Influence of Temperature on PM2.5 concentration over major cities in India during April and May

While high pollutants in the air are a significant concern in the country during the winter months of the year, this study reveals that higher temperatures too can lead to occasional spikes in PM2.5 due to the formation of secondary pollutants by chemical reactions and increased VOC emission(Volatile organic compounds).

Secondary Organic Aerosols (SOA) are created from the oxidation of VOCs, which then condense into particulate matter. Peroxyacetyl Nitrate (PAN) formed from the reaction of NO_x with hydrocarbons, contributing to photochemical smog.

This is particularly relevant with the country experiencing more frequent extreme weather events as temperatures increase and we witness more heatwave days as a growing impact of climate change.

The Rationale

The study attempts to establish the relationship between the concentrations of particulate matter, specifically PM2.5, and background meteorological parameters across five cities in India: Delhi, Lucknow, Kolkata, Mumbai, and Patna. This analysis utilized data from the Central Pollution Control Board (CPCB) for PM2.5 concentrations and temperature data from the ERA5 dataset. The study covers the months of April and May for the years 2022, 2023, and 2024.

This work presents the evaluation of air quality in these diverse locations, representing different urban environments and climatic conditions. The outcome of the study shows that meteorological parameters have a significant influence on PM2.5 concentrations.

Meteorology, the study of the atmosphere and its phenomena, significantly affects the behaviour and fate of atmospheric pollutants. Key meteorological factors, including wind speed, wind direction, temperature, atmospheric stability, and mixing height, substantially impact pollutant concentrations in specific areas. Numerous researchers have found that these parameters play vital roles in the dispersion, transformation, and removal of particulate matter in the lower atmosphere. Additionally, the dispersion of air pollutants is influenced by diurnal variations in boundary layer conditions and other meteorological factors.

By examining the effects of meteorology, we can better understand the local and regional causes of particulate pollution. April and May are critical months for influencing PM2.5 levels in urban areas. These months often signal the transition from spring to summer, characterized by increasing temperatures and changing atmospheric conditions. During April and May, rising temperatures can enhance the photochemical reactions in the atmosphere, leading to the formation of secondary pollutants, including secondary organic aerosols,

which are significant contributors to PM2.5. The increased solar radiation during these months accelerates these chemical processes, potentially raising PM2.5 concentrations.

Compound exposure to PM2.5 and high heat have severe impacts on human health. When PM2.5 exposure occurs concurrently with high heat, several synergistic effects can exacerbate health risks:

- ➔ Respiratory Stress: High heat can worsen respiratory conditions, and combined with PM2.5 exposure, it can increase the severity of respiratory symptoms and reduce lung function further.
- ➔ Cardiovascular Strain: Both PM2.5 and high heat can independently stress the cardiovascular system. Combined exposure may lead to increased heart rate, blood pressure, and inflammation, potentially triggering cardiovascular events.
- ➔ Heat-related Illness: PM2.5 exposure can impair lung function, making it harder for individuals to cope with the physiological stress of high temperatures, increasing susceptibility to heat-related illnesses.

Key Highlights:

Delhi

- PM2.5 levels decreased by 28.4% from 93.81 µg/m³ in April and May 2022 to 67.19 µg/m³ during the same period in 2023. However, in 2024, PM2.5 levels increased by 21.3% to 81.53 µg/m³ in the same months.
- The average temperature dropped from 32.15°C in 2022 to 28.72°C in 2023, then rose by 11% to 31.87°C in 2024 for the two months.

Kolkata

- There was a significant increase in PM2.5 levels from 2022 to 2023, followed by a notable decrease in 2024. Specifically, PM2.5 levels rose by 28.0% from 26.50 µg/m³ in 2022 to 33.93 µg/m³ in 2023, then fell by 11.3% to 30.10 µg/m³ in 2024.
- The temperature remained relatively stable from 2022 to 2023, with a minor decrease from 30.28°C to 30.27°C. However, it rose by 2.5% to 31.04°C in 2024.

Patna

- There has been a notable fluctuation in both PM2.5 levels and average temperature over the years. The drop in PM2.5 levels from 2022 to 2023 is followed by a significant rise in 2024. Similarly, temperature trends align with these fluctuations, showing a decrease from 2022 to 2023 and an increase in 2024.

Lucknow

- The data shows a significant reduction in PM2.5 levels from 2022 to 2023, followed by an increase in 2024. Temperature trends also show a decrease from 2022 to 2023 and a subsequent increase in 2024, indicating a correlation between temperature changes and PM2.5 concentrations.
- 2022 to 2023: PM2.5 levels decreased by 27.7%, from 73.16 µg/m³to 52.87 µg/m³ and 2023 to 2024: PM2.5 levels increased by 17.6%, from 52.87 µg/m³ to 62.17 µg/m³.

