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Characteristics of Ambient Air Pollutions in Delhi, India

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Abstract: Air pollution is characterised as the presence of one or more pollutants in the outdoor environment, such as dust, gases, mist, odour, smoke, or vapour. They are harmful to human, plant, or animal life or property or interfere with the healthy nature of life or property in specific amounts, characteristics, or periods. This study aimed to investigate the characteristics of ambient air pollution through relations between determinants to each SO_2, NO_2, PM_{10}, and suspended particulate matter (SPM) by applying linear regression. The data has been obtained from the official websites of the Indian government based on the real-time pollutant concentrations monitored by stations in an urban and resident areas from 2000 until 2015. The data consisted of eight (8) variables; SO_2, NO_2, PM_{10}, and SPM as outcomes, month, year, area, and monitoring stations as determinants. The model showed that the month, year, monitoring station, and area were correlated to SO_2, NO_2, and PM_{10} concentration. Yet, in SPM concentration, month, year, the station was correlated. The area was not correlated to SPM. Investigation of other predictors was needed to gain information about the increasing air pollution on a global scale.

Key words: Air pollution, regression, suspended particulate matter.

Introduction

In recent years, there has been a lot of research done on the health effects of air pollution (Brunekreef & Holgate, 2002). However, in the two decades, air pollution has resurfaced as a significant public health concern. One explanation for this is that, while air pollution from conventional fossil fuel combustion is now present in far lower amounts than 50 years ago, other components have gained prominence (Brunekreef & Holgate, 2002). Numerous studies were conducted to analyse air pollution in India (Ahmad & Sharma, 2014; Badami, 2005; Balakrishnan et al., 2014; Kandlikar & Ramachandran, 2000; Upadhyaya & Dashore, 2010; Yadav et al., 2013).

The Engineers Joint Council (EJC) defines air pollution as the presence in the outdoor atmosphere of one or more contaminants, such as dust, fumes, gas, mist, odour, smoke, or vapour. In quantities, characteristics, and duration could be injurious to human, plant, or animal life or property, or which unreasonably interferes with the comfortable enjoyment of life and property based on EJC (World Health Organization. Regional Office for Europe, 1980). According to WHO, Global Ambient Air Quality Database 2018 says that over the last two years, over 4300 cities and settlements in 108 countries have almost doubled. More settlements understand air pollution levels over the previous two years and their health effects. In the comparative

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evaluation of vulnerability (Lim et al., 2012), air pollution was a leading contributor to the burden of disease in South Asia due to the Global Burden of Disease (GBD) in 2010.

Air pollution in India has been regarded as a public interest and policy attention, according to Badami (2005). The fast growth of motor vehicle traffic in Indian and other high-income countries contributes, among other adverse social, political, health, and welfare effects, to high levels of urban air contamination. Estimates of the burden in India show approximately 1.04 million premature deaths and 31.4 million disability-adjusted life years (DALYs) to be attributable to household air pollution (HAP) resulting from solid cooking fuels. Moreover, 627,000 premature deaths and nearly 17.8 million DALYs are attributable to ambient air pollution (AAP) in the form of delicate particulate matter ≤ 2.5 µm in aerodynamic diameter ($PM_{2.5}$) (Balakrishnan et al., 2014). According to Badami (2005), the concentration of motor vehicles and other energy-consuming operations in the cities, and the high level of emissions in these activities, are causing high air pollution levels in Delhi and other major Indian cities. Air contamination is classified as an intangible assailant. It is crucial to investigate how air quality trends and patterns are identified using the statistical approach.

