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The relationship between air pollutants and meteorological parameters in Jaipur city: A statistical analysis

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Abstract
Growing air pollution has become one of the major concerns for mankind due to its detrimental effect on human health. Air quality is assessed worldwide to study the status of air pollution levels and associated health risks to the public. Indian cities such as Noida, Faridabad, Patna, Meerut, etc are featuring in top most polluted cities in the world. Several air pollutants reach very high concentrations in many regions across India. This study investigates the relationship between air pollutants (NO_2, SO_2, and PM_{10}) and meteorological parameters (temperature, relative humidity, wind speed, precipitation, and air pressure) in Jaipur City from January 2018 to December 2022. By utilizing the data from six RSPCB air pollution stations, the research conducts a detailed statistical analysis, including descriptive statistics, trend analysis, and Pearson's correlation coefficients as well as coefficient of determination using linear regression graph to show the dependency of pollutants on meteorological parameters. The results indicate significant seasonal variations and correlations among the pollutants and meteorological variables. Notably, PM_{10} concentrations are strongly influenced by precipitation and wind speed, while NO_2 and SO_2 show a high correlation with air pressure. The findings underscore the impact of meteorological conditions on air pollution levels, providing valuable insights for environmental policy and urban planning to mitigate air quality issues in Jaipur. This study highlights the urgent need for effective strategies to address the severe air pollution affecting urban areas in developing countries, with implications for public health and environmental sustainability.

Keywords: Air pollutants, meteorological parameters, descriptive statistics, Pearson's correlation coefficient, coefficient of determination, regression, urban planning, public health

Introduction
Air pollution in urban areas is an increasingly serious environmental issue in developing countries, significantly affecting global public health by contributing to cardiovascular and respiratory illnesses [1, 2]. Air pollution is caused by both natural as well as anthropogenic factors however, in the present time it's the anthropogenic factors that are the main force behind rising global air pollution. Human activities, such as the combustion of fossil fuels like natural gas, coal, and oil for industrial processes, motor vehicles, brick kilns, and other industrial operations, are the primary sources of pollutants that lead to air quality deterioration [3].

According to the World Health Organization (WHO), approximately 98% of cities in low- and middle-income countries fail to meet air quality guidelines, and over 80% of people living in urban areas are exposed to pollutant levels exceeding WHO standards [2]. Rapid industrialization and urbanization have significantly contributed to population growth and economic development in urban areas globally [3]. As the world population has already crossed the 8 billion mark in November 2022, it is projected that the world population will reach 9.3 billion by 2050, with most of this growth occurring in urban areas [4]. This will put more pressure on natural resources and subsequently will deteriorate air quality.

The present-day deterioration of air quality is not limited to metro cities but it is even worse in small towns and now it's touching the surrounding hinterland of cities that were earlier known for its clean air. A 2021 IAQI report indicates that 22 Indian cities are among the top 30 most polluted cities in the world. These cities include Ghaziabad, Bulandshahar, Bisrakh Jalalpur, Noida, Greater Noida, Kanpur, Lucknow, Meerut, Agra, and Muzaffarnagar in Uttar Pradesh; Bhiwari in Rajasthan; Faridabad, Jind, Hisar, Fatehabad, Bandhwari, Gurugram, Yamuna Nagar, Rohtak, and Dharuhera in Haryana; and Muzaffarpur in Bihar [16].

Although air pollution is not a local problem but it is a global issue and almost all urban area across the world is facing challenges due to it. However, the degree of air pollution in major cities across the world varies significantly despite similar levels of pollutants emission, for example, in India, Mumbai is bigger city than Delhi but Delhi face severe air pollution where as Mumbai is less affected by it. This is due to its location and local meteorological factors of the city.

Meteorological parameters are crucial factors influencing urban air quality [6, 2]. The key meteorological factors such as temperature, precipitation, relative humidity, wind speed and air pressure significantly impact the dispersion, removal, and formation of atmospheric particles. Thus meteorological factors significantly affect air pollutant concentrations. Additionally, rainfall can variably affect air pollutant concentrations by removing gaseous pollutants and depositing particulate matter through atmospheric chemical processes [7].