Mumbai

- Temperature decreased slightly from 29.55°C in 2022 to 29.42°C in 2023. It decreased further to 29.20°C in 2024.
- In 2022, PM2.5 was 43.17 µg/m³. In 2023, PM2.5 decreased to 30.84 µg/m³.
- In 2024, PM2.5 slightly decreased further to 30.46 µg/m³.

Data Selection and Analysis:

The PM2.5 data for the selected cities were obtained from the Central Pollution Control Board (CPCB) website (https://app.cpcbccr.com). This dataset includes measurements of various air pollutants, such as PM2.5, recorded at monitoring stations in five major Indian cities: Delhi, Lucknow, Patna, Kolkata, and Mumbai. Data were collected for April and May for the years 2022 to 2024. After downloading the data from the CPCB website, the data was organized by a monitoring station for each city. The next step involved calculating the average concentrations of the pollutants for each city. This was done by taking the mean of the pollutant measurements from all monitoring stations within the respective city. By averaging the data station-wise, a representative value for each pollutant for each city was obtained, providing an overall assessment of air quality in the selected urban areas.

Temperature data was collected from the ERA5 portal. This data was available on an hourly basis and was extracted using city shapefiles. The spatial resolution of the ERA5 data was 0.25 x 0.25 degrees.

Results

Patterns of PM2.5 and Temperature across the selected cities

Delhi

Figure-1 Between April 2022 and May 2024, the PM2.5 levels and temperature in Delhi showed considerable variation. In April 2022, PM2.5 levels started (April 1st) at 74.85 µg/m³ and experienced several peaks and troughs, reaching up to 124.79 µg/m³ by April 7th before decreasing to 65.43 µg/m³ on April 22nd. The levels remained relatively high throughout the month. Concurrently, temperatures increased steadily from 27.72°C at the beginning of April to around 33°C by the end of the month. The following month, May 2022, began with PM2.5 levels of 73.68 µg/m³, which fluctuated significantly, hitting a low of 26.57 µg/m³ on May

26th and peaking again at 108.07 µg/m³ on May 14th. Temperatures in May ranged between 30.37°C and 36.67°C, indicating a hot summer period.

Moving forward to April and May of 2023, PM2.5 levels generally showed lower concentrations compared to the previous year. April 2023 began with a PM2.5 level of 46.65 µg/m³, peaking significantly at 125.43 µg/m³ on April 11th before stabilizing to around 51.10 µg/m³ by the end of the month. May 2023 started with lower levels, but there were notable peaks, including 103.98 µg/m³ on May 6th and 131.58 µg/m³ on May 11th, reflecting occasional surges in pollution. Throughout these months, temperatures steadily increased from 21.76°C in early April 2023 to around 33°C by the end of May 2023. The data for April and May 2024 showed similar patterns, with April 2024 starting at 53.66 µg/m³ and ending at 67.18 µg/m³, and May 2024 experiencing significant fluctuations, reaching a high of 141.13 µg/m³ on May 5th. Temperatures continued to rise during this period, reflecting the typical seasonal progression towards summer.

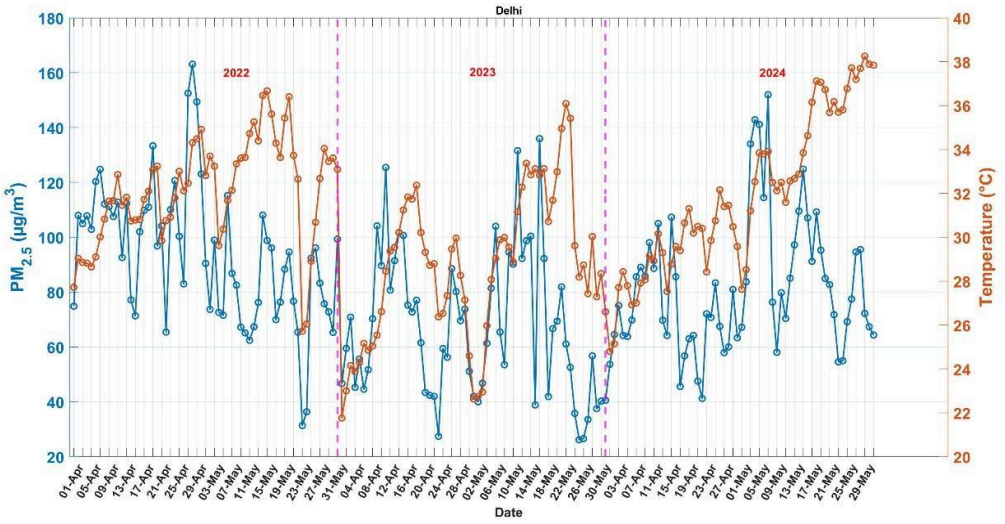

Fig 1 – Daily PM2.5 Concentration in Delhi and Temperature for the period 1st April to 31 May for the year (2022-2024).