Method

The study area covered Delhi, India, located around the central coordinate of 28.36ºN and 77.12ºE. New Delhi, the capital of India, comprises some of the most important locations and sites of Delhi. The map of Delhi is shown in Figure 1. Delhi, formally known as the National Capital Territory (NCT), is India's capital and is the second-most populous city in India after Mumbai. While Delhi is governed as a territory of the Union, the political administration of Delhi today resembles that of a state, with its legislature, High Court, and the executive council of ministers headed by the Chief Minister. Many major landmarks, buildings, and offices are located in Delhi. Delhi has an 11,007,835 population (2011 census) and occupies 1,484,0 square kilometres. Delhi has five seasons—summer and monsoon, fall, winter, and spring—weather in different locations (Map of India, 2017).

Sources of the data are from official websites of the Indian government that assessed real-time pollutant concentrations. Indian government provides open-source air pollution data. This study uses India's air pollution data from 2000 until 2015 consisting of eight (8) variables; SO_2, NO_2, PM_{10}, and suspended particulate matter (SPM) as outcomes, month, year, type of location, and monitoring stations as determinants. All outcomes are continuous variables, and the determinants are categorical variables. The month consists of twelve (12) categories from January to December. Twelve (12) monitoring stations are located in an industrial area and residential area. In some years, the period of data collection was not at the same level. In 2000-2002, the data was collected only once a month while they were collected more than once in other years. There are no missing values in the determinants.

The purpose of multiple regression is to construct the relationship of the outcome with all of the determinants. In this study, the outcome variables are continuous and must be one outcome for each model. Our independent variables are categorical. The equation for multiple regression is constructed in equation (1)

$$Y = b_0 + b_1X_1 + b_2X_2 +\ldots+ bnX_n + e \quad (1)$$

where Y is the outcome variable, b_0 is the intercept, b_1, b_2,…b_n are the regression coefficients of each independent variable, X_1, X_2, …, X_n are independent variables (month, year, monitoring station, and type of location) from 1, 2, 3, ..., n and e is the error term. After fitting the linear model, the normality assumption of residuals is required for evaluating the goodness of the model. For this study, the r-square, typical Q-Q plot, and fitted value against studentised residuals plot are used to assess the model. Sum contrasts (Tongkumchum & McNeil, 2009; Venables & Ripley, 2002) was used, and a confidence interval (CI) was calculated for comparing the adjusted air pollutant within each variable (SO_2, NO_2, PM_{10}, SPM) with the overall mean. All the statistical analyses and graphs were created by using the R program (R Core Team, 2018).

Figure 1 shows that the overall mean concentration of sulphur dioxide is 7.29 ppm. Assessment result from 2000-2015 depicts that the lowest concentration was in June, increasing from September, and the highest concentration was in November. The concentration of sulphur dioxide was decreasing by the year. The lowest concentration was in 2013, but it seemed to increase in 2014-2015. The highest concentration was measured in the Mayapuri station, and the lowest concentration was measured in Shahzada Bagh. The industrial area concentration of sulphur dioxide was more elevated than the overall mean, but the residential area was lower than the overall mean. The model shows that month, year, station, and area were correlated to sulphur dioxide concentration ($p < 0.0001$).

Figure 2 explains that the overall mean concentration of nitrogen dioxide is 56.07 ppm. Measurement by the station in New Delhi from 2000 to 2015 depicts that the lowest concentration was in June, increasing from August, and the highest concentration was in November. The concentration of nitrogen dioxide increased each year. The lowest concentration was in 2002 and the highest concentration was in 2013. The highest concentration was measured in the BSZ marg station, and the lowest concentration was measured in the DCE station. The industrial area concentration of nitrogen dioxide was more elevated than the overall mean, but the residential area was lower than the overall mean. The model shows that month, year, station, and area were correlated to nitrogen dioxide concentration ($p < 0.05$).

