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A Correlative Study of Air Pollution and Meteorological Factors in Visakhapatnam City, India

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ABSTRACT

Air pollution is considered to be one of the most important challenges that impacts negatively the health and environment around the world. The weather conditions are observed to function an important role to control the pollutant concentrations in various ways, such as chemical interactions, distribution, and dispersion in the atmosphere. The study aims to estimate the correlation among different pollutants, and they are SO_2, NOx, PM_{10}, $PM_{2.5}$, and NH_3, while the weather factors are temperature, precipitation, and wind speed. The data was gathered from public websites from the year 2018 to 2024 in Vishakhapatnam city. The data was obtained from the government monitoring station, specifically the Andhra Pradesh Pollution Control Board (APPCB) and the Central Pollution Control Board (CPCB). Pearson coefficient in SPSS program was used for the analysis to understand the relationship between the parameters. The results illustrated a strong positive correlation between SO_2 and NOx, and $PM_{2.5}$ and NH_3. In contrast, NH_3 showed a negative correlation with most of the variables. On the other hand, temperature stands out as an important factor which affects AQI and particulate matter, as well as precipitation reduces the pollution levels, specifically PM_{10}, while wind has the minimum effect.

Keywords: Air Pollution; Pollutants; Meteorological Parameters; AQI; Visakhapatnam.

I. INTRODUCTION

Air pollution is considered to be one of the most critical environmental and health challenges around the world, as it has a direct and indirect impact on human health, environmental systems, and climate change (Manisalidis et al., 2020). A great many dangerous pollutants, including CO, CO_2, Particulate Matter (PM), NO_2, SO_2, O_3, NH_3, and Pb, are released into the environment daily (Kumar & Pande, 2023; Meo et al., 2024).Many studies demonstrated that air pollutants contribute to increasing the rate of respiratory and heart diseases and premature death (Invally et al., 2017; Manisalidis et al., 2020). The air pollutant concentrations are determined by human and natural emissions, besides the complicated effects of the weather conditions (Lee et al., 2021).The sophisticated dynamic structures of air pollution make it very important to study, where the pollutant concentrations differ seasonally and spatially due to various factors, the weather conditions are one of the most important factors(Zhang, 2019; Liu et al., 2023). Therefore, in order to develop an efficient strategy to reduce air pollution and estimating the air quality, it becomes important to comperhense the interactions between air pollutants and weather conditions.

The solid particles are considered to be the basic and important components of air pollution, that contains a huge number types that causes pollution, for example, dust, pollen, and spores. As what Simu et al. (2020) and Onivefu and Imarhiagbe (2024), mentioned in their studies, the air pollutants are basically divided into two main classes, and are primary and secondary pollutants. The first class emitted directly from specified processes, such as the human daily works. While due to the interactions including the primary pollutant, the secondary pollutants are emitted and produced.

The weather conditions, such as temperature, rainfall, humidity, and wind speed, play a key role in controlling air pollutant concentrations, by managing their chemical interactions, their distribution, and their dispersion in the atmosphere (Feng et al., 2019). As mentioned by Wang et al. (2016), and Nakyai et al. (2025), an increase in temperature may boost the photochemical reactions, causing in form secondary pollution. Whilst wind speed participates in transferring the pollutants to further distances or reducing their concentration at specific part, in the other hand rain can affect both physical and chemical characteristics of pollutants and shift its capability in diffusion and deposition (Chang et al., 2023; Nakyai et al., 2025).