Figure 2 - The study includes a detailed plot showcasing hourly temperature data for Delhi, with the y-axis representing the hours of the day (00 to 23) and the x-axis representing the months of April and May. This plot uses colour to indicate the temperature at each hour, providing a clear and comprehensive visualization of temperature variations throughout the day and across the two months. The colour gradient effectively highlights temperature fluctuations, making it easy to identify patterns and trends. For example, it illustrates how temperatures peak during the afternoon hours and cool down at night, as well as any notable changes in temperature between April and May. This plot is particularly useful for understanding diurnal temperature variations and their progression over these months in Delhi

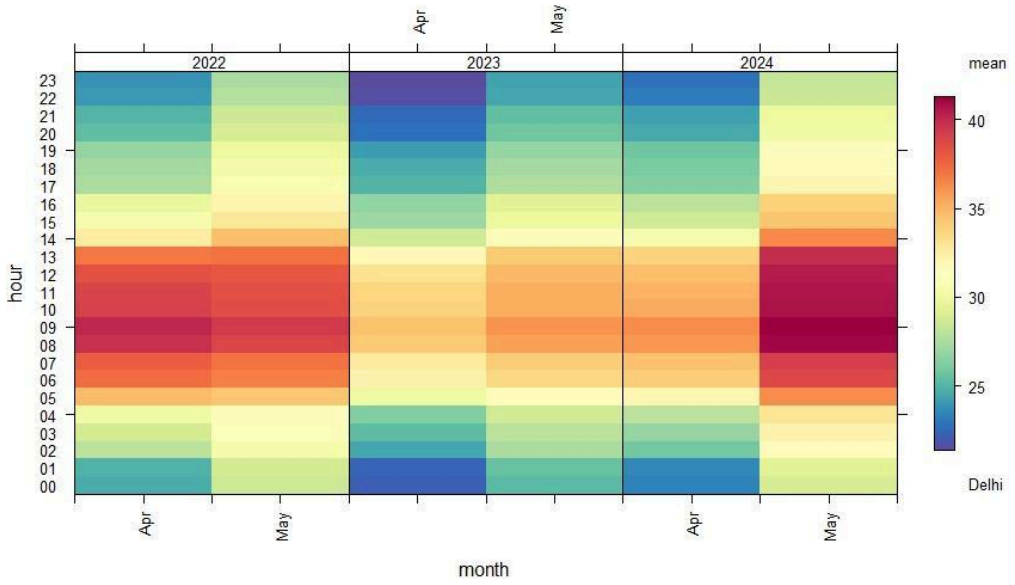

Fig 2 – Hourly variations of Temperature during April and May for Delhi.

Lucknow

Figure 3 - The air quality and temperature trends for Lucknow from April 2022 to May 2024 show significant variability in PM2.5 levels and temperatures over the two years. In April 2022, PM2.5 levels were generally high, starting at 92.065 µg/m³ and peaking at 121.015 µg/m³ by the end of the month. Correspondingly, temperatures increased from around 29.95°C at the beginning of April to approximately 33.93°C by the end of May 2022. This indicates a typical pre-monsoon pattern where rising temperatures are accompanied by higher pollution levels, likely due to increased vehicular and industrial emissions and dust in the air.

From April 2023, there is a noticeable drop in PM2.5 levels, starting at 20.072 µg/m³ and remaining relatively lower compared to the previous year, even as temperatures ranged between 22.10°C and 30.19°C. However, by mid-May 2023, both PM2.5 levels and temperatures rose again, with PM2.5 peaking at 109.77 µg/m³ and temperatures reaching up to 35.97°C. This suggests that seasonal changes and possibly policy interventions might have influenced the temporary improvement in air quality. By April 2024, the data shows a fluctuating pattern with PM2.5 levels varying significantly, peaking at 99.31 µg/m³ in mid-May, while temperatures consistently stayed high, reaching up to 38.21°C by the end of May 2024. This highlights the persistent issue of air pollution in Lucknow, which remains a challenge despite seasonal variations and efforts to control it.

