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Geographical Analysis of the Interplay Between Air Pollutants and Meteorological Factors in Bhiwadi Town

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Abstract
Air quality serves as a critical measure globally for evaluating current air pollution levels and their associated health risks. In India, many regions experience alarmingly high concentrations of key air pollutants. This study explores the relationship between specific air pollutants (NO_2, SO_2, and PM_{10}) and meteorological parameters (temperature, relative humidity, precipitation, and air pressure) in Bhiwadi town over a five-year period, from January 2019 to December 2023. Using data from two RSPCB air monitoring stations, a comprehensive statistical analysis was conducted, including trend assessments and Pearson's correlation coefficients, to examine interactions between pollutants and weather variables. The analysis revealed notable seasonal variations and significant correlations. For instance, PM_{10} levels were heavily influenced by precipitation and wind speed, while NO_2 and SO_2 demonstrated strong associations with air pressure. These findings emphasize the critical role of meteorological factors in shaping air pollution levels and offer valuable insights for formulating policies aimed at improving air quality in Bhiwadi town. The study highlights the pressing need for effective measures to address severe urban air pollution in developing nations, with far-reaching implications for public health and environmental sustainability.

Keywords: Air Quality, Meteorological Factors, Trend Analysis, Pearson's Correlation, , Urban Development, Environmental Policy, Health Impacts.

Introduction

Air pollution in urban areas has become a critical environmental challenge in developing countries, posing significant risks to global public health by contributing to respiratory and cardiovascular diseases (Cohen et al., 2017; Manju et al., 2010). While air pollution can stem from both natural and human-induced factors, anthropogenic activities are now the primary drivers of its global increase. Key contributors include the combustion of fossil fuels—such as coal, oil, and natural gas—for industrial processes, transportation, brick manufacturing, and various industrial operations, which release pollutants that degrade air quality (Begum et al., 2008).

The World Health Organization (WHO) reports that approximately 98% of cities in low- and middle-income countries fail to meet air quality standards, with over 80% of urban residents exposed to pollutant levels exceeding recommended limits (Manju et al., 2018). Rapid industrialization and urbanization have driven significant population growth and economic progress in urban areas globally (Begum et al., 2010). By November 2022, the global population had surpassed 8 billion and is expected to reach 9.3 billion by 2050, with the majority of this growth occurring in urban regions (Gurjar et al., 2016).

Air quality degradation is no longer confined to large metropolitan areas; it has increasingly affected smaller towns and nearby rural areas that were once known for their clean air. A 2021 IAQI report highlights that 22 Indian cities are among the 30 most polluted cities globally. These include Ghaziabad, Noida, Kanpur, and Lucknow in Uttar Pradesh; Bhiwadi in Rajasthan; Gurugram, Rohtak, and Faridabad in Haryana; and Muzaffarpur in Bihar (BloombergQuint, 2021).

Despite air pollution being a global concern, its severity varies significantly between cities, even with comparable pollutant emission levels. For example, while Mumbai is larger than Delhi, Delhi suffers from much worse air pollution. This difference is primarily due to local meteorological conditions, such as wind speed, temperature, and humidity, which influence the dispersion and concentration of pollutants (Dey et al., 2017; Manju et al., 2018). Factors like rainfall and wind can help reduce pollutant concentrations by dispersing particles or removing them through atmospheric processes (Shukla et al., 2008).

The escalating air pollution crisis, worsened by unfavourable local weather conditions, poses serious risks to both the environment and public health. WHO estimates that air pollution is responsible for one-third of all premature deaths in the Western Asia-Pacific region and causes approximately 7 million deaths annually worldwide. It also contributes to severe health issues, including respiratory diseases, cardiovascular disorders, lung infections, and even cancer. This problem is particularly acute in metropolitan areas, where air quality has significantly deteriorated over the past decade (Rahaman et al., 2021).

Indian cities face even graver challenges, with a majority of the 20 most polluted cities globally located in the country. Delhi has been the world's most polluted capital for six consecutive years.