Linear and nonlinear models are examples of advanced analytical methods, whose its use has increased significantly in the recent years. The study of Cha & Kim (2018) illustrates that there was an obvious connection between different weather factors and the pollutants, especially the particulate matter (PM), and they used for their study the SPSS program. Whereas the results of Okimiji et al. (2021) and Liu et al. (2023) found that the characteristics of different seasons and regions were obviously noticed, as it demonstrates the negative impacts of weather conditions, especially wind speed, and precipitation, on the pollutants by lowering their concentrations in the atmosphere. In the other hand many studies showed that the relation between pollutants and meteorological factors are not always as simple as may thought but in contrast it is complex and often nonlinear, what makes the researchers to use more advanced methods to be able to understand these connections, as well as capturing the nonlinear interactions in the environmental data analysis, this was established by Santamaría et al. (2006) who used the Generalised Correlation Function (GCF) in order to achieve that goal.

In order to develop the accuracy of air quality forecasting models and to draw up sustainable environmental and health policies, the study and analyse of the correlation between air pollutants and meteorological factors has gain more importance. Therefore, to detect both strength and direction of this relationship a correlation coefficient (R), ranging from -1 to +1, was determined (Kafle, 2019; Chao & Min, 2022; Nakyai et al., 2025).The positive values pointout that any increase in one variable, either pollutant concentrations or meteorological factors, is linked with higher value of Air Quality Index (AQI), which mean poorer air quality, while the negative values proposed a lower Air Quality Index (AQI) levels, which mean improved air quality (Jacob & Winner, 2009; Liu et al., 2023).

The data for the study were collected from different air quality monitoring stations at Visakhapatnam, which were obtained from government monitoring stations, specifically the websites of the Andhra Pradesh Pollution Control Board (APPCB) and the Central Pollution Control Board (CPCB), for the period from 2018 to 2024. The parameters used for the analytical study are: SO_2, NOx, PM_{10}, $PM_{2.5}$, NH_3, temperature, precipitation, and wind speed at all the stations.

The goal of this study is to determine the main parameters and factors impacting the air quality, and to better understand the spatial and temporal patterns of pollutants, which helps policy-makers to improving effective strategies in order to control the emissions and reduce the effects on the heath.

II. METHODOLOGY

2.1Study Area and Data Sample

The study was carried out for the city of Visakhapatnam (also known as Vizag), which is located in the state of Andhra Pradesh, between the Eastern Ghats and the coast of the Bay of Bengal(Rani, 2016). The climate of Visakhapatnam is a tropical climate with hot, humid summers and mild winters. The year is divided into the following seasons:

- Winter: from December to February
- Summer: from March to May
- Monsoon: from June to September
- Autumn: from October to November

The hottest month of the year is May with average highs of 35°C and lows of 28°C. while December is considered to be the coolest month with average highs of 27°C and lows of 20°C.

The Air Quality Index (AQI) and its impacting factors for the period from 2018 to 2024 are applied to bethe sample data, and it was downloaded from the Andhra Pradesh Pollution Control Board (APPCB) and the Central Pollution Control Board (CPCB) websites for six stations named as follows:

- Industrial Estate, Autonagar
- Mindi Gudivada Appanna Kalyanamandapam
- Seethammadhar
- Gnanapuram
- PedaGantyada
- Raitu Bazar

The data consisted of an average of 7,960 samples for each manual station. The data was downloaded from the website where it was represented on an hourly basis. By taking the average of these measurements, it was transferred into daily measurements, and that helps simplifying the calculations and analysis procedures. The following parameters: SO_2, NOx, PM_{10}, $PM_{2.5}$, NH_3, Temperature, Precipitation, and Wind Speed, are considered for the monitoring stations.