This rising air pollution across the world and further aggravated by local meteorological condition is causing harm not only to environment but also to man and wealth as well. The World Health Organization (WHO) estimates that a third of all premature deaths in the western Asia–Pacific region are due to air pollution. Globally, every year, 7 million people die because of exposure to a high level of air pollutants while many more suffer from breathing ailments, heart disease, lung infections, and even cancer. These problems become severe in all metro cities of the world. In the last decade, the air quality of most metro cities in the world is the poorest [11].

In this regard case of Indian cities are not different but even worse as out of the 20 most polluted cities majority are Indian cities. Delhi is the most polluted capital city consecutively in the last six years. Like other cities in India, Jaipur is also facing the problem of increased urbanization, industrial emissions, traffic congestion, and poor road conditions. Besides these, Jaipur is also a tourist place. All these factors resulted in increased air pollution in the city [14].

Study Area

Jaipur is situated in the eastern part of Rajasthan, surrounded on three sides by the rugged Aravalli hills. Jaipur is located at 26°55′ N 75°49′ E (26.92° N 75.82° E). It is surrounded by Alwar and Sikar in the North; by Sikar, Nagaur, and Ajmer in the West; by Ajmer, Tonk, and Sawai Madhopur in the South, and by Dausa and Bharatpur districts in the East. It has an average elevation of 430 m (1414 ft). Jaipur has a semi-arid climate. The climate of Jaipur is dry and healthy and is subject to the extremeness of cold and heat in various places. The minimum and maximum temperatures recorded in the Jaipur district vary from 5 °C to 48 °C. Normal annual rainfall is 50 cm.

Research Methodology

Data Collection:

Data on air quality, comprising monthly average concentrations of three criteria air pollutants namely PM_{10} (µg/m^3), NO_2 (µg/m^3) and SO_2 (µg/m^3), were gathered from six out of a total of nine RSPCB air pollution stations. These stations cover densely populated area as well as major industrial cluster of the city. Selected stations for the study are Ajmeri Gate station, Chandpol station, Jhalana station, MIA industrial area station, Nagar Nigam station and Sitapura station. The database for the period spanning January 2018 to December 2022 is collected for all three pollutants. Meteorological monthly average data of temperature, precipitation, relative humidity, wind speed and air pressure for the period of January 2018 to December 2022 is obtained from NASA Power larc.

Data Analysis

First, descriptive statistics were computed for both air pollutants and meteorological data using IBM SPSS Statistic 21. Mean, median, standard deviation for all three air pollutants and five meteorological parameters were calculated. Trend analysis of air pollutants was done using MS Excel to create a polylinear graph of five years.

Pearson’s correlation method was subsequently employed to assess significant correlations between the air pollutants and meteorological data spanning from January 2018 to December 2022. Pearson’s Correlation Coefficient (PCC) method is easy to apply and clearly depicts the relationship between meteorological variables and pollutants in temporal and seasonal sequences. Additionally, pollutants are more influenced by meteorological factors, including temperature, precipitation, and humidity, all of which are negatively correlated with very low to high degree.

Degree of correlation

1. Perfect: If the value of correlation coefficient is close to ±1.
2. High: If the correlation coefficient value is between ±0.50 and ±1.
3. Moderate: If the value of correlation coefficient falls between ±0.30 and ±0.49.
4. Low: When the value of correlation coefficient is less than ±.30. No correlation: When the value is zero, there is no association.

Along with correlation linear regression graph with R^2 (Coefficient of determination) value is derived using IBM SPSS software which shows the degree of dependency of the dependent (air pollutants) variable upon the independent variable (meteorological factors).

Results and Discussion

Descriptive Statistics

Table 1: Descriptive Statistics

Descriptive Statistics						
	N	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
NO_2 (µg/m^3)	12	21.89	30.11	25.9700	.85417	2.95893
PM_{10} (µg/m^3)	12	89.49	151.97	128.9392	6.41542	22.22366
SO_2 (µg/m^3)	12	5.78	7.20	6.5558	.14481	.50164
Temperature (°C)	12	14.12	34.56	25.2025	2.00955	6.96128
Relative Humidity (%)	12	21.39	80.70	47.0183	5.56625	19.28207
Wind Speed(m/s)	12	1.45	2.97	2.0717	.15013	.52007
Precipitation(mm)	12	.52	244.47	57.2392	23.93635	82.91795
Air Pressure(kPa)	12	99.81	101.74	100.7775	.20855	.72245

Table 1, Presents the summary statistics of air pollutants as well as meteorological data in Jaipur city from January 2018 to December 2022. Over this period, the mean concentrations of NO_2, SO_2 and PM_{10} ranged from 21.89 to 30.11 µg/m^3, 5.78 to 7.20 µg/m^3 and 89.49 to 151.97 µg/m^3, respectively. Additionally, the meteorological parameters temperature, relative humidity, wind speed, precipitation and air pressure show variations between 14.12 to 34.56 °C and 21.39 to 80.70 %, 1.45 to 2.97 m/s, 0.52 to 244.47 mm, and 99.81 to 101.74 kPa respectively.