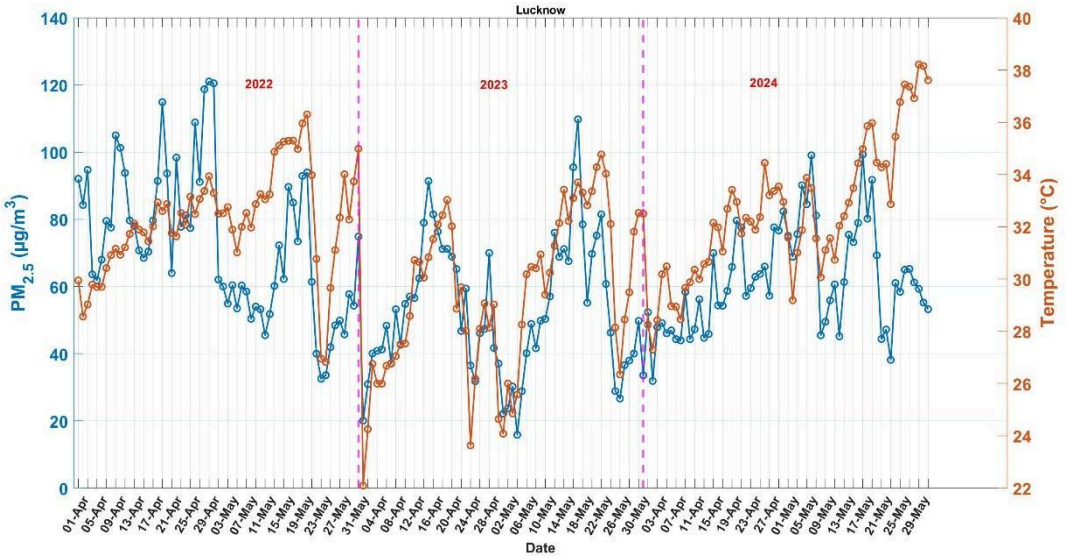

Fig 3 – Daily Pm 2.5 Concentration in Delhi and Temperature For the period 1st April to 31 May for the year (2022-2024)

Figure 4 - The study includes a detailed plot showcasing hourly temperature data for Lucknow, with the y-axis representing the hours of the day (00 to 23) and the x-axis representing the months of April and May. This plot uses colour to indicate the temperature at each hour, providing a clear and comprehensive visualization of temperature variations throughout the day and across the two months. The colour gradient effectively highlights temperature fluctuations, making it easy to identify patterns and trends. For example, it illustrates how temperatures peak during the afternoon hours and cool down at night, as well as any notable changes in temperature between April and May. This plot is particularly useful for understanding diurnal temperature variations and their progression over these months in Lucknow.

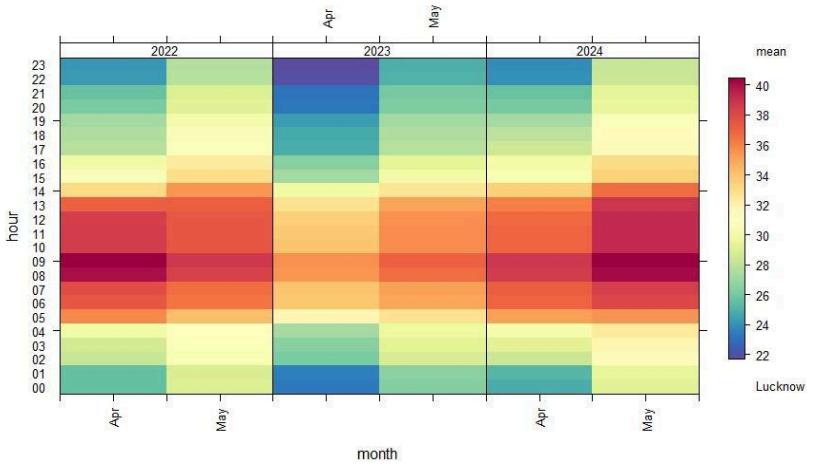

Fig 4 – Hourly variations of Temperature during April and May for Lucknow

Kolkata

Figure 5 Based on the PM2.5 levels and temperature from April 2022 to May 2024, a clear relationship between these variables can be observed. PM2.5 concentrations exhibit noticeable fluctuations throughout the dataset, ranging from as low as around 10 µg/m³ to peaks exceeding 60 µg/m³. These variations often correspond with changes in temperature, which generally ranges from approximately 24°C to 36°Cover the same period.

A closer examination reveals that PM2.5 levels tend to rise during warmer months, particularly from April to May in both 2023 and 2024. During these periods, temperatures are consistently higher, reaching their annual peaks. Conversely, lower PM2.5 concentrations are often recorded during cooler months, such as in early 2022 and the latter parts of each year. This inverse relationship between PM2.5 and temperature suggests that higher temperatures may contribute to increased atmospheric pollutants, possibly due to enhanced chemical reactions or reduced dispersion rates under stable atmospheric conditions.

