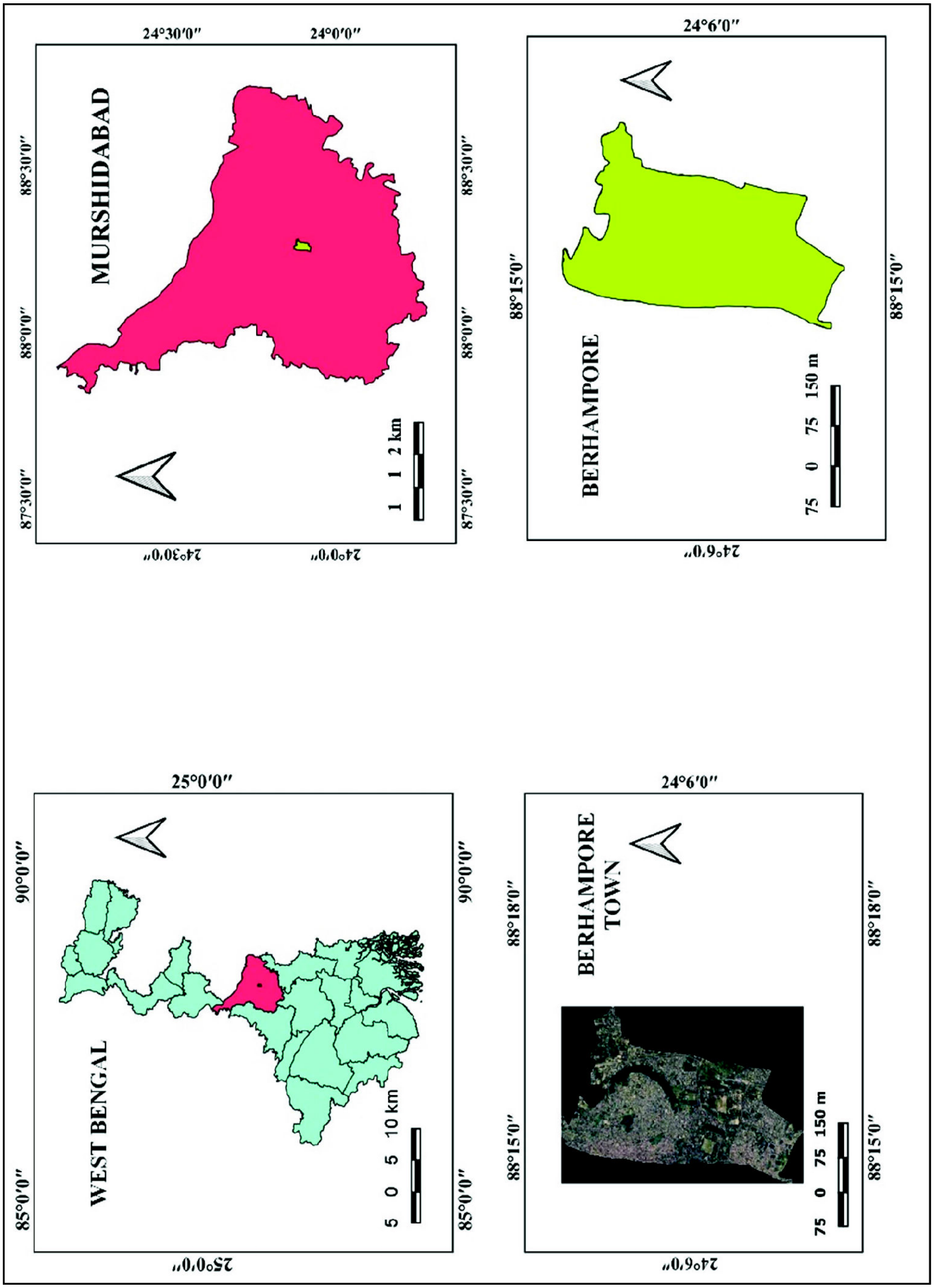

Fig. 1: Location Map

Source: DIVA-GIS and prepared by QGIS 3.16 the sub-indices for particular pollutants at a monitoring station are calculated using the pollutants' health breakpoint concentration range and 24-hourly average concentration value (except for CO and O_3). At least three pollutants were required to calculate the AQI, where one PM must be used, either $PM_{2.5}$ or PM_{10}. The CPCB provided a total of eight pollutant break points, such as particulate matter PM_{10} and $PM_{2.5}$, nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), ammonia (NH_3) and lead (Pb) (Ghosh et el,.2023), (Bishoi et al,.2009).

5. Statistical analysis: MS Excel and QGIS v3.16 were utilized to conduct the statistical analysis. The data screening, curing, managing, and calculating mean, standard deviation, minimum, and maximum were carried out by using MS Excel and the Julia language.