2.2 Correlation Between Pollutants and Meteorological Factors

The relationship between air quality and meteorological factors is one of the important fundamental aspectsto understand the air pollution dynamics as well as to explain how the pollutant concentrations, such as $PM_{2.5}$, PM_{10}, NO_2 , and SO_2 , are varies based on the spatial and temporal phases, in addition to that it is influenced by weather conditions like temperature, humidity, wind speed, and precipitation (Chao & Min, 2022; Liu et al., 2023). The meteorological factors have direct and indirect influence in the pollutant concentrations by affecting their spread, change, or are removed from the atmosphere, which help reducing their negative impacts (Santamaría et al., 2006; Liu et al., 2023). The correlation coefficient (R) is one of the basic analytical tools used in determining both strength and direction of the relation between two variables, whether it was between meteorological factors only, air pollutants only, or between them together. This coefficient values ranging from -1 to +1, where the positive values related to direct relations, while the negative values related to inverse relations, but the values that are taking a place near the zero indicate weak or absent correlation (Kafle, 2019; Chao & Min, 2022). When applying the correlation coefficient in air quality studies, the high positive values indicates that any increase in meteorological factor or the pollutant concentration causes an increase in air quality index (AQI), meaning there would be a decrease in air quality due to the pollutant concentrations increasing. In contrast, the negative correlation indicates that any increase in any of the variables causes a decrease in air quality index (AQI), that reflect an improving at the air quality, this kind of correlation usually noticed with the weather factors that play a role in dispersion or removal of the pollutant, such as wind speed and rainfall(Jacob & Winner, 2009; Liu et al., 2023). Table 2.2.1 shows the strength of the Correlation Coefficient (R). Ranges Recap:

Table *2.2.1*: Correlation Coefficient (R) Ranges Recap

Ranges	Strength
0.00–0.09	No or Negligible correlation
0.10–0.29	Weak correlation
0.30–0.49	Moderate correlation
0.50–0.69	Strong correlation
0.70–1.00	Very strong correlation

Source: Kafle, 2019

The symbols of stars (*) and (**), in statistical analysis, are used to show how significant a correlation is:

- Two stars (**): Indicates the correlation is significant at the 0.01 level (2-tailed), meaning there is less than a 1% probability ($p < 0.01$) that the correlation happened by chance, suggesting a very strong relationship.
- One star (*): Indicates a correlation is significant at the 0.05 level (2-tailed), meaning there is less than a 5% probability ($p < 0.05$) that the correlation occurred by chance, suggesting a reasonably strong relationship.

III. RESULTS

The correlation between SO_2 and variables for all the stations

Station Name	NOx	PM_{10}	$PM_{2.5}$	NH_3	AQI	Temperature	Precipitation	Wind Speed
Industrial Estate	0.669**	0.238**	-0.027	-0.112**	0.259**	-0.120**	-0.112**	-0.115**
Gudivada Appanna Kalyanamanda	0.708**	0.297**	0.171**	0.006	0.316**	-0.141**	-0.097**	-0.080*

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Seethammadhara	0.628**	0.270**	0.196**	0.165**	0.274**	-0.119**	-0.117**	-0.079*
Gnanapuram	0.631**	0.245**	0.224**	0.246**	0.212**	-0.133**	-.0107**	-0.068
Peda Gantyada	0.606**	0.290**	0.109**	-0.040	0.287**	-0.102**	-0.078*	-0.068
Raitu bazar	0.601**	0.291**	0.014	-0.035	0.286**	-0.092*	-0.065	0.029

The correlation between NOx and variables for all the stations

Station Name	SO_2	PM_{10}	$PM_{2.5}$	NH_3	AQI	Temperature	Precipitation	Wind Speed
Industrial Estate	0.669**	0.188**	-0.059	-0.050	0.204**	-0.156**	-0.119**	-0.081*
Gudivada Appanna Kalyanamandapam	0.708**	0.236**	0.141**	0.021	0.277**	-0.153**	-0.117**	-0.071*
Seethammadhara	0.628**	0.155**	0.089*	0.098**	0.173**	-0.093**	-0.110**	-0.072*
Gnanapuram	0.631**	0.284**	0.287**	0.360**	0.254**	-0.171**	-0.151**	-0.011
Peda Gantyada	0.606**	0.238**	0.036	-0.065	0.255**	-0.162**	-0.098**	-0.057
Raitu bazar	0.601**	0.190**	0.007	-0.008	0.167**	-0.099**	-0.100**	-0.006