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Air pollution in the National Capital Region (NCR) of India, particularly in Delhi, has reached alarming levels, posing significant health risks and environmental challenges. The region is among the most polluted urban areas globally, with PM2.5 accounting for approximately 80% of air pollution-related deaths (Agarwal et al., 2024). The issue is exacerbated by rapid urbanization, industrialization, and various contributing factors such as geographical, chemical, and meteorological conditions (Agarwal et al., 2024; Kumar, 2024).
Interestingly, while fire detection counts from satellites over Punjab and Haryana declined by 50% or more during 2015-2023, PM2.5 concentrations in Delhi remained stable (Mangaraj et al., 2024). This suggests that crop residue burning may not be the primary contributor to Delhi's air pollution. In fact, model simulations estimate that only about 14% of PM2.5 in Delhi-NCR was directly contributed by emissions from crop residue burning in Punjab during October-November 2022 (Mangaraj et al., 2024).
The impact of air pollution in NCR extends beyond human health, affecting agriculture and the economy. A study estimated an annual economic loss of about 1.27 billion USD due to ozone pollution alone in the region (Sharma, 2016). To address this complex issue, a multifaceted approach is necessary, incorporating innovative solutions such as advanced air purification technologies, vertical gardens, sustainable transportation systems, and smart urban planning strategies (Kumar, 2024). Additionally, targeted interventions, district-level strategies, and season-specific measures are crucial for effective air quality management in the NCR (Deshpande et al., 2024).

Study Area

Bhiwadi, located in the Alwar district of Rajasthan, is a rapidly developing town situated about 70 kilometres from Delhi. Geographically, it lies in the National Capital Region (NCR), benefiting from proximity to major urban centres like Delhi and Gurgaon. The town's strategic location along National Highway 48 (formerly NH-8) and its connectivity via road and rail make it a significant hub for trade and transportation.

Figure 1: Study Area, Bhiwadi Urban Area

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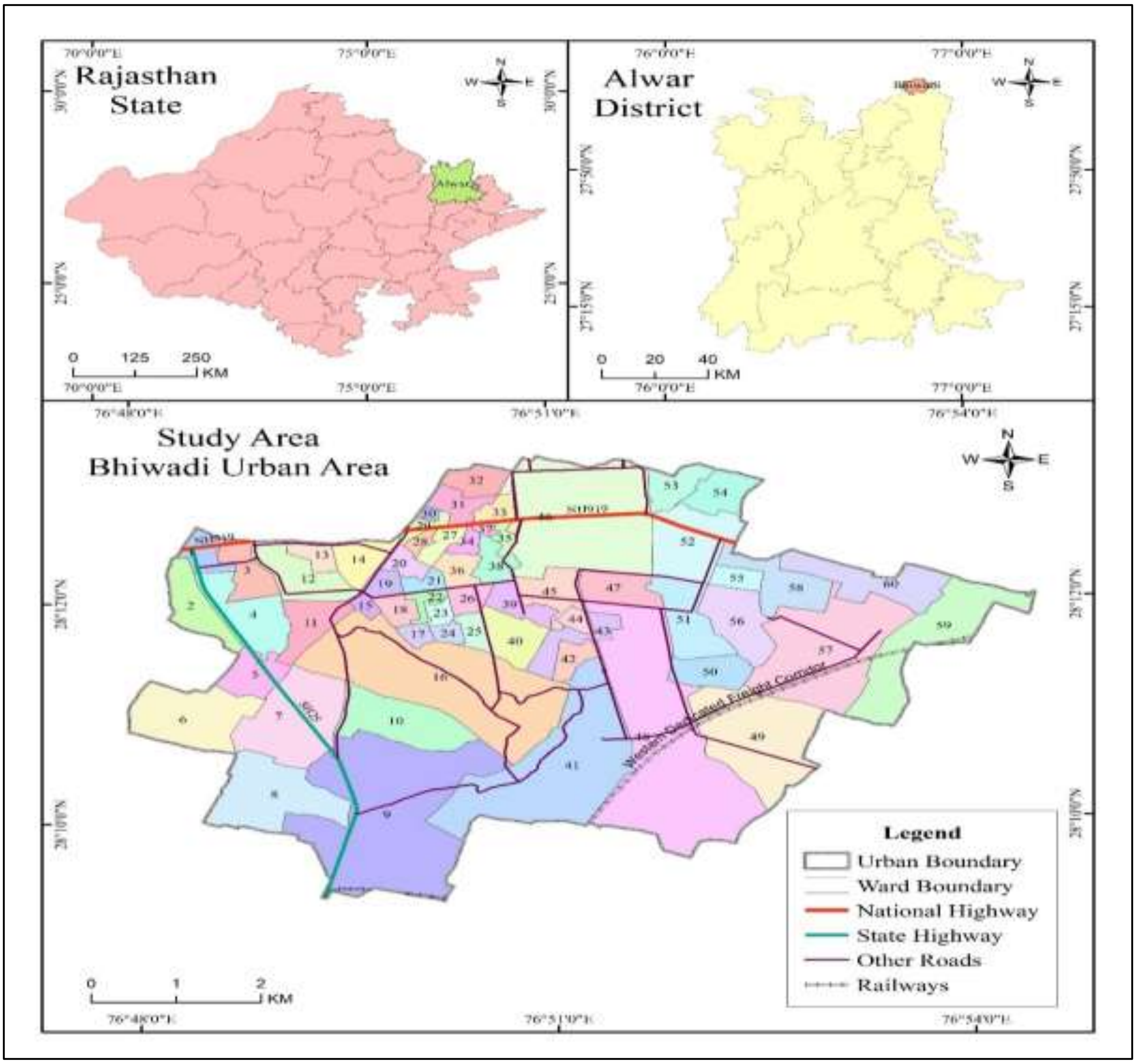