6. Exceedance factor (EF): Exceedance factors (EF) are utilized to determine the air quality status of a certain place and the degree to which it surpasses the National Ambient Air Quality Standard (NAAQS) for 24 hour and annual average (Ghosh et al,. 2024). The EF is a pivotal metric utilized in our research to quantify the degree to which concentrations of pollutants exceed predetermined limits or established regulatory standards. EF provides a quantitative assessment of the extent to which air pollution surpasses permissible thresholds, thereby offering valuable insights into the severity of the air pollution issue. The EF helps to quantify deviation from standards, analyze the severity of air pollution, identify the air pollution hotspots, and analyze the temporal and spatial variability of air of an area. To calculate the EF, the annual average mass con centration of selected criteria pollutants and the annual national ambient air quality standard are divided. The EF ratio category and pollution levels are provided in Table 1**.** The following equation is used to compute the exceedance factor.

EF = Cpi /Spi

Where EF = exceedance factor

Cpi = observed *i*th criteria pollutant concentration

Spi = Central Pollution Control Board (CPCB)–provided standard or threshold *i*th pollutant concentration.

Table 1: Exceedance factor category and pollution levels

	Category exceedance factor	Level of pollution
1.	>1.5	Critical pollution (CP)
2.	1.0–1.4	High pollution (HP)
3.	0.5–0.9	Moderate pollution (MP)
4.	<0.5	Low pollution (LP)

Results and Discussion

Spatiotemporal Distribution of AQI:

The dataset shows the average monthly and annual Air Quality Index (AQI) values in Berhampore from 2016 to 2024. In the (Table. 2) the data reveals a clear seasonal pattern, with higher AQI values during winter months, from November to January, and lower values during the monsoon and post-monsoon months, from June to September (Ghosh et el,.2023) For example, the AQI in January ranged from 186 in 2016 to 111 in 2024, showing a decreasing trend over the years. Several data points for 2019 and 2020 are marked as "N/A," likely due to missing records during the COVID-19 pandemic. The annual average AQI fluctuates over the years, peaking at 132 in 2018 and dropping to a low of 70 in 2020. After 2020, AQI values mostly stayed within the "Satisfactory" range, which is between 51 and 100, indicating a gradual improvement in air quality. When categorized using the CPCB colour code, the AQI values show a transition from "Moderate" (101 to 200) to "Satisfactory" (51 to 100) or nearly "Good" (0 to 50) for many months in recent years. (Ghosh et al,.2023).

Table 2: Year-wise monthly variations of AQI in Berhampore from 2016 to 2024

	2016	2017	2018	2019	2020	2021	2022	2023	2024
January	186	132	140	N/A	105	86	89	79	111
February	178	134	142	N/A	N/A	90	81	68	123
March	140	131	156	99	N/A	95	77	74	110
April	105	112	143	99	N/A	76	80	70	91
May	80	83	116	98	N/A	66	78	71	62
June	78	71	171	98	55	58	77	77	60
July	66	72	124	92	59	70	75	69	44
August	60	73	120	85	61	80	74	50	48
September	64	76	114	87	64	70	72	45	50
October	83	72	108	165	66	75	84	54	63
November	125	107	126	108	75	91	74	96	102
December	141	150	120	98	76	85	74	97	122
Annual	109	102	132	103	70	79	78	71	82
AQI Color code	Good (0-50)	Satisfactory (51-100)		Moderate (101-200)		Poor (201-300)	Very Poor (301-400)		Severe (401-500)

Table 3: Seasonal Distribution of AQI Data in Berhampur (2016-2024)

	Winter	Summer	Monsoon	AQI	Colour code
	169	88	64	Good	(0-50)
	139	89	74	Satisfactory	(51-100)
	134	143	120		
	98	98	88	Moderate	(101-200)
	91	55	61	Poor	(201-300)
	87	65	74	Very Poor	(301-400)
	82	78	74		
	82	73	55	Severe	(401-500)
	119	71	48		

Source: *WBPCB Air Quality data (2016-2024)*

Seasonal Distribution of AQI:

The seasonal AQI data from 2016 to 2024 are in Table 3. shows clear changes in air quality over time in Berhampore. Winter months consistently have the highest AQI values across nearly all years, with peaks of 169 in 2016 and 139 in 2017. This indicates poorer air quality during the colder months. AQI values usually drop during the monsoon, when rain helps reduce pollution levels. This is evident in 2016, with an AQI of 64, 2020 at 61, and 2024 at 48. Summer AQI values stay in a mid-range, varying between 55 and 143. Notably, 2018 recorded an unusually high summer AQI of 143, which is the highest summer value in the dataset (Ghosh et el,.2023). The AQI color code classification shows progress from “Moderate” and “Poor” in earlier years to “Satisfactory” in more recent years, especially during the monsoon and summer. However, in 2023, the winter AQI reached an unusual high of 82, even though summer and monsoon values were lower. This suggests localized winter pollution sources or unusual weather patterns. The bar graph (Fig. No.2) shows the changes in AQI over the seasons in Berhampore from 2016 to 2024. Winter (green bars) usually has the highest AQI values. In 2016, it reached around 170, in 2017 it was about 140, and in 2018 it was approximately 135. This indicates significant air pollution during winter. An unusual spike in summer AQI occurred in 2018, hitting around 145. This was higher than the winter levels, which may point to a unique pollution event. On the other hand, monsoon AQI (yellow bars) is the lowest in most years, especially after 2020, when values fall to around or below 60, showing the cleansing effect of rainfall. From 2019 to 2023, seasonal AQI values are closer together, typically ranging between 60 and 100. This suggests some stability in air quality. However, in 2024, winter AQI increased to about 120, while summer and monsoon values stayed low. This points to a return of seasonal imbalance.

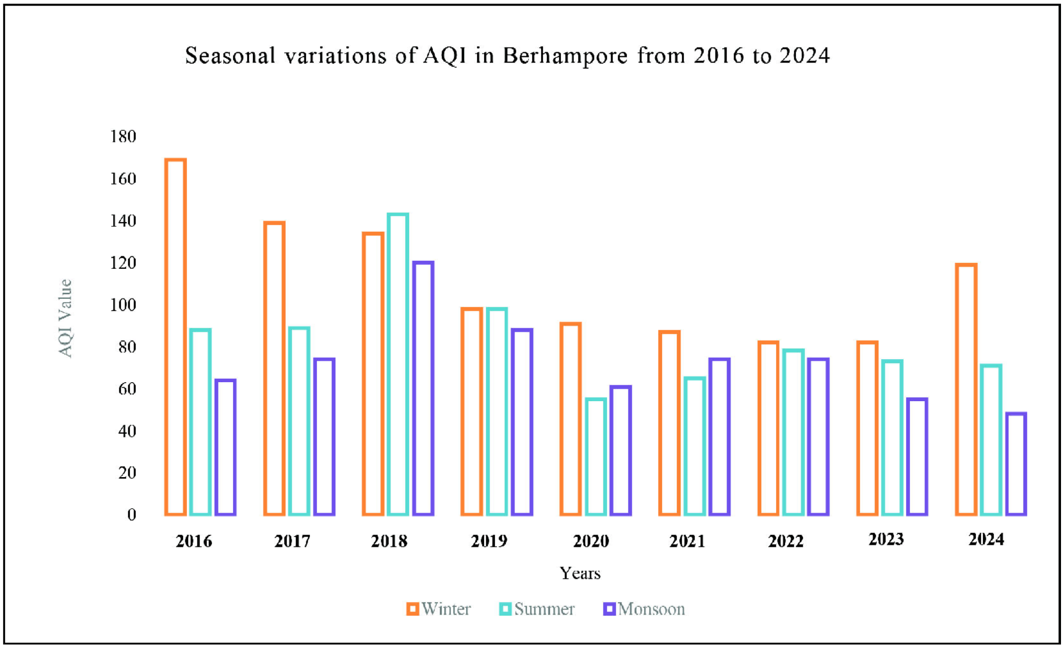

Fig. 2: Seasonal variations of AQI in Berhampore from 2016 to 2024

The graph shows the monthly AQI levels over 9 years, along with a linear trend line that indicates the overall direction of change. The AQI values vary greatly from month to month, with several high peaks, especially in the early years from 2016 to 2018, when monthly AQI levels often went above 150 to 180. There is a noticeable drop in values to nearly zero in 2019 and 2020, which may indicate periods of unusually clean air, possibly due to lockdowns. The red linear trend line has a slight negative slope (y = -0.0141x + 708.6), suggesting a slow decline in AQI over time. The R^2 value of 0.1346 shows that the trend line explains only about 13.5% of the variance in the data, meaning that while there is a general downward trend, the AQI is heavily affected by short-term, seasonal, or irregular events.

Annual Distribution of PM_{10}, NO_2 and SO_2:

In the (Table 4) presents annual average concentrations (± standard deviation) and observed maximum and minimum ranges for PM_{10}, NO_2, and SO_2 from 2016 to 2024. PM_{10} levels peaked in 2018 at 147.39 ± 38.08 µg/m³, with a sharp maximum value of 258 µg/m³. The lowest average was recorded in 2020 at 68.42 ± 15.91 µg/m³, likely due to reduced emissions during pandemic-related lockdowns. A similar downward trend is seen in NO_2 concentrations, which fell from 52.94 µg/m³ in 2016 to 12.88 µg/m³ in 2024, with a significant low in 2020 at 16.19 µg/m³. SO_2 levels consistently