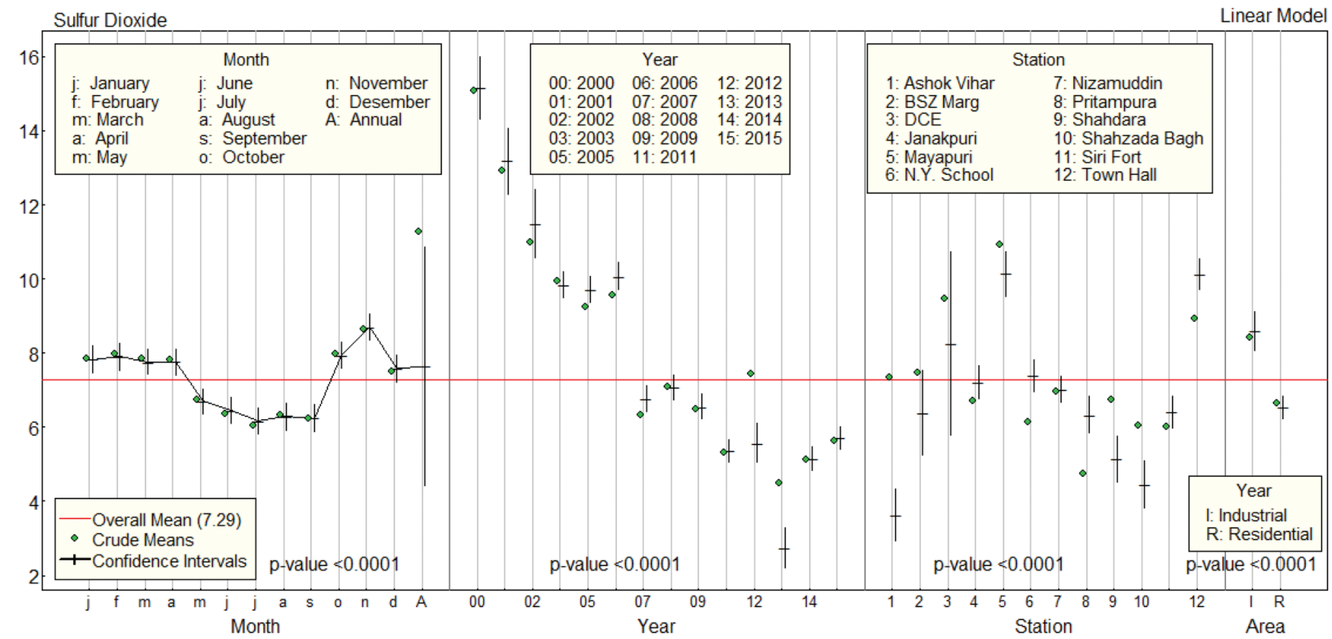

Figure 1: CI plot of sulphur dioxide (SO_2) and determinant.