Source: Map made by scholar using QGIS

Bhiwadi is renowned as an industrial hub, hosting a diverse range of industries, including manufacturing, textiles, pharmaceuticals, and automobile components. It houses numerous industrial areas such as RIICO Industrial Area and has attracted investments due to its industrial infrastructure and incentives.

Demographically, Bhiwadi has witnessed rapid population growth, driven by industrial expansion and urbanization. The town has a mix of local residents and migrant workers employed in industries. This growth has led to increasing demands for housing, services, and urban amenities.

Research Methodology and Data Collection

This study focuses on analyzing air quality data from two out of the three air pollution monitoring stations managed by RSPCB in Bhiwadi. These stations represent densely populated areas and as well as major industrial clusters R.O.RSPCB Building, Uttam Strip. The dataset includes monthly average concentrations of three key air pollutants: PM10 (μg/m³), NO2 (μg/m³), and SO2 (μg/m³). The data was collected for a five-year period, from January 2019 to December 2023.

To better understand the relationship between air quality and weather conditions, meteorological data for the same period was obtained from NASA's Power LARC database. This included monthly averages for temperature, precipitation, relative humidity, and air pressure for same period monthly data.

Data Analysis

The analysis began with descriptive statistics, computed using Microsoft Excel 2021 to summarize the data for air pollutants and meteorological parameters. This included calculating the mean, and correlation for each pollutant and weather variable.

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Table 1. Meteorological Parameter and Air pollutants data from 2019 to 2023

Meteorological Parameter					**Pollutants**		
Month	**Surface Pressure (kPa)**	**Temperature at 2 Meters (C)**	**Relative Humidity at 2 Meters (%)**	**Precipitation Corrected (mm)**	**Nitrogen Dioxide (NO2) ug/M3**	**Sulphur Dioxide (SO2) ug/M3**	**Particulate Matter size less than 10um or PM10 (RSPM) ug/M3**
January	97.876	13.24	49.616	28.766	41.766	25.538	253
February	97.75	17.472	40.302	5.212	44.896	28.285	259
March	97.432	23.746	34.438	14.802	44.492	29.888	247
April	97.06	30.386	24.212	11.552	44.35	28.068	247
May	96.662	33.796	27.15	39.39	40.701	23.171	216
June	96.318	35.156	38.062	45.392	38.912	20.156	203
July	96.262	31.974	63.25	207.482	36.736	17.432	197
August	96.412	29.352	74.626	139.294	33.057	17.159	182
September	96.82	28.4	71.688	108.872	34.974	19.026	187
October	97.374	25.182	51.426	24.242	42.149	24.708	235
November	97.76	20.204	45.488	2.356	41.857	25.501	279
December	97.966	14.49	44.336	3.94	40.573	24.8	272

Source: Meteorological data from Power Larc NASA.
Source: Air Pollutants from RSPCB

Trend analysis was conducted using MS Excel to visualize the changes in air pollutant concentrations over five years. Seasonal patterns were also identified, dividing the year into four seasons based on the classification by Salam et al. (2003):

1. Pre-monsoon (April–June)
2. Monsoon (July–September)
3. Post-monsoon (October–December)
4. Winter (January–March)

To explore the relationships between air pollution levels and meteorological factors, Pearson's correlation analysis was applied. This method provided a clear understanding of how variables such as temperature, precipitation, and humidity influence air pollutants over time and across seasons. Typically, temperature, precipitation, and humidity showed negative
correlations with pollutant concentrations, ranging from weak to strong relationships.