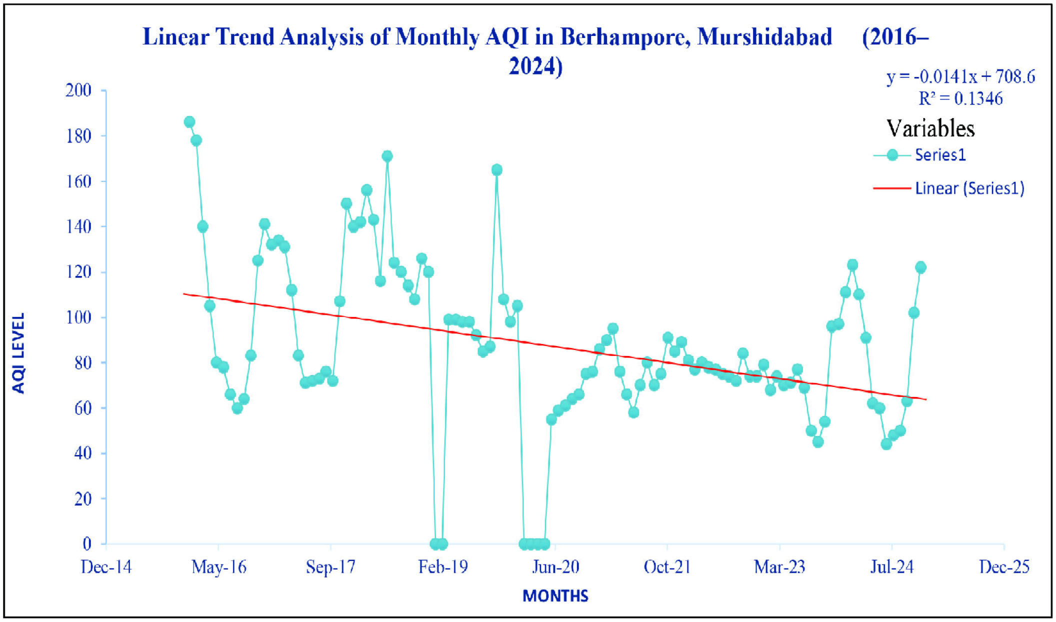

Fig. 3: Linear Trend Analysis of Monthly AQI in Berhampore, Murshidabad (2016–2024)

remained below critical limits and also showed a steady decline, dropping from 10.54 μg/m³ in 2018 to around 2 to 2.6 μg/m³ from 2020 onward. The standard deviation values were relatively higher in the earlier years, indicating greater fluctuations. In contrast, the later years, especially from 2022 to 2024, show lower variability for PM_{10} and SO_2, suggesting more stable pollution levels.

Monthly variation of PM_{10} (μg/m³)

The monthly AQI data for Berhampore from 2016 to 2024 shows clear seasonal and yearly changes. Generally, AQI levels are highest in the winter months of November to January and drop significantly during the monsoon from June to September. The highest AQI recorded in the dataset is from June 2018 at 205.7, followed closely by January 2016 at 223.4, February 2018 at 162.5, and December 2016 at 162.1. All of these indicate moderate to poor air quality. In contrast, the lowest values occur in August 2016 at 41.56 and December 2023 at 9.25; the latter may suggest unusually clean air. From 2020 on, there is a noticeable decrease in AQI levels, especially in the summer and monsoon months. The data also includes missing values for some months in 2019 and 2020, likely due to data collection issues during the COVID-19 pandemic. Despite changes, the overall trend after 2020 shows lower and more stable AQI levels compared to earlier years.

Table 4: Annual Distribution of PM_{10}, NO_2 and SO_2 in Berhampore from 2016 to 2024

Pollutants	PM_{10} (μg/m³)	NO_2 (μg/m³)	SO2 (μg/m³)
Year	Average ± SD (max.–min.)	Average ± SD (max.–min.)	Average ± SD (max.–min.)
2016	118.64 ± 69.10 (300-25)	52.94 ± 6.84 (69-43)	7.51 ± 0.89 (10-5)
2017	108.47 ± 44.13 (222-50)	48.04 ± 4.43 (60-40)	7.23 ± 1.04 (10-5)
2018	147.39 ± 38.08 (258-71)	52.10 ± 4.40 (65-44)	10.54 ± 1.02 (14-8)
2019	105.37 ± 51.92 (455-67)	23.21 ± 4.97 (49-16)	6.59 ± 2.56 (22-2)
2020	68.42 ± 15.91 (122-40)	16.19 ± 4.25 (26-10)	2.43 ± 1.15 (7-2)
2021	78.35 ± 13.91 (125-47)	18.63 ± 3.75 (28-12)	2.11 ± 0.55 (5-2)
2022	77.86 ± 6.67 (104-66)	32.64 ± 15.99 (65-10)	2.13 ± 0.78 (8-2)
2023	69.59 ± 16.53 (109-19)	18.69 ± 4.08 (29-3)	2.64 ± 1.21 (9-2)
2024	83.31 ± 36.20 (168-26)	12.88 ± 5.04 (27-7)	2.53 ± 1.18 (10-2)