Trends of Concentrations of Air Pollutants and Meteorological Variables from 2018 To 2022

Table 2: Year-wise Air Pollutants Mean Concentration

Year	NO_2 (µg/m^3)	PM_{10} (µg/m^3)	SO_2 (µg/m^3)
2018	31.31	134.64	7.36
2019	27.33	128.67	6.66
2020	21.95	113.18	6.58
2021	23.73	124.19	6.25
2022	25.53	144.01	5.92

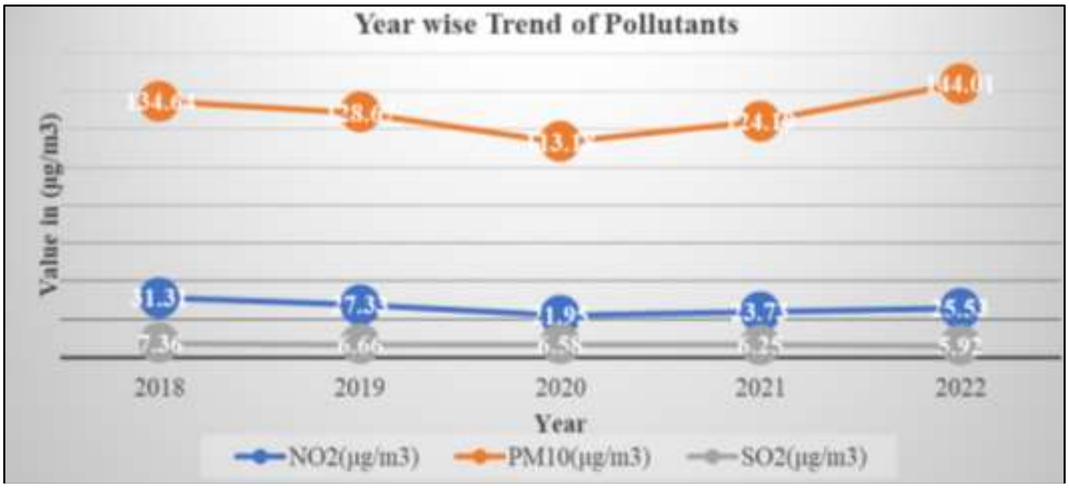

Fig 1: Air pollutants concentration trend (2018- 2022)

Table 2, shows the average monthly concentration of three pollutants over five years from January 2018 to December 2022. Table 2, and Figure 1 shows a clear visible trend of pollutants as pollutants concentration is high in the year 2018, and 2019 while it significantly declines in the year 2020, this shows the impact of COVID-19 and the lockdown aftermath. The second wave of COVID-19 which lasted more than 3 to 4 months year 2021 is the reason for the relatively low pollutant concentration in the year 2021.

The concentration of SO_2 show consistent declining trends is due to changing vehicle norm from BS4 to BS6 since 2018 as well as government initiatives to curb SO_2 pollution.

The monthly concentration of pollutants in the city is shown in Table 3 and Figure 2. From the monthly average data, it is evident that NO_2 concentration is high in the month of November to March which is winter time in the city SO_2 follow a similar pattern, while PM_{10} show a different pattern as a high concentration of PM_{10} is in the month of May – June as well as December – January.