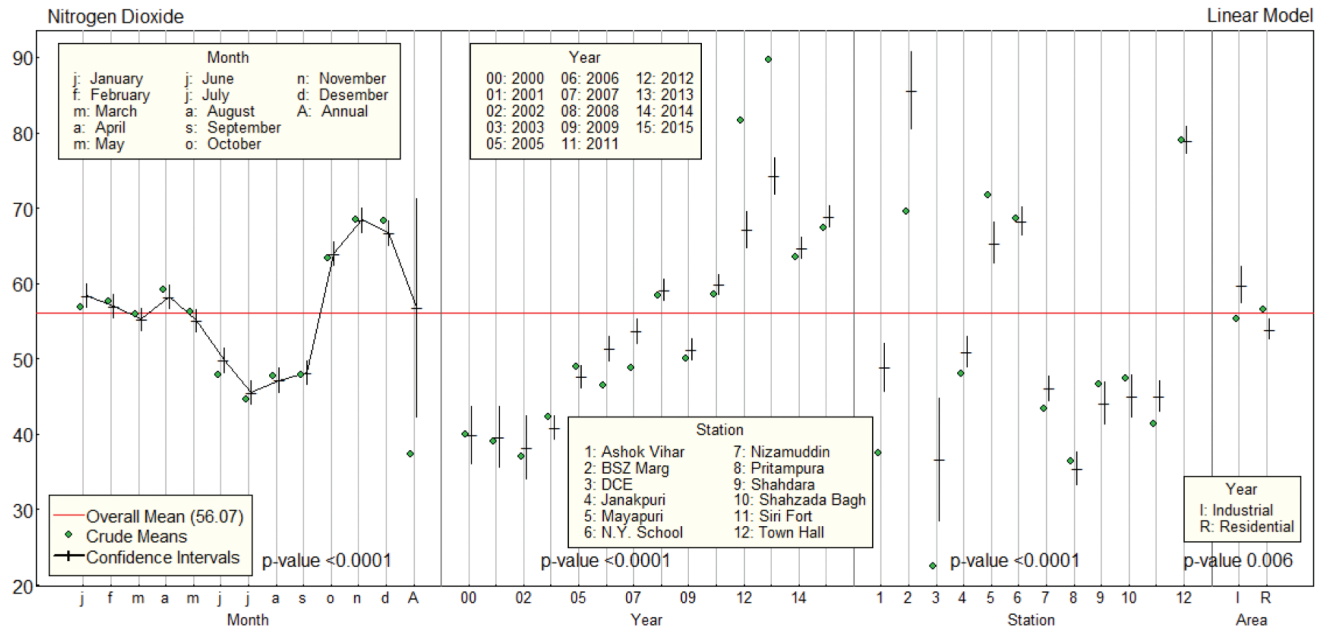

Figure 2: CI plot of nitrogen dioxide (NO_2) and determinant.

Figure 3 explains that the overall mean concentration of PM_{10} is 196.64 μg/m^3. Measurement result from 2000 to 2015 depicts that the lowest concentration was in August, increasing from September and the highest concentration was in December. The concentration of PM_{10} was rising from 2000 to 2009. Concentration in 2010-2015 was decreasing but fluctuated. The lowest concentration was in 2000 and the highest concentration was in 2009. The highest concentration was measured in the Mayapuri station, and the lowest concentration was measured in Ashok Vihar. The industrial area concentration of PM_{10} was more heightened than the overall mean, but the residential area was lower than the overall mean. The model shows that month, year, station, and area were correlated to PM_{10} concentration ($p < 0.05$).

Figure 4 explains that the overall mean concentration of SPM is 378.41 μg/m^3. Measurement result from 2000-2015 depicts that the lowest concentration was in August and the highest concentration was in October. The concentration of SPM fluctuated from 2000-2005. Concentration in 2006-2009 was increasing and the highest concentration was in 2009. Data from 2010-2014 was not available. The lowest concentration was