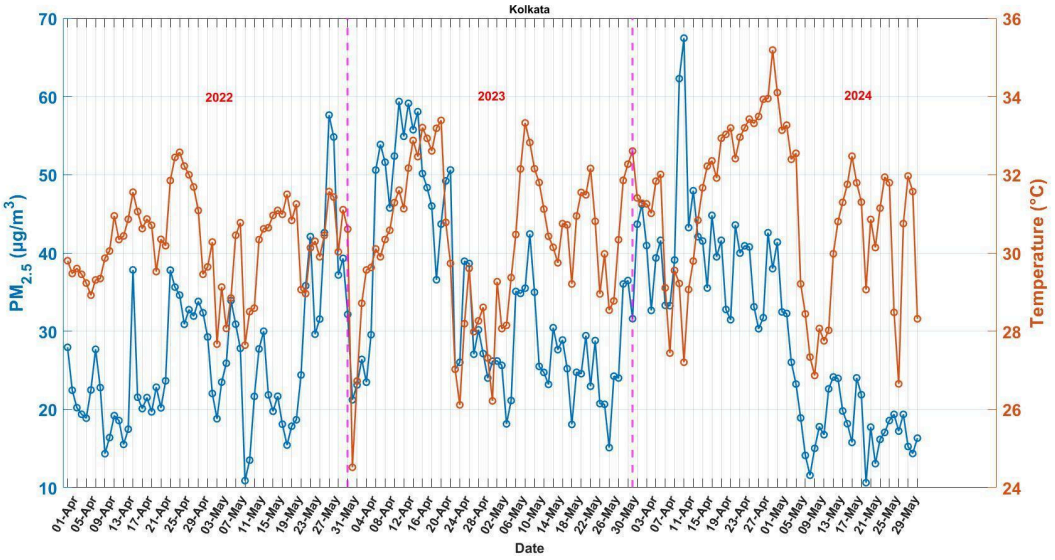

Fig 5 – Daily Pm 2.5 Concentration in Kolkata and Temperature For the period 1st April to 31 May for the year (2022-2024)

Figure 6 - The study includes a detailed plot showcasing hourly temperature data for Kolkata, with the y-axis representing the hours of the day (00 to 23) and the x-axis representing the months of April and May. This plot uses colour to indicate the temperature at each hour, providing a clear and comprehensive visualization of temperature variations throughout the day and across the two months. The colour gradient effectively highlights temperature fluctuations, making it easy to identify patterns and trends. For example, it illustrates how temperatures peak during the afternoon hours and cool down at night, as well as any notable changes in temperature between April and May. This plot is particularly useful for understanding diurnal temperature variations and their progression over these months in Kolkata.

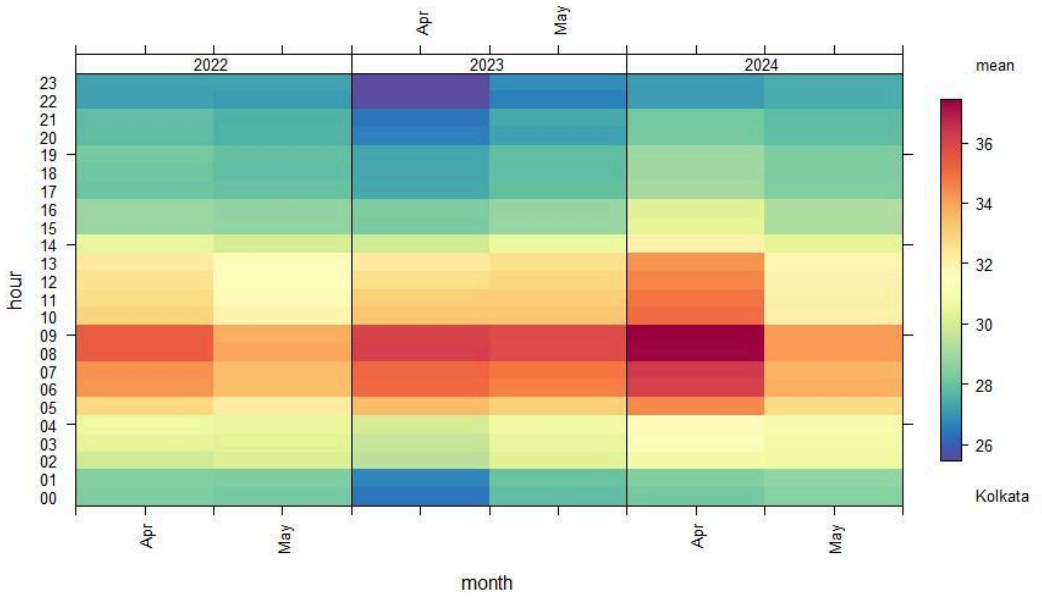

Fig 6 – Hourly variations of Temperature during April and May for Kolkata

Mumbai

Figure 7 - Based on the data, the relationship between PM2.5 levels and temperature exhibits interesting patterns and trends. In April 2022, there were noticeable spikes in PM2.5 concentrations corresponding with higher temperatures. For instance, on April 21, 2022, PM2.5 levels reached 58.41 when the temperature was 31.05°C. Similarly, on April 22, 2022, PM2.5 levels rose to 65.74 alongside a temperature of 30.98°C. These instances suggest that higher temperatures might contribute to increased PM2.5 concentrations, possibly due to enhanced chemical reactions in the atmosphere or increased emissions of pollutants.