Table 3: Mean Monthly Pollutants Concentration from 2018 to 2022

Month (2018-2022)	NO_2 (µg/m^3)	PM_{10} (µg/m^3)	SO_2 (µg/m^3)
January	29.22	143.9	7.14
February	30.11	141.67	6.99
March	27.75	137.83	6.75
April	25.59	140.77	6.45
May	25.65	151.97	6.44
June	21.89	131.57	6.1
July	22.38	96.43	5.93
August	22.36	89.49	5.78
September	23.89	98.4	6.13
October	25.06	120.67	6.59
November	29.44	148.57	7.17
December	28.3	146	7.2

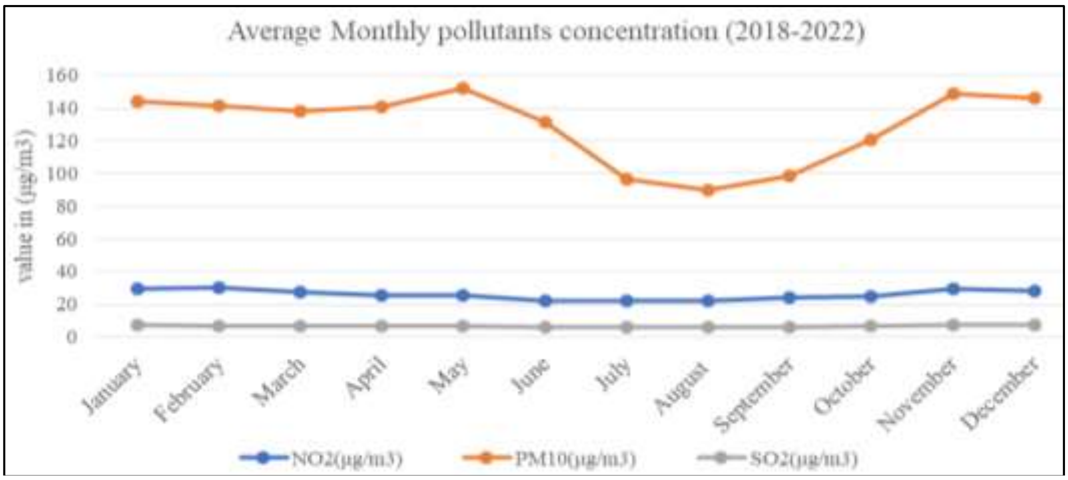

Fig 2: Mean monthly pollutants concentration trend

The overall relationship between air pollutants and meteorological parameters as well as pollutants among themselves.

Table 4: Pearson's Correlation matrix

Correlation	NO_2	PM_{10}	SO_2	Temperature	Relative Humidity	Wind Speed	Precipitation	Air Pressure
NO_2	1.00							
PM_{10}	0.74	1.00						
SO_2	0.95	0.80	1.00					
Temperature	-0.81	-0.35	-0.82	1.00				
Relative humidity	-0.49	-0.87	-0.51	0.01	1.00			
Wind speed	-0.70	-0.22	-0.74	0.88	-0.10	1.00		
Precipitation	-0.73	-0.88	-0.80	0.42	0.75	0.44	1.00	
Air pressure	0.93	0.61	0.95	-0.92	-0.31	-0.88	-0.71	1.00

To understand the relationship among the pollutants as well between pollutants and meteorological parameters this study is Pearson's correlation coefficient matrix that is calculated using MS Excel at 5% level of significance.

This research compared Pearson's correlation coefficient and seasonal concentration of pollutants to assess the impact of meteorological parameters on air pollutant concentrations. The performance of the models was further evaluated by calculating the coefficient of determination (R^2) and Scatter diagram with a linear regression line.

From Table 4 it is evident that NO_2 and PM_{10} show a positive correlation at 0.74 whereas NO_2 and SO_2 show a strong positive correlation at 0.95 that signifies that increase in one have positive increase in another, SO_2 and PM_{10} also show high degree of positive correlation value at 0.80. From the above analysis is clear that pollutants have a strong interrelation among themselves and they occur mostly in combination like from exhaust of vehicle or industrial emission.

Meteorological parameters and their effects of air pollutants

PCC matrix table 4 shows the overall relationship between different meteorological parameters and air pollutants that is properly explained below:

Temperature has a strong negative correlation with NO_2 and SO_2 with values -0.81 and -0.82 respectively. Temperature increases in the city create relatively low-pressure zones and wind speed increases, which help in the dispersal of air pollutants. Another factors for this is that in summer high temperatures relative movement of vehicles decreases. The inverse relation of temperature and NO_2 and SO_2 can also explained by the linear regression graph in Figure 4. Coefficient of determination (R^2) value for temperature as the independent variable and NO_2 as the dependent variable is 0.656. That is, 65.6% decrease in NO_2 can be explained by temperature, similarly for temperature and $SO_{2,}$ R^2 value is 0.672 or 67.2%. Temperature and PM_{10} show very low negative correlation value of -0.35. Regression line explains this low relation as R^2 value is 0.120 or 12%.