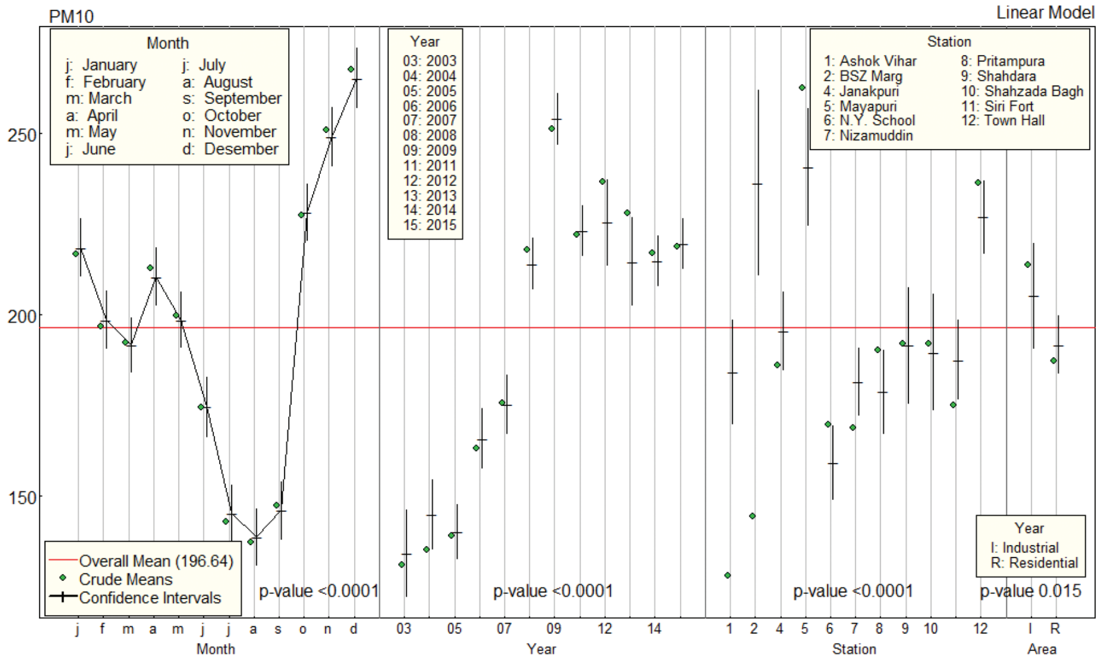

Figure 3: CI plot of PM_{10} and determinant.

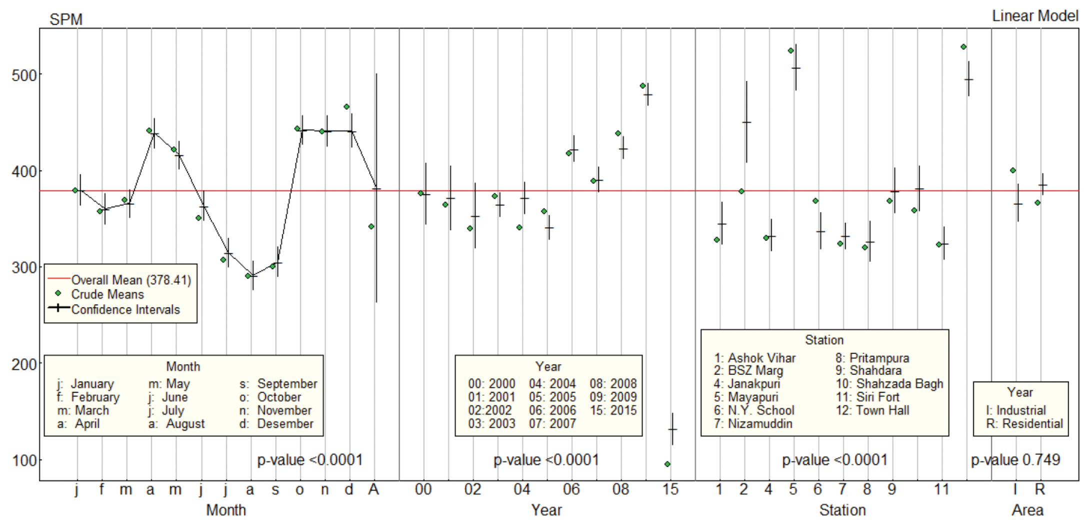

Figure 4: CI plot of SPM and determinant.

in 2015. The highest concentration was measured in the Mayapuri station, and the lowest concentration was measured in Pitampura and Siri Fort. The industrial area concentration of SPM was more heightened than the overall mean, but the residential area was lower than the overall mean. The model shows that the station was correlated to SPM concentration ($p < 0.05$). The area was not correlated to SPM ($p > 0.05$).

Discussion

Increased pollution concentrations in the air can rise quickly, affected not only by the number of pollutant sources but also by meteorological factors. Temperature, relative humidity, wind speed, wind direction, hurricanes, solar radiation, and other meteorological factors may affect pollutant concentrations (Gibson et al., 2013; Guo et al., 2019; Mishra & Goyal, 2015). Furthermore, changes in temperature and rainfall from year to year can influence the increase in contaminants from the atmosphere (Yoo et al., 2014). The environmental conditions and topology of the region will affect the meteorological parameter conditions in each location. The capital city of India, Mumbai, is one of the significant contributors to rising pollution levels. Delhi is one of the most polluted cities globally (Beig et al., 2015; Marrapu et al., 2014; Zhu et al., 2012).