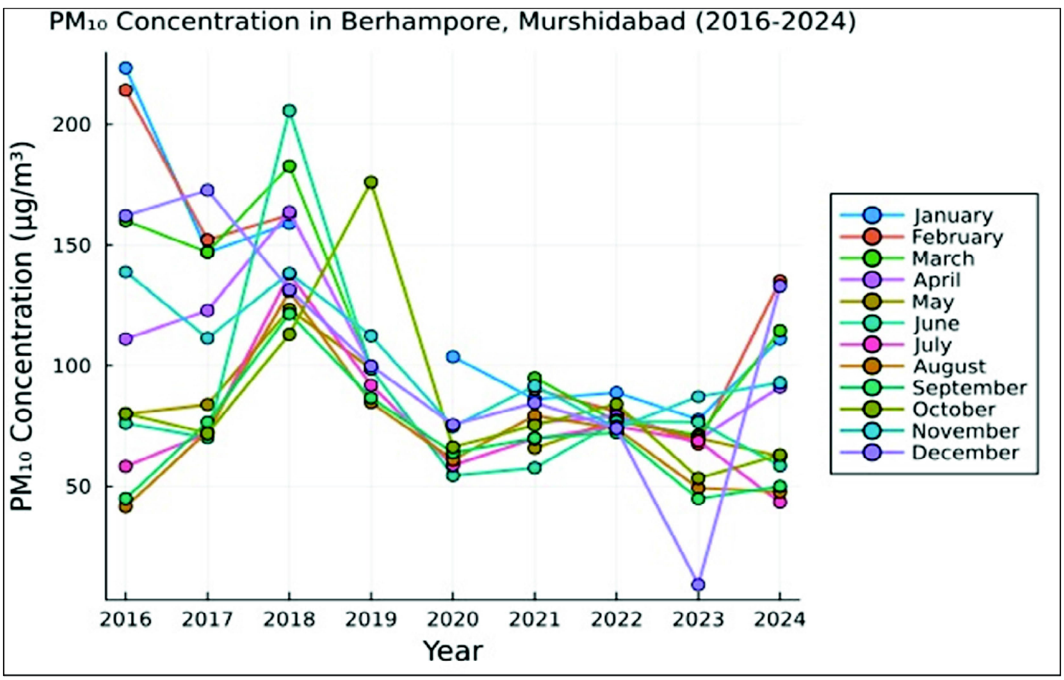

Fig. 4: Monthly Concentration of PM_{10} in Berhampore (2016-2024)

Seasonal variation of PM_{10} (μg/m^3):

The seasonal breakdown of AQI from 2016 to 2024 shows clear patterns of pollution variation across winter, summer, and monsoon periods. AQI levels during winter consistently peak. In 2016, the seasonal average reached its highest point at 199.9, followed by 2017 at 157.23 and 2018 at 150.96. In contrast, monsoon AQI levels tend to be the lowest across most years. The averages were particularly low in 2024 at 49.83 and in 2016 at 58.6. A notable exception occurred in 2018 when all three seasons reported unusually high AQI values, including a surprising monsoon average of 158.1. This suggests widespread pollution events that year. In 2020, the summer AQI was recorded as zero. This likely happened due to missing data or gaps during COVID-19 lockdowns. From 2021 onward, there has been a clear decline in AQI across all three seasons. This is especially true for winter and monsoon months, showing gradual improvements in air quality.