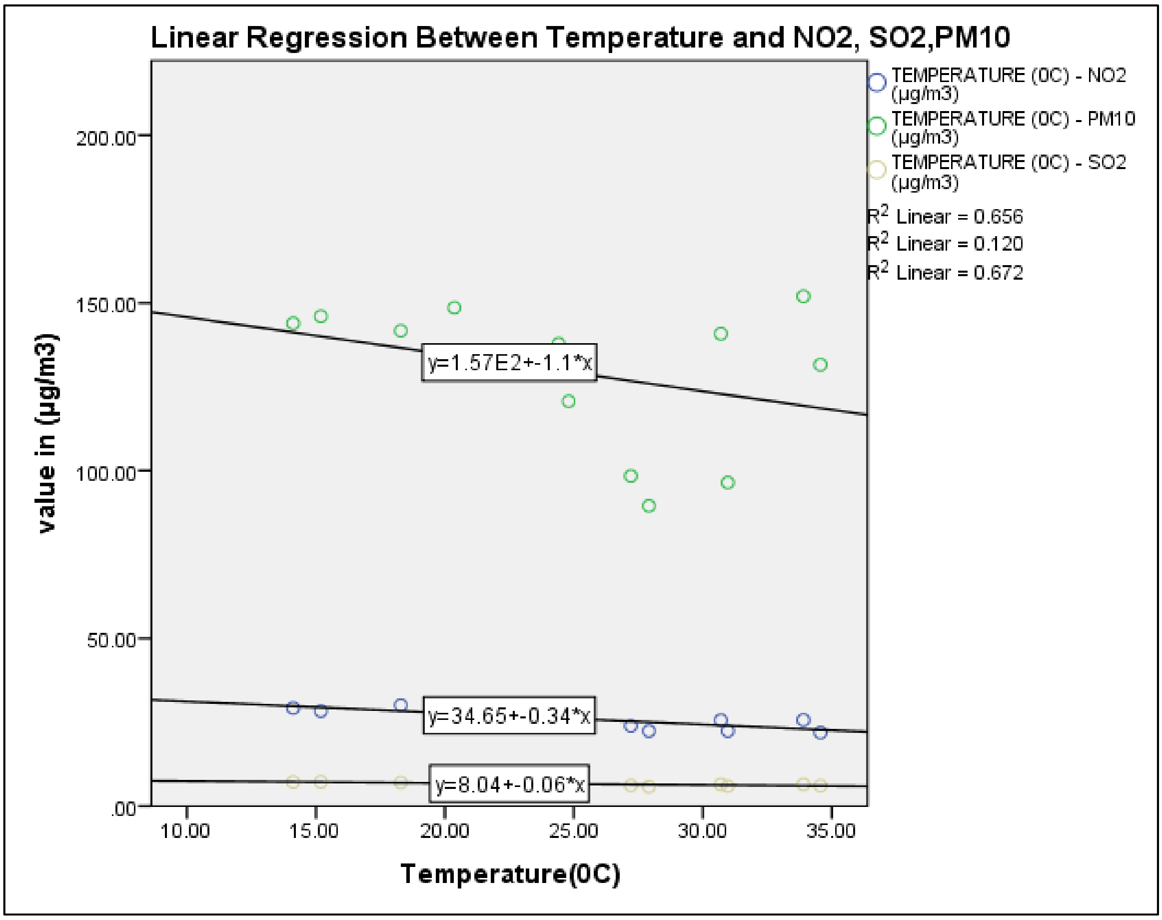

Fig 4: Linear regression scatter graph

Relative Humidity: Relative humidity has moderate to low correlation with NO_2 and SO_2 values as -0.49 and -0.51 as given in Table 4. Figure 5 shows the R^2 value of Relative humidity with respect to NO_2 and SO_2 as 0.239 and 0.256 respectively. This shows a low effect of relative humidity upon SO_2 and NO_2. Whereas relative humidity has a strong negative correlation with PM_{10} as coefficient value is -0.87 and R^2 is 0.764. That means 76.4% of PM_{10} concentration can explained by the effect of relative humidity.