New Delhi is India's most vital commercial and economic hub. The city is home to many multinational corporations and has a substantial market share in the Asia Pacific region. While this is helpful to a developing economy, it has a significant adverse effect on air pollution. The rapid growth of the manufacturing sector is correlated to the increased use of automobiles, the leading source of air pollution. For the first time in 70 years, frost was observed in New Delhi in early December 2005, as cold air from the Himalayas produced a low temperature of 0.2°C (32.3°F). New Delhi's weather is forecast to be around -6°C (31°F) (National Climatic Data Center, 2006).

India has five distinct seasons, each of which occurs in other months. The spring season begins in early February and lasts until the end of March, with temperatures ranging from 20°C to 25°C. Summer lasts from April to June, with temperatures ranging from 25°C to 45°C. The monsoon (rainy) season lasts from July to September, with temperatures ranging from 30°C to 35°C. The autumn season lasts from September to November, with temperatures ranging from 20°C to 30°C, and the winter season lasts from December to January, with temperatures ranging from 5°C to 25°C (Weather and Climate, 2020).

The presence of temperature is a critical factor in the distribution of air pollution. The surface temperature is high in the dry season. It is much higher than the temperature of the air layer above it, which causes the air to rise and contaminants to be transported upward, expanding the spreading region. On the other hand, the surface temperature drops below that of the air layer above it during the rainy season, causing the air to stagnate and travel downward, increasing pollutant deposition. Every month, the average air temperature, and differences in SO_2, NO_2, PM_{10}, and suspended particulate matter (SPM) in the air is nearly similar. Maximum concentrations were recorded between October and December (autumn and winter seasons), and minimum concentrations were recorded between July and September (monsoon season). During the moonson season (July-mid-September), the monthly average temperature ranged from 30°C to 35°C.

Meanwhile, the average monthly temperature for autumn (September-November) is 20°C to 30°C, and the average monthly temperature for winter (December-January) is 5°C to 25°C. Moonson season has lower concentrations than the other months. This condition may be attributed to contaminants being washed away by rain, lowering the air concentration in the air (Mishra & Goyal, 2015). Pollutants such as aerosols will grow in the months leading up to the rainy season, which lasts from March to July. After the rainy season is over, there will be an increase (Dey et al., 2004; Singh et al., 2014; Singh et al., 2004).

Besides temperature, the wind has a significant effect on the distribution of air pollution. The direction of the wind often determines the distribution of contaminants. Every month, the variations in SO_2, NO_2, PM_{10}, and suspended particulate matter (SPM) in the air are nearly identical. Maximum concentrations were recorded between October and December, and minimum concentrations were recorded between July and September (monsoon season) (autumn and winter season). Wind speed and direction are two variables that can influence air pollution (Gibson et al., 2013). The average wind speed for July-mid-September is 5.9 mph, and the average wind speed for October-December is 5.6 mph (Weatherspark, 2021). Wind movement with an average speed of 5.6-5.9 mph allows the concentration of pollutants SO_2, NO_2, PM_{10}, and suspended particulate matter (SPM) in residential areas to be lower than in industrial areas. Besides the wind speed, it is necessary to pay attention to the direction of the wind that blows.

The laying of fumes in the industry can be a factor in the spread of pollutants in the air. The higher the pollutant chimney, the smaller the pollutant concentration in the residential area.