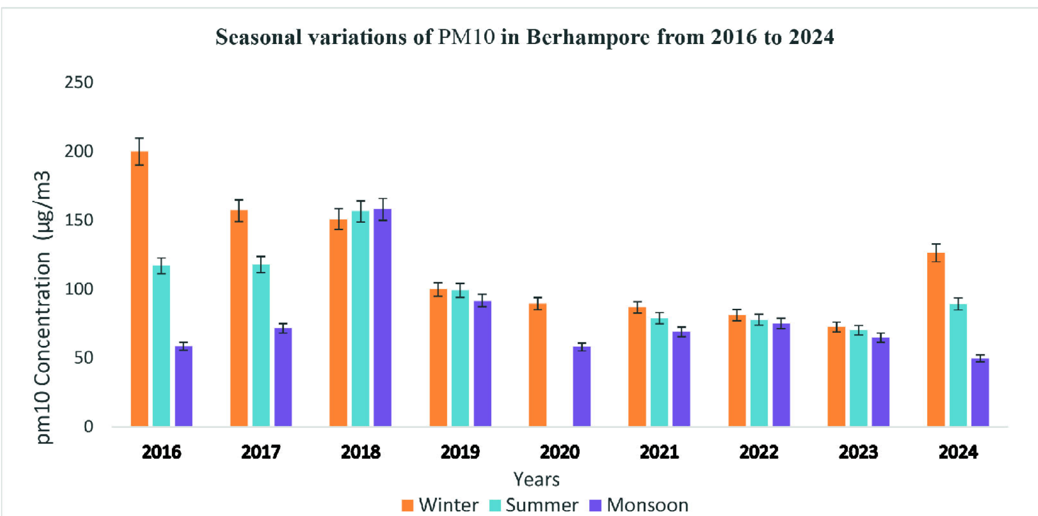

Fig. 5: Seasonal variations of PM_{10} in Berhampore (2016-2024)

NAAQS (National Ambient Air Quality Standards)

The National Ambient Air Quality Standards (NAAQS) are guidelines created by the Central Pollution Control Board (CPCB) under the Ministry of Environment, Forest and Climate Change, Government of India (Ghosh et el,.2023). These standards aim to regulate and maintain the quality of air across the country by setting limits for various air pollutants that could harm public health and the environment. NAAQS provide a legal measure for assessing air quality in urban and rural areas (Ghosh et el,. 2023). Authorities use these standards to begin actions when pollution levels go above safe limits. NAAQS address a range of major air pollutants, including Particulate

Matter (PM_{10} and $PM_{2.5}$), Nitrogen Dioxide (NO_2), Sulphur Dioxide (SO_2), Carbon Monoxide (CO), Ozone (O_3), Ammonia (NH_3), Lead (Pb), and specific toxic pollutants like Benzene, Benzo(a)pyrene, and Arsenic. For instance, the annual limit for PM_{10} is 60 µg/m³, for $PM_{2.5}$ it is 40 µg/m³, and for NO, it is 40 µg/m³. These limits are based on assessments of health risks and scientific research. They aim to protect vulnerable groups such as children, the elderly, and individuals with respiratory or heart conditions. The standards apply to various areas, including industrial, residential, rural, and ecologically sensitive zones. The NAAQS play an important role in shaping environmental policy, setting goals for better air quality, and supporting sustainable development in India.

PM_{10}, NO_2 and SO_2 Variation with NAAQS from 2016-2024:

In the (Fig No 6,7 & 8) from 2016 to 2019, SO_2 concentrations in Berhampore showed a fluctuating trend, with values mostly around 7 to 10 µg/m³. Specifically, concentrations were about 7 to 8 µg/m³ in 2016 and 2017. They rose to just above 10 µg/m³ in 2018 and then dropped to around 7 µg/m³ in 2019. From 2020 to 2024, there was a clear and steady decline in SO_2 levels, with concentrations staying very low, generally below 3 µg/m³. This suggests a significant improvement in SO_2 air quality during this time. Importantly, throughout the entire study period from 2016 to 2024, the annual average SO_2 concentrations in Berhampore stayed well below the NAAQS limit of 50 µg/m³. This indicates that SO_2 levels were consistently within safe limits. The low concentrations observed, especially from 2020 onwards, suggest that SO_2 may not be a major air pollution concern in Berhampore during this period, or that effective measures have been in place to control its emissions.

AOD (Aerosol Optical Depth):

The interannual time series graph presents the trend of AOD at 550 nm, as derived from the MODIS-Terra MOD08_M3 v6.1 product over the Berhampore region, during the period from January 2016 to December 2024, which was collected from Giovanni. It is known that AOD is an important measure for the quantification of the amount of aerosols in the atmosphere. Consequently, higher values mean more aerosols are present and hence higher levels of air pollution. It is identified that changes in AOD levels have fluctuated significantly during the study period. The lowest ever recorded value was in 2019 at about 0.81, while the highest reached around 0.98 in 2024. It has been steadily increasing in recent years. AOD fell after 2016, reaching a low point in 2017, and peaked in 2018 at approximately 0.95. Another steep fall was seen in 2019, and this could be because of better emission control measures or due to favourable weather elements in that year, with increased rainfall or stronger winds. After that, an overall increase from 2020 onwards suggests human activities or stagnant weather conditions are causing the buildup of aerosols.