A similar trend is observed in April 2023 and 2024. On April 18, 2023, PM2.5 levels were at 40.49 with a temperature of 30.79°C, and on April 19, 2023, they peaked at 49.21 with a temperature of 31.09°C. In April 2024, notable peaks in PM2.5 levels also coincide with high temperatures, such as on April 16, 2024, where PM2.5 reached 47.54 and the temperature was 31.11°C. These recurring patterns across different years emphasize a consistent correlation where higher temperatures tend to coincide with elevated PM2.5 levels. This relationship highlights the importance of monitoring air quality, especially during warmer periods, to mitigate the adverse effects of air pollution on health and the environment.

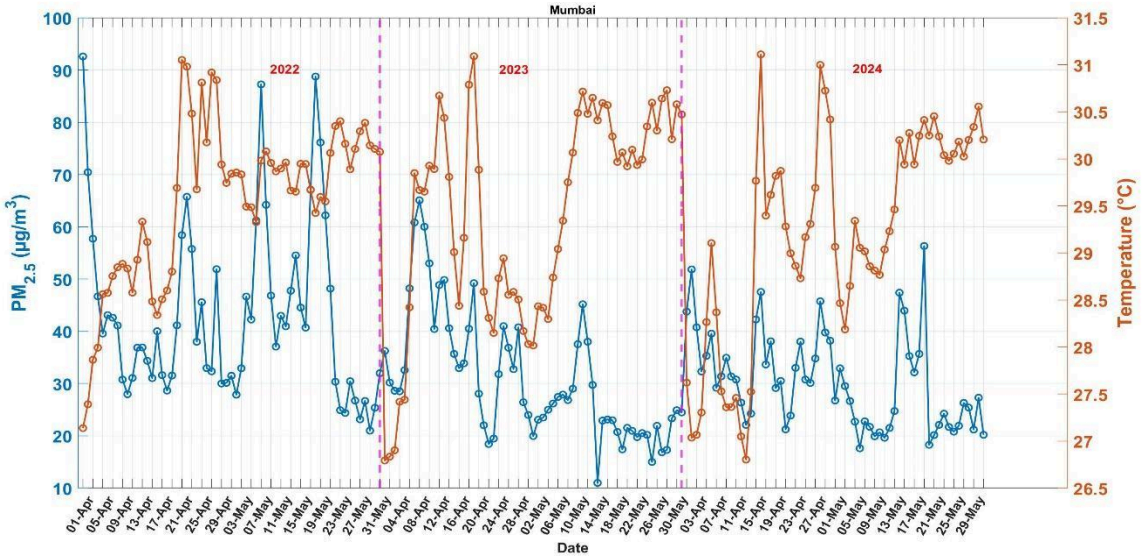

Fig 7 – Daily Pm 2.5 Concentration in Mumbai and Temperature For the period 1st April to 31 May for the year (2022-2024)

Figure 8 - The study includes a detailed plot showcasing hourly temperature data for Mumbai. The plot uses a colour-coded representation where the y-axis represents the hours of the day (00 to 23), and the x-axis represents the months of April and May. This visualization effectively illustrates temperature variations throughout the day and across the two months, utilizing a colour gradient to highlight fluctuations. It allows for easy identification of patterns such as peak temperatures during the afternoon hours and cooler temperatures at night. Additionally, it facilitates the observation of any notable changes in temperature between April and May, providing insights into diurnal temperature variations and their progression over these months in Mumbai.