Correlation Strength Interpretation

The degree of correlation was interpreted as follows:

- **Perfect correlation:** Values near ±1 indicate a perfect relationship.
- **High correlation:** Values between ±0.50 and ±1 show a strong connection.
- **Moderate correlation:** Values between ±0.30 and ±0.49 indicate a moderate relationship.
- **Low correlation:** Values less than ±0.29 suggest a weak connection.
- **No correlation:** A value of 0 indicates no association between variables.

This comprehensive analysis offers valuable insights into how meteorological factors shape air quality patterns in Bhiwadi Town, providing a foundation for more targeted environmental and policy interventions.

Trends Of Concentrations of Air Pollutants From 2019 To 2023

Table 2: Year data of air pollutants from 2019 to 2023

Year	**Nitrogen Dioxide (NO2) ug/M3**	**PM10 (ug/M3)**	**Sulphur Dioxide (SO2) ug/M3**
2019	44.36	245	28.55
2020	43.28	190	31.59
2021	45.98	216	27.96
2022	42.44	249	21.79
2023	34.87	276	17.46

Source: RSPCB, Jaipur

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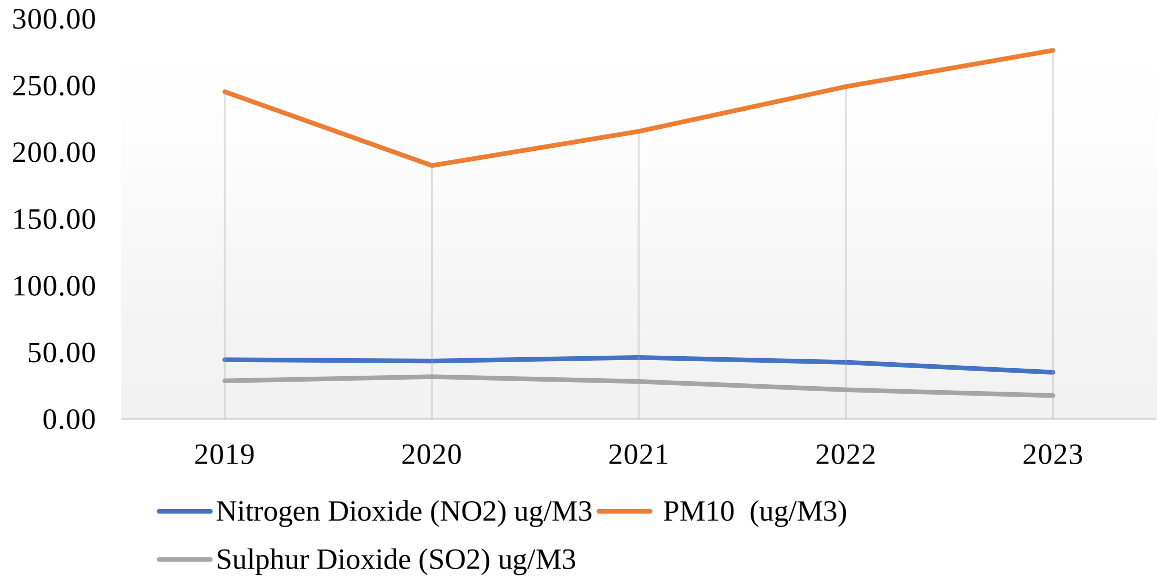
Figure 2: Air pollutants Concentration 2019 to 2023



Nitrogen Dioxide (NO_2) levels in Bhiwadi have shown a gradual decline from 44.36 µg/m³ in 2019 to 34.87 µg/m³ in 2023, representing a 21% reduction. This decline can be attributed to regulatory measures such as stricter pollution controls, improved compliance with environmental standards by industries, and the implementation of advanced vehicular emission norms like BS-VI. The industrial base of Bhiwadi, including manufacturing activities and vehicular emissions, is a significant contributor to NO_2 levels. The sharp drop in 2020 suggests the impact of reduced emissions during the COVID-19 lockdowns, with only a limited rebound observed in subsequent years.