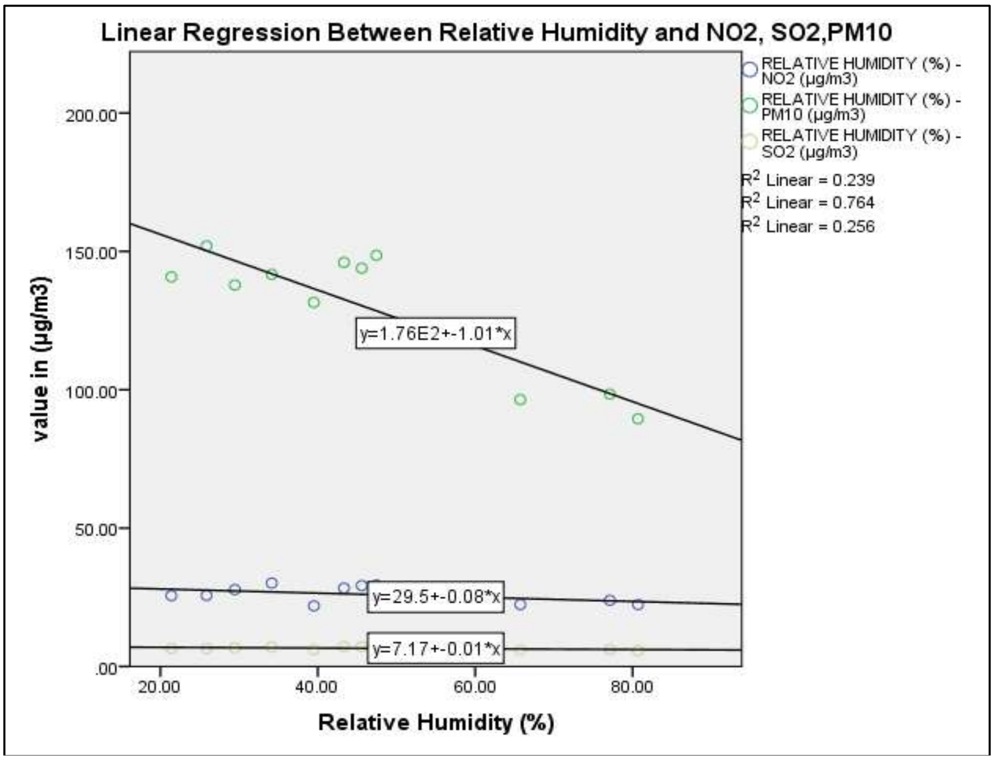

Fig 5: Linear regression scatter graph

Wind speed: Table 4 shows a strong negative correlation of wind speed with NO_2 and SO_2, with coefficient values as -0.70 and -0.74 respectively, Figure 6 shows the coefficient of determination value of wind speed and NO_2 and SO_2 as 0.494 and 0.54. This shows moderate effect of relative humidity upon SO_2 and NO_2. Whereas wind speed has a very low negative correlation with PM_{10} value of -0.22 and R^2 value of 0.050. This means only 5% of PM_{10} concentration is affected by wind speed in Jaipur city.