Topographic factors in each region, such as cooler temperatures, lack of wind, and high humidity levels, may cause an increase in SO_2, NO_2, PM_{10}, and suspended particulate matter (SPM). Suppose there is not enough wind to blow away the accumulated dust and pollutants or significant raindrops to clean up. In that case, smoke and fog getting within tall buildings and some channels in industrial and residential areas will result in increased SO_2 and NO_2 readings. PM_{10} and particulate matter suspended in the air (SPM).

PM_{10} and SPM pollution levels rose in September, peaking in October, November, and December. During the autumn and early winter, the highest PM and SPM values occurred, while the lowest occurred during the rainy season. The highest PM_{10} concentration is recorded during the post-rainy season (October-December), while the lowest concentration is recorded during the rainy season (June-September), according to research conducted by Jain et al. (2020). During the dry season, dust storms from the Arabian Peninsula and the Thar Desert lead to a higher PM_{10} ratio. Cleaner airflow, rainfall, and emissions from the biomass combustion process can all be decreased during the rainy season, resulting in lower pollution levels (Yadav et al., 2017). In addition to local emissions and meteorology detected from two areas, namely industry and resident area. The factors that cause the rise and fall of pollutant concentrations at the sample points vary, including transportation, long-distance, deposition, biomass burning, and windblown dust, which all play a role in the accumulation of pollutants in urban areas (Bhanarkar et al., 2018; Yadav et al., 2014). Paved road dust, construction activities, power plants, household wood burning, and vehicle exhaust are considered primary sources of PM_{10} in Delhi (Gargava et al., 2014; Singh et al., 2020). Cars (34 percent), buses (23 percent), and heavy commercial vehicles (HCV, 17 percent) contribute the most to overall PM emissions, which are controlled by dust resuspension (Singh et al., 2020).

In addition, the burning of agricultural residues during harvest is a significant source of episodic atmospheric pollution. Every year the burning of agricultural residues, especially during the harvest of wheat, rice, cotton, and capacitance is identified as the cause of the intensification of pollutant concentrations in the air, especially in October and November (Isha & Sharma, 2020).

Delhi is a landlocked urban city with hot summers and harsh winters that sits at an altitude of 216 meters above sea level. Winter happens due to Western disturbances from the Mediterranean region, which carry winds and make the winter season cold. Dust storms can occur in Delhi during the pre-rainy season. After rainy (pre-monsoon and post-monsoon), dusty winds blow in from the Sahara, the Aran desert, the Gulf, and the Thar Desert (Singh & Naseema Beegum, 2013; Tiwari et al., 2014). The rainy season (monsoon) is historically thought to remove particulate matter and purify the air. According to previous studies, the effect of air pollution on India's rainy season causes a decrease in particle levels in the air (UNEP, 2018). According to Lelieveld et al. (2018), the circulation that occurs during the rainy season effectively removes contaminants from the atmosphere and transports the polytan residue to higher elevations.

The presence of weak local winds trapping pollutants on the surface is one of the conditions that cause air pollution to rise in Delhi. The presence of solid winds contributes significantly to the worsening and accumulation of pollutants in the air. The late arrival of the rainy season in Delhi in some years can be a factor in the year-to-year variance in particulate values (Beig et al., 2019).

One of the factors that enable the emergence of pollutants in the air that is currently happening in New Delhi is the result of industrial developments that are already growing. Considering that New Delhi is one of the cities that has a strong enough power in the economy. Rapid industrial development and the use of traditional fuels and the use of sustainable technology materials can be a factor in decreasing ambient air quality. This has been associated with 1.24 million premature deaths and 38.7 million Disability Adjusted Life-years. /DALYs) in India resulting in a national public health crisis (Isha & Sharma, 2020).