In contrast, PM_{10} levels have exhibited a fluctuating pattern, peaking at 276 µg/m³ in 2023, marking a 13% increase from 2019. High PM_{10} levels in Bhiwadi are driven by industrial emissions, unpaved roads, construction dust, and nearby mining activities. The dip in 2020 reflects the slowdown of industrial and construction activities during the lockdown, but the sharp rebound and continued rise emphasize the persistent particulate pollution in the region. Additional contributors, such as biomass burning and regional dust storms, particularly during dry seasons, may have exacerbated PM_{10} levels.

Sulphur Dioxide (SO_2) levels, on the other hand, have steadily declined from 28.55 µg/m³ in 2019 to 17.46 µg/m³ in 2023, reflecting a significant 39% reduction. The primary sources of SO_2 include industrial processes, particularly in thermal power plants and manufacturing units. The decline is likely due to stricter enforcement of sulfur emission limits and the adoption of cleaner industrial technologies. Furthermore, the implementation of BS-VI fuels standards, which reduced the sulphur content in fuels, has contributed significantly to the reduction of SO_2 emissions.

Seasonal variations of air pollutant concentrations

The seasonal classification in this research follows the framework provided by (Salam et al. 2003), dividing the year into four distinct seasons:

1. Pre-monsoon (April-June)
2. Monsoon (July -September)
3. Post-monsoon (October-December)
4. Winter (January - March)

Table 3: Seasonal Concentration of Air Pollutants

Seasons	Nitrogen Dioxide (NO2) ug/M3	Sulphur Dioxide (SO2) ug/M3	PM10 (ug/M3)
Pre-Monsoon (April-June)	41.32	23.80	222
Monsoon (July-Sep.)	34.92	17.87	189
Post-Monsoon (Oct.- Dec)	41.53	25.00	262
Winter	43.72	27.90	253

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(Jan.-March)			

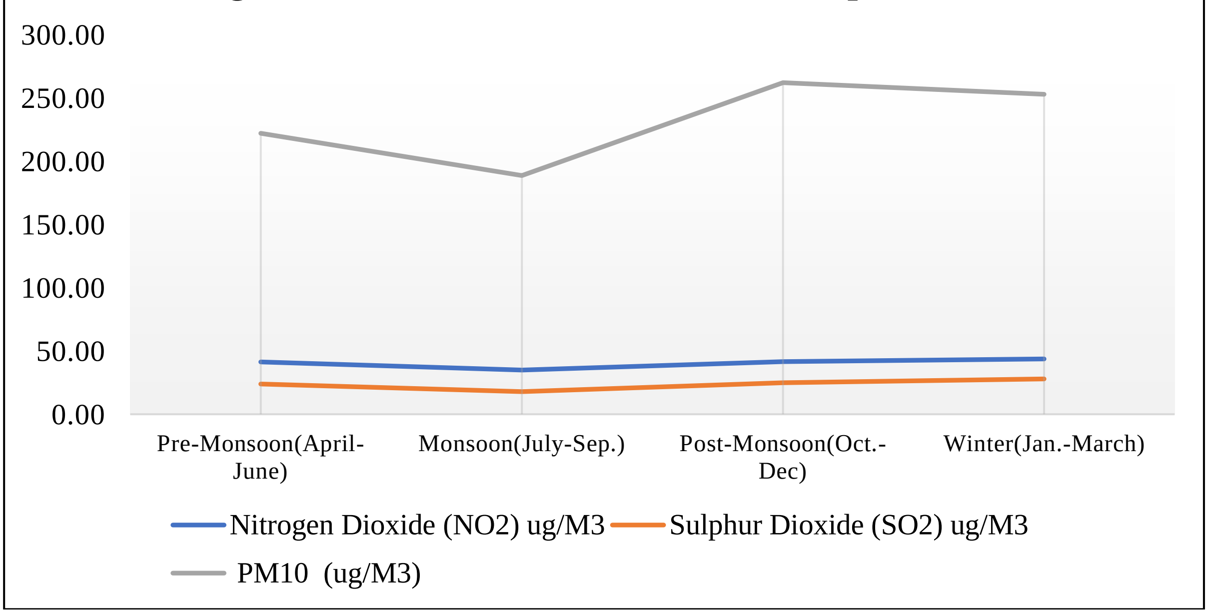

Figure 3: Seasonal concentration of Air pollutants

The seasonal air quality data for Bhiwadi reveals notable variations in pollutant concentrations. Nitrogen Dioxide (NO_2) levels are highest in winter (43.72 µg/m³) and post-monsoon (41.53 µg/m³) due to temperature inversions and increased industrial emissions. In contrast, the lowest NO_2 concentration occurs during the monsoon (34.92 µg/m³), when rainfall effectively removes pollutants from the atmosphere. Similarly, Sulphur Dioxide (SO_2) peaks in winter (27.90 µg/m³) and post-monsoon (25.00 µg/m³), with the lowest levels in the monsoon (17.87 µg/m³) due to wet deposition processes.