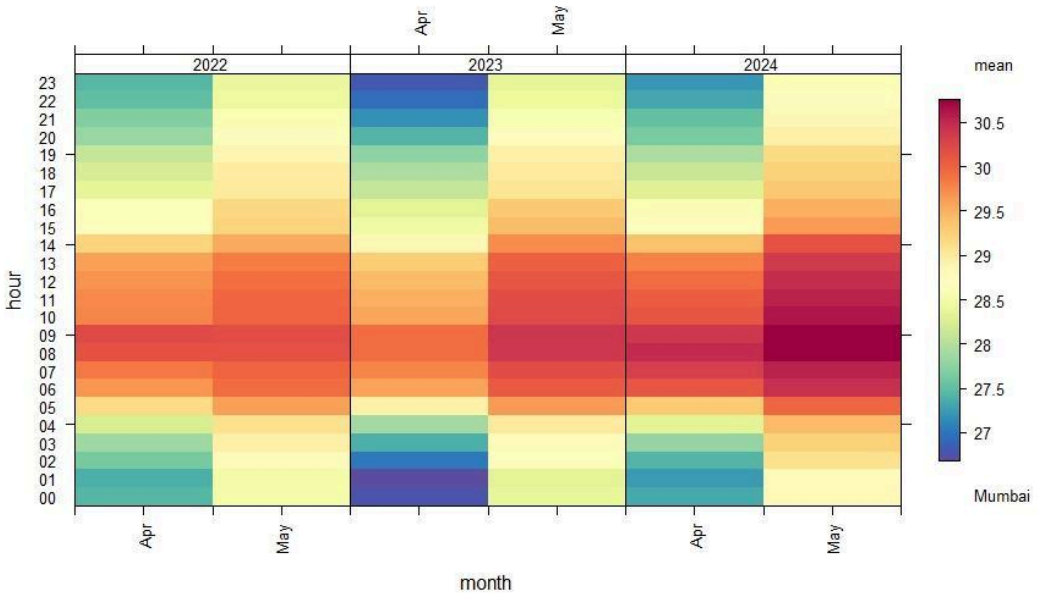

Fig 8 – Hourly variations of Temperature during April and May for Mumbai

Patna

Figure-9 The data reveals a distinct relationship between PM2.5 levels and temperature over multiple years, with notable peaks and troughs. In April 2022, there are two significant peaks in PM2.5 levels, around mid-April and towards the end of the month. The highest PM2.5 levels reached 140.94 on April 17 and 164.36 on April 24, correlating with temperatures of 32.36°C and 32.98°C, respectively. This pattern indicates a tendency for higher PM2.5 concentrations when temperatures rise above 32°C. Similar trends are observed in subsequent years, where higher temperatures often coincide with increased PM2.5 levels, suggesting a possible causal relationship where elevated temperatures may contribute to the formation or accumulation of PM2.5 pollutants.

Further analysis of the data from 2023 and 2024 supports this observation. For instance, in April 2023, PM2.5 levels again show peaks in mid to late April, with a notable spike to 123.95 on April 12 when the temperature was 31.27°C. By the end of April, PM2.5 levels and temperatures remained high, with values peaking at 71.61 and 27.02°C on April 30. In April 2024, the pattern persists, with significant PM2.5 spikes such as 128.97 on April 19 and 120.15 on April 30, accompanied by temperatures around 34°C and 35.6°C. These recurring patterns underscore the strong correlation between higher temperatures and elevated PM2.5 levels, suggesting that temperature increases could exacerbate air pollution problems, potentially due to increased emissions or chemical reactions that form particulate matter.

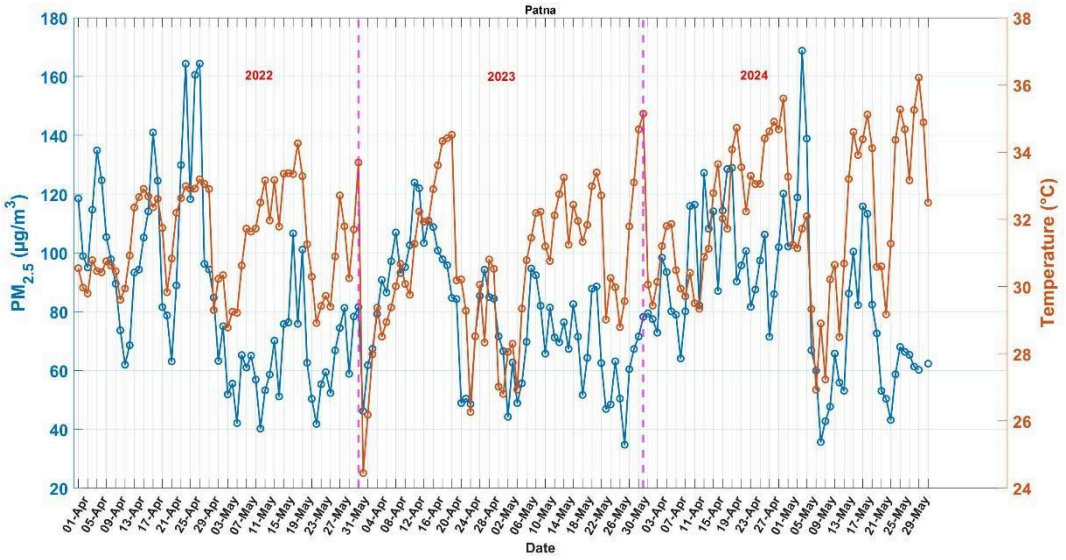

Fig 9 – Daily Pm 2.5 Concentration in Patna and Temperature For the period 1st April to 31 May for the year (2022-2024)

Figure 10 - The study includes a detailed plot showcasing hourly temperature data for Patna. This plot uses a color-coded representation where the y-axis represents the hours of the day (00 to 23), and the x-axis represents the months of April and May. The colour gradient effectively highlights temperature fluctuations, enabling clear identification of patterns such as peak temperatures during the afternoon hours and cooler temperatures at night. This visualization provides a comprehensive view of how temperatures vary throughout the day and across the two months, offering insights into diurnal temperature variations and any notable changes between April and May in Patna.