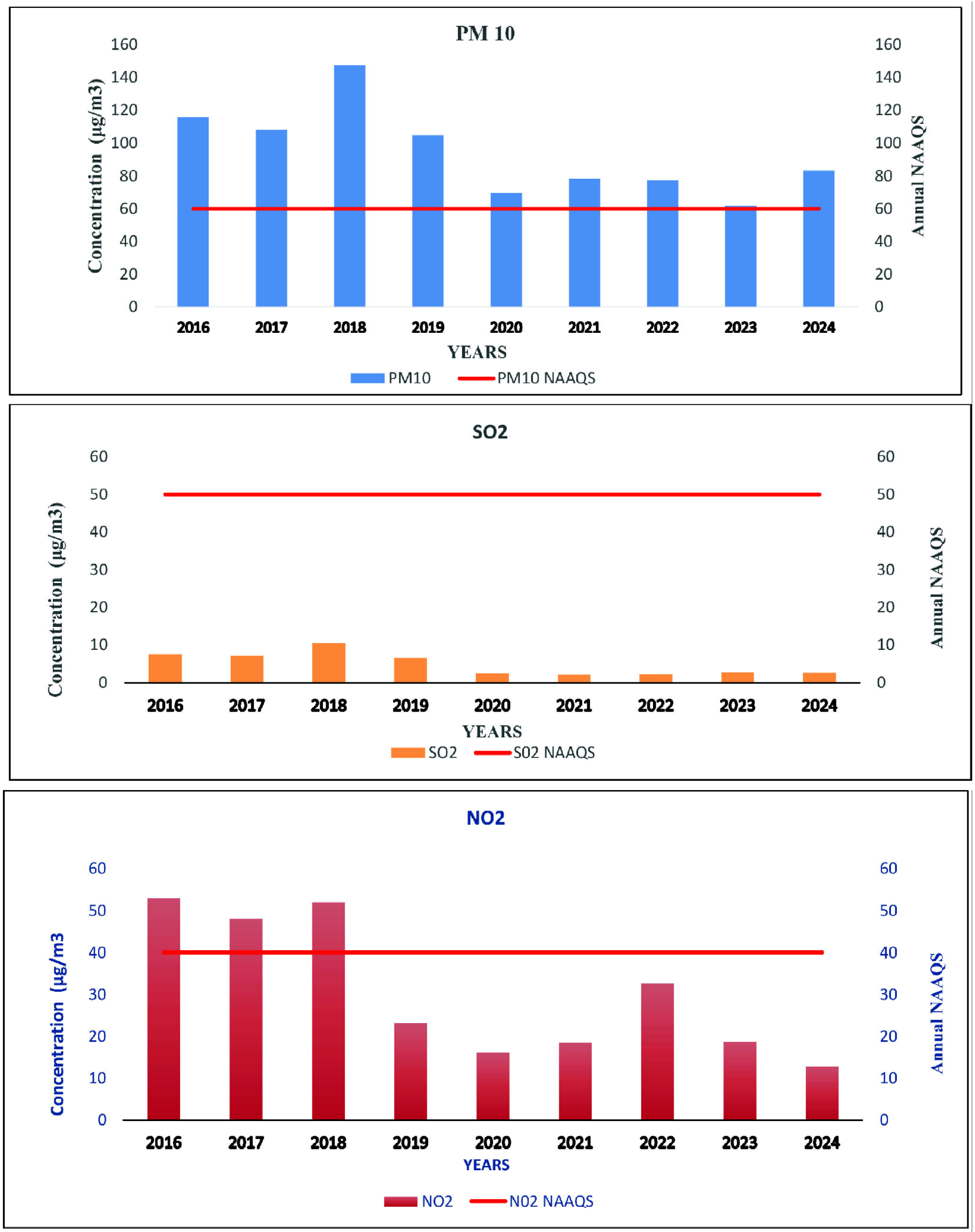

Fig 6,7 & 8: PM10 and NO_2 SO_2 variation with NAAQS in Berhampore from 2016-2024

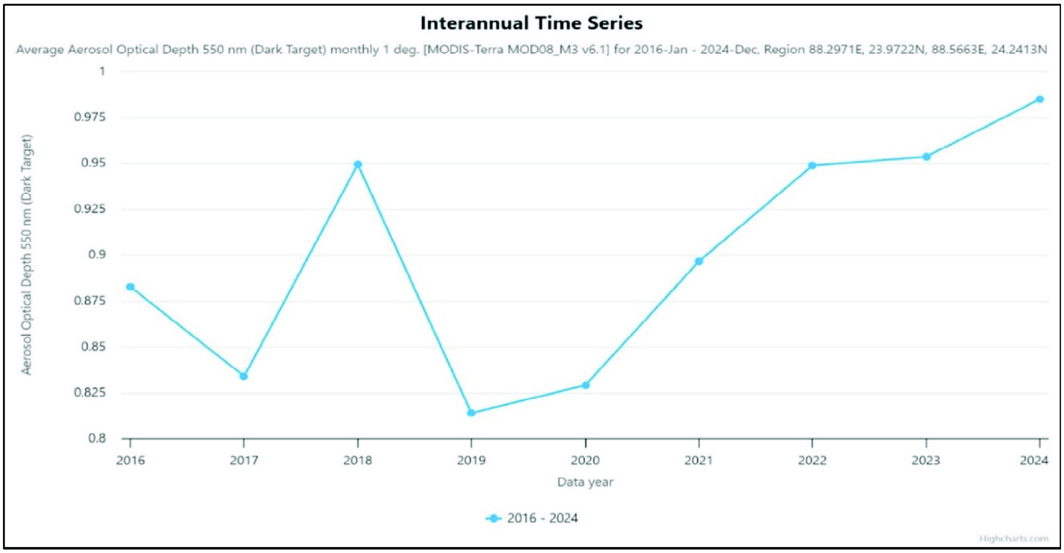

Fig. 9: Average Aerosol Optical Depth 550 nm (Dark Target) monthly.