PM_{10}, the most persistent pollutant, is highest in the post-monsoon (262 µg/m³) and winter (253 µg/m³) seasons, likely driven by stubble burning, industrial emissions, and atmospheric stability. The monsoon season shows the lowest PM_{10} levels (189 µg/m³), reflecting the cleansing effect of rainfall. These trends emphasize the need for stringent pollution control measures during winter and post-monsoon periods, particularly to address industrial emissions and particulate matter, while leveraging the monsoon for air quality improvements.

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The Overall Relationship between Air Pollutants and Meteorological Parameters as Pollutants Among themselves.

Table 4: Correlation matrix table

Correlation	*Surface Pressure (kPa)*	*Temperature (ºC)*	*Relative Humidity (%)*	*Precipitation Corrected (mm)*	*Nitrogen Dioxide (NO2) ug/M3*	*Sulphur Dioxide (SO2) ug/M3*	*PM10 (ug/M3)*
Surface Pressure (kPa)	1						
Temperature (ºC)	-0.928438305	1					
Relative Humidity (%)	-0.279767562	0.000512805	1				
Precipitation Corrected (mm)	-0.742088153	0.498046713	0.724836507	1			
Nitrogen Dioxide (NO2) ug/M3	0.658169614	-0.41702776	-0.81793403	-0.80826241	1		
Sulphur Dioxide (SO2) ug/M3	0.757991986	-0.53219864	-0.73227319	-0.8490004	0.95445617	1	
PM10 (ug/M3)	0.903081792	-0.75349691	-0.55815055	-0.80367727	0.81100194	0.83559	1

The table 4 explain the correlation between air pollutants and meteorological parameters. The detail of each pollutant and meteorological parameters relation is given as follow-

Nitrogen Dioxide (NO_2)

- **Surface Pressure (0.658)**: Moderate positive correlation. As surface pressure increases, NO_2 levels tend to rise. High pressure is often associated with stable atmospheric conditions, which can trap pollutants closer to the surface.
- **Temperature (-0.417)**: Weak negative correlation. Higher temperatures are associated with slightly lower NO_2 levels, likely due to increased chemical reactions in the atmosphere that break down NO_2 or due to enhanced dispersion in warmer weather.
- **Relative Humidity (-0.818)**: Strong negative correlation. Higher humidity levels are linked to lower NO_2 concentrations, possibly because humidity enhances the removal of NO_2 through deposition or chemical reactions in the atmosphere.
- **Precipitation (-0.808)**: Strong negative correlation. Rainfall significantly reduces NO_2 concentrations by washing it out of the atmosphere.

Sulphur Dioxide (SO_2)

- **Surface Pressure (0.758)**: Strong positive correlation. Higher surface pressure corresponds to increased SO_2 levels, as stable atmospheric conditions can lead to the accumulation of pollutants.
- **Temperature (-0.532)**: Moderate negative correlation. Warmer temperatures are linked to lower SO_2 levels, possibly due to increased dispersion or enhanced chemical reactions converting SO_2 into secondary pollutants like sulfate aerosols.
- **Relative Humidity (-0.732)**: Strong negative correlation. Increased humidity reduces SO_2 levels, likely due to the conversion of SO_2 into sulfates in the presence of moisture.
- **Precipitation (-0.849)**: Strong negative correlation. Rainfall effectively removes SO_2 from the atmosphere through wet deposition processes.

PM_{10}

- **Surface Pressure (0.903)**: Very strong positive correlation. Higher surface pressure is strongly associated with higher PM_{10} levels, as stable atmospheric conditions under high pressure can prevent particulate matter from dispersing.
- **Temperature (-0.753)**: Strong negative correlation. Higher temperatures are associated with lower PM_{10} levels, potentially due to enhanced vertical mixing and dispersion in warmer weather.