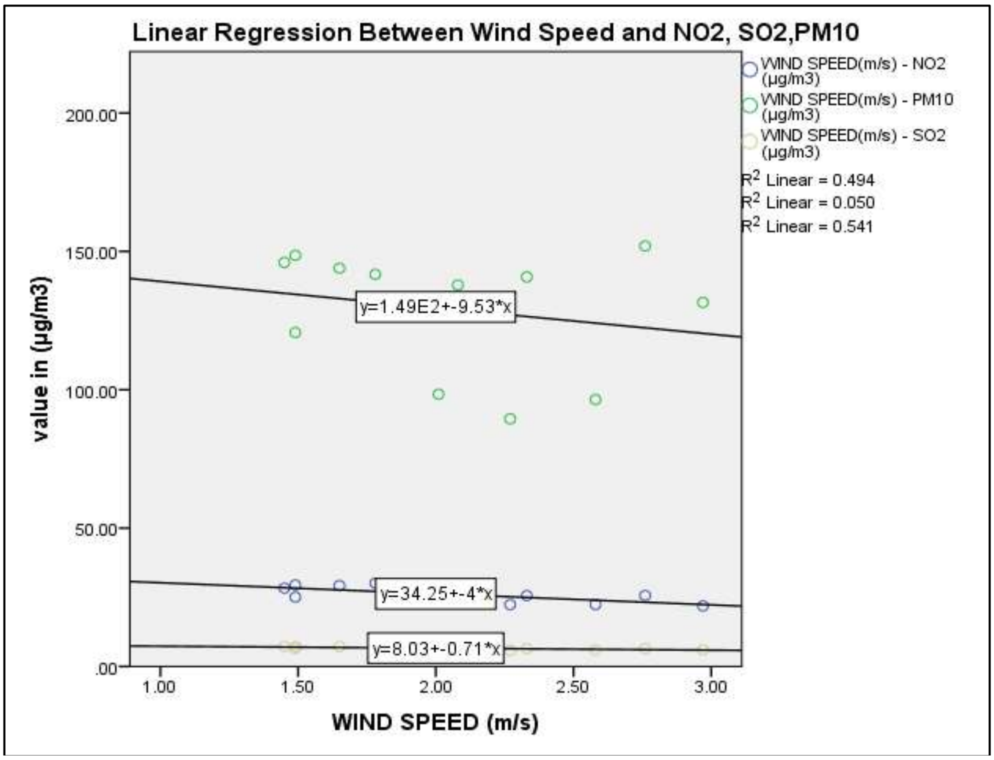

Fig 6: Linear regression scatter graph

Precipitation: Precipitation has a strong negative correlation with all three air pollutant NO_2, SO_2 and PM_{10} with correlation values as -0.73, -0.80 and -0.88 respectively (Table 4). This is evident from the seasonal pattern of the air pollutants concentration as lowest in the monsoon period. Linear regression from Figure 7 shows the R^2 value for precipitation to NO_2, SO_2 and PM_{10} as 0.534, 0.633 and 0.77 respectively. This shows that precipitation has a strong inverse relation with PM_{10} concentration in Jaipur city. As particulate matter, primarily composed of soil or road dust, absorbs water vapour from the atmosphere and subsequently deposits on the ground more easily due to precipitation.