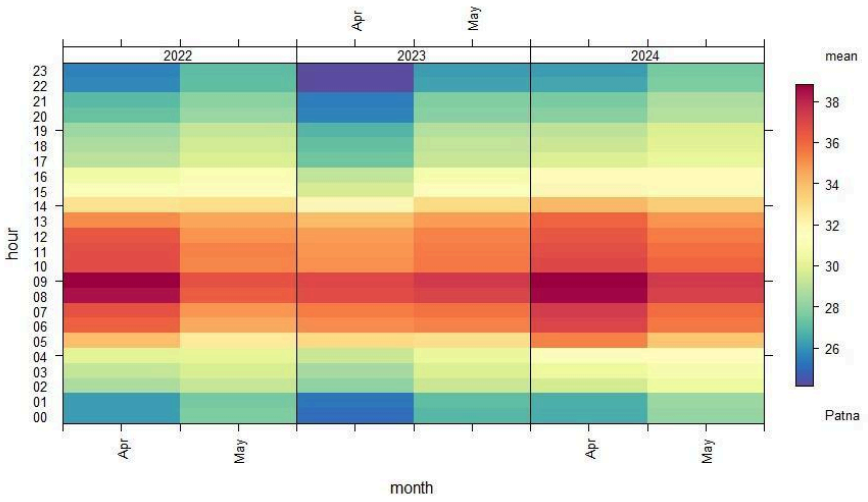

Fig 10 – Hourly variations of Temperature during April and May for Patna

Conclusion:

- The presence of particulate matter (PM2.5) in the atmosphere is influenced significantly by meteorological factors like wind speed, rainfall, humidity and temperature.

- While summer in India is considered to have favourable (there is generally an inverse relationship between temperature and PM 2.5 levels) meteorological conditions for cleaner air as compared to the winter months, for our study, it has been observed that PM 2.5 concentrations across the studied cities consistently exceed the national standards throughout most days in April and May from 2022 to 2024.

- The analysis of average daytime and nighttime temperatures from April to May between 2022 and 2024 reveals distinct thermal profiles across major Indian cities. Delhi experienced daytime averages of 34.52°C and nighttime averages of 27.12°C, while Lucknow recorded 34.95°C during the day and 27.92°C at night. Kolkata observed daytime temperatures at 32.33°C and nighttime at 28.77°C, while Mumbai saw averages of 29.72°C and 28.28°C for the day and night, respectively. Patna registered daytime temperatures averaging 34.41°C and nighttime temperatures of 28.46°C. These findings underscore regional temperature variations and provide essential insights into climate dynamics and heat patterns during these months in these urban centres. Understanding this correlation is crucial for assessing air quality dynamics and implementing effective pollution control measures, especially in urban environments where PM2.5 pollution can significantly impact public health.

- Compared to 2022, PM2.5 concentration generally showed variability but indicated occasional improvements in 2023 and 2024. Analyzing PM2.5 concentrations for the cities from 2022 to 2024 reveals that there was variability in the levels throughout these years. PM2.5 concentrations showed fluctuations over time. However, there were noticeable improvements observed in 2023 and 2024 compared to 2022. These improvements might suggest changes in local environmental policies, weather patterns affecting air quality, or other factors influencing pollution levels in the region and will need to be studied further.

- The relationship between temperature and PM2.5 levels is influenced by several atmospheric factors, as evidenced by our data showing occasional spikes in pollution levels. In winter, temperature inversions trap cooler air near the surface, preventing pollutants from dispersing and resulting in higher PM2.5 concentrations. Lower temperatures reduce atmospheric mixing and are coupled with increased emissions from heating sources, further elevating PM2.5 levels. Conversely, in summer, higher

temperatures enhance vertical mixing and are accompanied by stronger winds, which help disperse pollutants more effectively, generally lowering PM2.5 concentrations. However, our data also indicates that summer conditions can lead to occasional spikes in PM2.5 due to the formation of secondary pollutants like ground-level ozone and dust storms. Overall, the seasonal variations in temperature significantly impact the behaviour and concentration of PM2.5 in the atmosphere.

Quotes

Dr Palak Balyan, Research Lead, Climate Trends

"PM2.5 concentration can be influenced by various factors, including temperature. Extreme temperatures can enhance the photochemical reactions that can lead to the formation of various secondary pollutants, while also influencing atmospheric stability and pollutant dispersion. So while we are alarmed by the record-breaking levels of air pollution in the winter months, the pollution in the summer months could harm us in different ways. Understanding the interplay between PM2.5 levels and temperature is crucial for developing effective air quality management and public health protection strategies."

Dr Harshal Salve, Additional Professor, Community Medicine, AIIMS New Delhi

"High levels of pollutants such as PM2.5 and PM10 can exacerbate respiratory conditions, trigger asthma attacks, and lead to cardiovascular problems. We already see vulnerable groups, including children and the elderly, exhibiting heightened signs of these during the winter months, its burden during summer further adds to the risk. Heat waves increase dust pollution adding to the double whammy. Policymakers must undertake measures that reduce sources of air pollution throughout the year and not just mask them during the winter months. Climate and health co-benefits of air pollution mitigation must be considered while ideating and implementing policies."