• **Relative Humidity (-0.558)**: Moderate negative correlation. Higher humidity may contribute to the removal of PM_{10} through processes like hygroscopic growth and wet deposition, but the relationship is less pronounced compared to NO_2 and SO_2.
• **Precipitation (-0.804)**: Strong negative correlation. Rainfall plays a significant role in reducing PM_{10} concentrations by washing out particulate matter from the atmosphere.

Summary

The data shows that meteorological factors play a crucial role in shaping air pollution levels:

1. **High surface pressure** leads to the accumulation of all three pollutants (NO_2, SO_2, and PM_{10}) by suppressing atmospheric mixing.
2. **Higher temperatures** reduce pollutant concentrations through increased dispersion and chemical reactions.
3. **Increased humidity** significantly reduces NO_2 and SO_2 levels, as these gaseous pollutants undergo deposition or chemical conversion in moist conditions. The effect on PM_{10} is moderate but still significant.
4. **Precipitation** strongly reduces concentrations of all pollutants, highlighting the critical role of rain in cleansing the atmosphere.

This analysis underscores the complex interplay between meteorological conditions and air pollution, emphasizing the need to consider weather patterns in pollution management strategies.

References

1. Begum, B. A., & Hopke, P. K. (2018). Ambient air quality in Dhaka, Bangladesh over two decades: Impacts of policy on air quality. *Aerosol and Air Quality Research, 18*(8), 1910-1920. https://doi.org/10.4209/aaqr.2017.11.0465
2. Dominick, D., Juahir, H., Latif, M. T., Zain, S. M., & Aris, A. Z. (2012). Spatial assessment of air quality patterns in Malaysia using multivariate analysis. *Atmospheric Environment, 60*, 172-181. https://doi.org/10.1016/j.atmosenv.2012.06.021
3. Gurjar, B. R., Ravindra, K., & Nagpure, A. S. (2016). Air pollution trends over Indian megacities and their local-to-global implications. *Atmospheric Environment, 142*, 475-495. https://doi.org/10.1016/j.atmosenv.2016.06.030
4. Kayes, I., Shahriar, S. A., Hasan, K., Akhter, M., Kabir, M. M., & Salam, M. (2019). The relationships between meteorological parameters and air pollutants in an urban environment. *Global Journal of Environmental Science and Management, 5*, 265-278. https://doi.org/10.22034/gjesm.2019.03.01
5. Manju, A., Kalaiselvi, K., Dhananjayan, V., Palanivel, M., Banupriya, G., Vidhya, M., Karunamoorthy, P., & Ravichandran, B. (2018). Spatio-seasonal variation in ambient air pollutants and influence of meteorological factors in Coimbatore, Southern India. *Air Quality, Atmosphere & Health, 11*. https://doi.org/10.1007/s11869-018-0617-x
6. Markandeya, Verma, P.K., Mishra, V., et al. (2021). Spatio-temporal assessment of ambient air quality, their health effects and improvement during COVID-19 lockdown in one of the most polluted cities of India. *Environmental Science and Pollution Research, 28*(8), 10536–10551. https://doi.org/10.1007/s11356-020-11248-3
7. Rahman, M. M., Paul, K. C., Hossain, M. A., Ali, G. G. M. N., Rahman, M. S., & Thill, J.-C. (2021). Machine Learning on the COVID-19 Pandemic, Human Mobility and Air Quality: A Review. *IEEE Access, 9*, 72420-72450. https://doi.org/10.1109/ACCESS.2021.3079121
8. Ruhela, M., Maheshwari, V., Ahamad, F., & et al. (2022). Air quality assessment of Jaipur city Rajasthan after the COVID-19 lockdown. *Spatial Information Research, 30*(4), 597-605. https://doi.org/10.1007/s41324-022-00456-3
9. Salam, A., Ullah, B., & Islam, S. (2013). Carbonaceous species in total suspended particulate matters at different urban and suburban locations in the Greater Dhaka region, Bangladesh. *Air Quality, Atmosphere, & Health, 11*(8), 925–935. https://doi.org/10.1007/s11869-011-0166-z
10. Zhang, Q., Qiu, Z., Chung, K., & Huang, S. (2014). Link between environmental air pollution and allergic asthma: East meets West. *Journal of Thoracic Disease, 7*(1). https://jtd.amegroups.org/article/view/3582