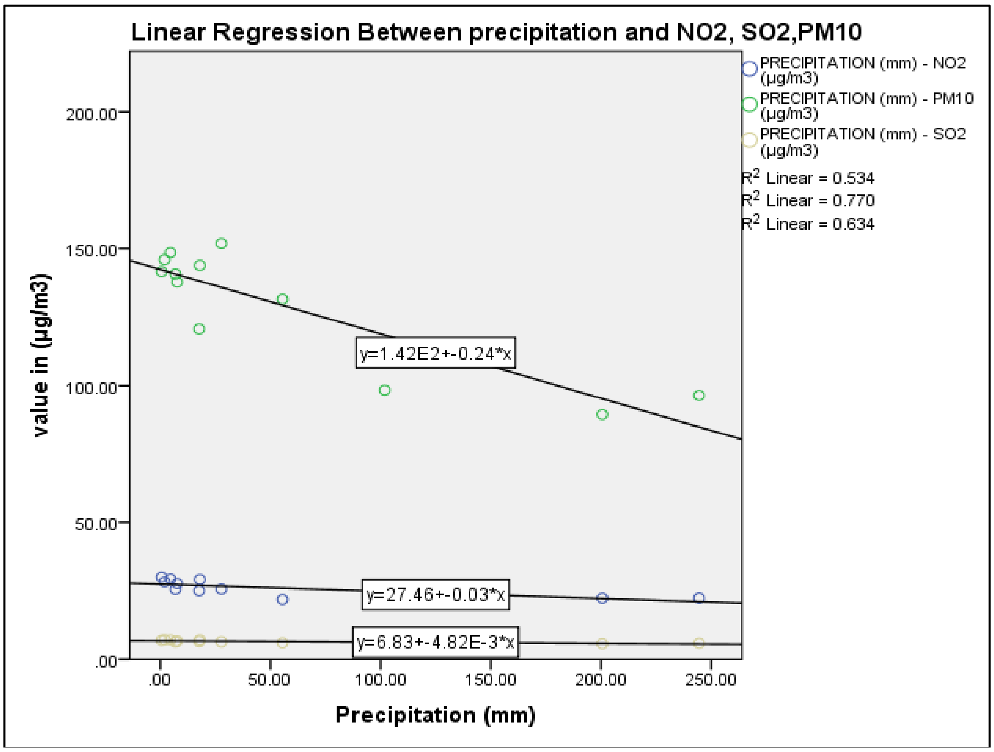

Fig 7: Linear regression scatter graph

Air Pressure: Air pressure shows a very high degree of positive correlation with NO_2 and SO_2 with coefficient value as 0.93 and 0.95 respectively, and moderate to high concentration of PM_{10} with r = 0.61 as given in Table 4. High air pressure in the city traps air pollution near the ground and concentration rises rapidly. This is validated from Figure 8, as the value of R^2 for NO_2 and SO_2 with respect to air pressure as 0.858 and 0.908 respectively. While for PM_{10} R^2 is 0.369, showing low degree of dependency on air pressure.

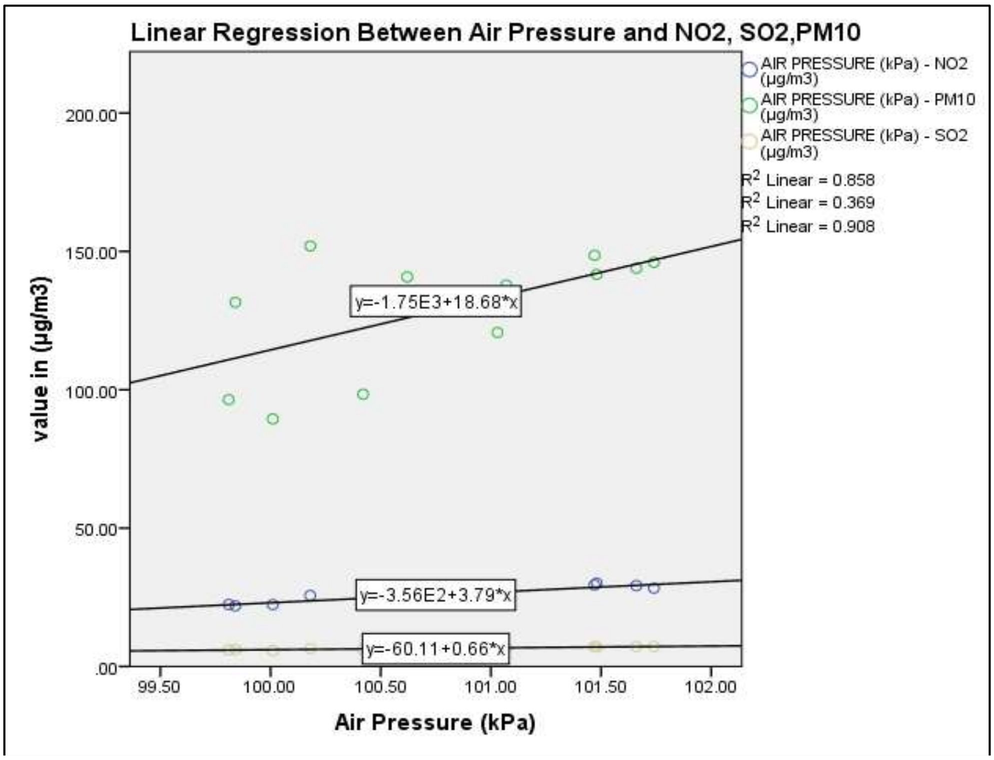

Fig 8: Linear regression scatter graph

Conclusion

This study has elucidated the significant relationship between air pollutants and meteorological parameters in Jaipur city over a five-year period. The analysis revealed that concentrations of NO_2, SO_2, and PM_{10} are influenced by various meteorological factors, with temperature and air pressure showing strong correlations. Seasonal trends indicate higher pollutant levels during winter and pre-monsoon periods, while monsoon seasons see reduced concentrations due to increased precipitation and wind speed.

The findings highlight the critical role of local meteorological conditions in exacerbating as well as mitigating air pollution levels. The observed decline in pollutant concentrations during the COVID-19 lockdown period underscores the impact of human activities on air quality. These insights are vital for formulating targeted strategies to improve air quality, such as enhancing public transportation, regulating industrial emissions, and implementing urban green spaces.

Overall, this research emphasizes the need for integrated environmental management practices that consider both anthropogenic and natural factors. By addressing the interplay between meteorological conditions and air pollution, policymakers can develop more effective interventions to safeguard public health and promote sustainable urban development in Jaipur and similar urban areas.

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