The correlation between PM_{10} and variables for all the stations

Station Name	SO_2	NOx	$PM_{2.5}$	NH_3	AQI	Temperature	Precipitation	Wind Speed
Industrial Estate	0.238**	0.188**	0.408**	-0.088*	0.933**	-0.385**	-0.178**	-0.042
Gudivada Appanna Kalyanamandapam	0.297**	0.236**	0.584**	-0.042	0.946**	-0.528**	-0.139**	-0.152**
Seethammadhara	0.270**	0.155**	0.437**	0.034	0.946**	-0.328**	-0.125**	-0.069
Gnanapuram	0.245**	0.284**	0.498**	0.033	0.933**	-0.285**	-0.175**	-0.007
Peda Gantyada	0.290**	0.238**	0.581**	0.071*	0.943**	-0.428**	-0.148**	-0.136**
Raitu bazar	0.291**	0.190**	0.370**	-0.039	0.860**	-0.389**	-0.155**	-0.086*

The correlation between $PM_{2.5}$ and variables for all the stations

Station Name	SO_2	NOx	PM_{10}	NH_3	AQI	Temperature	Precipitation	Wind Speed
Industrial Estate	-0.027	-0.059	0.408**	0.522**	0.384**	-0.280**	-0.100**	0.037
Gudivada Appanna Kalyanamandapam	0.171**	0.141**	0.584**	0.485**	0.570**	-0.347**	-0.083*	-0.020
Seethammadhara	0.196**	0.089*	0.437**	0.555**	0.413**	-0.175**	-0.040	0.021
Gnanapuram	0.224**	0.287**	0.498**	0.538**	0.447**	-0.228**	-0.094**	0.066
Peda Gantyada	0.109**	0.036	0.581**	0.555**	0.543**	-0.261**	-0.096**	-0.016
Raitu bazar	0.014	0.007	0.370**	0.552**	0.282**	-0.234**	-0.06	-0.029

The correlation between NH_3 and variables for all the stations

Station Name	SO_2	NOx	PM_{10}	$PM_{2.5}$	AQI	Temperature	Precipitation	Wind Speed
Industrial Estate	-0.112**	-0.050	-0.088*	0.522**	-0.127**	-0.015	-0.027	0.084*
Gudivada AppannaKalyanamandapam	0.006	0.021	-0.042	0.485**	-0.074*	-0.013	-0.027	0.074*
Seethammadhara	0.165**	0.098**	0.034	0.555**	-0.004	-0.039	-0.021	0.078*
Gnanapuram	0.246**	0.360**	0.033	0.538**	-0.007	-0.012	-0.024	0.094**
PedaGantyada	-0.040	-0.065	0.071*	0.555**	0.040	-0.025	-0.023	0.087*
Raitu bazar	-0.035	-0.008	-0.039	0.552**	-0.066	0.042	-0.027	0.043

The correlation between AQI and variables for all the stations

Station Name	SO_2	NOx	PM_{10}	$PM_{2.5}$	NH_3	Temperature	Precipitation	Wind Speed
Industrial Estate	0.259**	0.204**	0.933**	0.384**	-0.127**	-0.372**	-0.158**	-0.054
Gudivada AppannaKalyanamandapam	0.316**	0.277**	0.946**	0.570**	-0.074*	-0.526**	-0.144**	-0.163**
Seethammadhara	0.274**	0.173**	0.946**	0.413**	-0.004	-0.329**	-0.127**	-0.081*
Gnanapuram	0.212**	0.254**	0.933**	0.447**	-0.007	-0.271**	-0.171**	0.005
PedaGantyada	0.287**	0.255**	0.943**	0.543**	0.040	-0.438**	-0.151**	-0.145**
Raitu bazar	0.286**	0.167**	0.860**	0.282**	-0.066	-0.341**	-0.101**	-0.044