The Government of India has also formulated laws, policies, and programs to protect the environment Water (Prevention and Control of Pollution) Act, 1981 and the Environment (Protection) Act, 1986 (Vaish & Mehta, 2017). Industrial emissions are regulated under the Environment Protection Act, of 1986 which involves the installation of pollution control equipment to meet the emission guidelines. In addition, the obligation for industry to fulfill environmental permits from the Ministry of Environment and Forestry (KLHK) has been made mandatory for the establishment of development projects. In addition, mitigation efforts in the case of the most emissions from the industrial sector are by reducing the sulfur content of coal, industrial relocation (relocation of industry from the inside of the city to the outside), the use of environmentally friendly fuels (the use of less ash and coal sulfur content, etc.), use of gas fuels (LPG) and the application of air pollution control device applications have been taken up). Water spraying systems and the use of closed structures have been adopted to reduce dust emissions from stone crusher (Gurjar et al., 2016).

In addition, the Ministry of Environment in India has begun to establish a policy regarding efforts to protect air quality, known as the GRAP (Graded Response Action Plan) (Singh & Kulshrestha, 2020). GRAP (Graded Response Action Plan) is a set of emergency Actions that are implemented gradually in four stages according to the severity of air pollution. The GRAP was first notified in January 2017 by the Ministry of Environment, Forest, and Climate Change (Singh Gurhash, 2022). The result of the plan is to take Actions to be taken when air quality deteriorates. The GRAP is incremental whereas the air quality drops from 'poor' to 'very poor' The steps listed under both sections must be followed. Stage 1 of GRAP is activated when the AQI is in the 'poor' category (201 to 300), Stage 2 is when it's in the 'Very poor' category (301-400), Stage 3 is when the AQI is the 'Severe ' category (401-450) and finally Stage 4 is when it rises to the 'Severe +' category (more than 450).

Based on the analysis of the factors that cause poor air quality in the city of New Delhi and the analysis of wind speed and temperature conditions, it is deemed necessary to implement GRAP Phase IV immediately as a preventive measure. The implementation of stage IV is carried out to avoid further deterioration of overall air quality. The following are steps that can be taken in an effort to deal with the deteriorating air quality in New Delhi: (1) Ban on the use of four-wheeled diesel light motor vehicles in Delhi-NCR; BS-VI, essential and emergency services vehicles exempted; (2) Ban on entry of trucks other than electric and CNG ones in Delhi; those carrying essential commodities exempted; (3) Ban on construction and demolition works in linear public projects such as highways, flyovers, overbridges, power transmission, pipelines in Delhi-NCR; (4) Closure of all industries that are not running on clean fuels in NCR ordered, even in areas which do not have PNG infrastructure and supply, other than the fuels as per the standard list of approved fuels for NCR. Industries like milk and dairy units and those involved in manufacturing life-saving medical equipment or devices, drugs and medicines shall, however, be exempted from these restrictions; (5) States to decide on closure of schools, non-emergency commercial activities, odd-even schemes for vehicles; (6) Central, state governments may decide on permitting work from home for their employees; (7) Ban on Delhi-registered diesel-run medium and heavy goods vehicles in the capital. Those carrying essential commodities and providing essential services are exempted (India News, 2022). The emergence of several prohibitions contained in GRAP is a form of mitigation effort in preventing the deterioration of air quality which is getting worse.

Conclusion

This research aims to identify the time series trend of air pollution in New Delhi and investigate the relationship between determinants with SO_2, NO_2, PM_{10}, and SPM. Linear regression has been implemented to analyse. The determinant is month, year, station, and area. The indicators of air pollution considered are SO_2, NO_2, PM_{10}, and SPM. The model shows that month, year, station, and area were correlated to SO_2, NO_2, and PM_{10} concentration. Yet, in SPM concentration, month, year, the station was correlated. The area was not correlated to SPM. Investigation of other predictors was needed to gain information about the increasing air pollution on a global scale. This study analysed air pollution in different local scale areas and based on that circumstance. Individual correlation needs to be more investigated to look at the relationship of each dependent variable to air pollution. A global scale of assessment was required to counter climate change due to its unwanted effect.

Conflict of Interest

The authors declare no conflict of interest. This research is original. Hence, there is no potential conflict of interest.

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