Source: *Giovanni (NASA Earth Data).*

Public Awareness of Air Pollution:

The data in Table 5 shows that many surveyed households lack awareness and knowledge about air pollution and its harmful effects. Although air pollution is a major environmental and public health problem, most respondents do not understand its impact, health risks, or necessary precautions. This lack of awareness might stem from insufficient public information campaigns, low understanding of environmental issues, or the absence of local air quality monitoring and reporting. Only 20% of respondents said they knew the health effects of air pollution, including asthma, lung diseases, and heart issues. Even though the region is exposed to pollutants like

Table 5: Awareness Criteria of the residents of Berhampore.

Awareness Criteria	Yes (%)	No (%)	Total (%)
Aware of what air pollution is	30	70	100
Heard of AQI (Air Quality Index)	22	78	100
Knows health risks (asthma, lung issues, etc.)	20	80	100
Takes preventive measures (mask, air purifier, etc.)	12	88	100
Believes pollution affects them or their family's health	13	87	100

Source: *Household Survey in Berhampore 2025*

PM_{10} and NO_2 , 80% of people remain unaware of the health risks involved. In terms of protective behaviour, only 12% reported taking any preventive steps, such as wearing masks or using air purifiers. In contrast, 88% did not take any precautions. This shows a lack of response to the worsening air quality. Additionally, only 13% believed that pollution affects their health or their family's health, while 87% did not think so. This highlights a significant gap between exposure to pollution and personal health perceptions.

Exceedance factor (EF):

The Exceedance Factor (EF) analysis indicates significant fluctuations in pollutant levels against the National Ambient Air Quality Standards (NAAQS) (Ghosh et el,. 2024). For PM_{10} , EF values from 2016 to 2019 ranged from 1.75 to 2.46, classifying the air quality as critically polluted, peaking in 2018 at 2.46. A decline began in 2020, attributed to reduced human activity during the pandemic and stricter regulations, with EF values dropping to between 1.14 and 1.38. NO, levels were categorized as high pollution from 2016 to 2018 but showed a downward trend post-2019, reaching 0.32 by 2024 due to improved fuel quality and reduced industrial output, indicating effective pollution control. Despite improvements in NO, management, PM_{10} remains a major environmental and public health concern, necessitating targeted actions to reduce emissions.

Table 6: Exceedance factor (EF) of air pollutants in Berhampore from 2016 to 2024

	2016	2017	2018	2019	2020	2021	2022	2023	2024
PM10	1.97	1.81	2.46	1.75	1.14	1.31	1.29	1.15	1.38
NO2	1.32	1.2	1.3	0.58	0.4	0.47	0.81	0.46	0.32

Findings and Recommendations

PM_{10} pollution is critical in Berhampore, as it often exceeds national safety standards, especially during winters. Air quality is poorest in winters and best during the monsoon season. Though improving after the year 2020 due to the reduction of human activities during the lockdowns imposed, most of these improvements have worn off, and the values have bounced back. NO, is reduced, showing that its emissions are within control, while SO, levels remain within safe limits. Meteorological factors don't affect PM_{10} levels to a large degree, pinning responsibility on human activity. AOD data indicates that there is an increase in aerosol concentrations since 2020, which indicates increased pollution in this town after the lockdowns. Public awareness regarding pollution and health effects is very poor. Recommendations include improvement of AQI monitoring, seasonal pollution control measures, public awareness creation, integration of environmental education at schools, promotion of use of cleaner fuels and public transport, and phase-out of old vehicles.

Conclusion

The study shows that air pollution is still a major environmental and public health problem in Berhampore, with PM_{10} as the main pollutant. There has been some improvement since 2020, mainly due to reduced activities during the COVID-19 pandemic, but the overall trend is still unstable and could worsen. There are clear seasonal changes, with winter being the most polluted time due to a mix of natural weather conditions and human emissions. The limited effect of weather on PM_{10} levels, highlighted by statistical analysis, points to the strong influence of human sources. Many people still lack information and are unprepared, which greatly hinders efforts to address the problem. Effective air quality management in Berhampore needs a broad approach that includes scientific monitoring, strict policy enforcement, and active public participation. If these components are not brought together, air pollution will keep threatening the health and well-being of the local population.

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