The correlation between Temperature and variables for all the stations

Station Name	SO_2	NOx	PM_{10}	$PM_{2.5}$	NH_3	AQI	Precipitation	Wind Speed
Industrial Estate	-0.120**	-0.156**	-0.385**	-0.280**	-0.015	-0.372**	-0.024	0.187**
Gudivada AppannaKalyanamandapam	-0.141**	-0.153**	-0.528**	-0.347**	-0.013	-0.526**	-0.019	0.188**
Seethammadhara	-0.119**	-0.093**	-0.328**	-0.175**	-0.039	-0.329**	-0.024	0.187**
Gnanapuram	-0.133**	-0.171**	-0.285**	-0.228**	-0.012	-0.271**	-0.024	0.187**
PedaGantyada	-0.102**	-0.162**	-0.428**	-0.261**	-0.025	-0.438**	-0.024	0.187**
Raitu bazar	-0.092*	-0.099**	-0.389**	-0.234**	0.042	-0.341**	-0.032	0.191**

The correlation between Precipitation and variables for all the stations

Station Name	SO_2	NOx	PM_{10}	$PM_{2.5}$	NH_3	AQI	Temperature	Wind Speed
Industrial Estate	-0.112**	-0.119**	-0.178**	-0.100**	-0.027	-0.158**	-0.024	0.147**
Gudivada AppannaKalyanamandapam	-0.097**	-0.117**	-0.139**	-0.083*	-0.027	-0.144**	-0.019	0.148**
Seethammadhara	-0.117**	-0.110**	-0.125**	-0.040	-0.021	-0.127**	-0.024	0.147**
Gnanapuram	-0.107**	-0.151**	-0.175**	-0.094**	-0.024	-0.171**	-0.024	0.147**
PedaGantyada	-0.078*	-0.098**	-0.148**	-0.096**	-0.023	-0.151**	-0.024	0.147**

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Raitu bazar	-0.065	-0.100**	-0.155**	-0.06	-0.027	-0.101**	-0.032	0.145**

The correlation between Wind Speed and variables for all the stations

Station Name	SO_2	NOx	PM_{10}	$PM_{2.5}$	NH_3	AQI	Temperature	Precipitation
Industrial Estate Gudivada	-0.115**	-0.081*	-0.042	0.037	0.084*	-0.054	0.187**	0.147**
AppannaKalyan amandapam	-0.080*	-0.071*	-0.152**	-0.020	0.074*	-0.163**	0.188**	0.148**
Seethammadhara	-0.079*	-0.072*	-0.069	0.021	0.078*	-0.081*	0.187**	0.147**
Gnanapuram	-0.068	-0.011	-0.007	0.066	0.094**	0.005	0.187**	0.147**
PedaGantyada	-0.068	-0.057	-0.136**	-0.016	0.087*	-0.145**	0.187**	0.147**
Raitu bazar	0.029	-0.006	-0.086*	-0.029	0.043	-0.044	0.191**	0.145**

IV. CONCLUSIONS

This study aimed to identify the key indicators affecting air quality and to examine how meteorological factors influence and potentially mitigate poor air quality. The relationships and correlations between these indicators and the AQI were analysed in Visakhapatnam using historical and real-time data obtained from pollution control websites of the Andhra Pradesh Pollution Control Board (APPCB) and the Central Pollution Control Board (CPCB).

The analysis was carried out using SPSS software, and the following conclusions were drawn from the results obtained, which have shown similarity with the earlier works on the familiar topics of study.

- A strong positive correlation was observed among the variables, SO_2 and NOx, and $PM_{2.5}$ and NH_3, indicating that an increase in one pollutant tends to be associated with an increase in others (Chao & Min, 2022). In the study, the correlations between SO_2 and NO_3 ranged from 0.601 to 0.708. while the correlation between $PM_{2.5}$ and NH_3 ranged from 0.485 to 0.572.
- In contrast, some variables showed a negative (inverse) correlation, where an increase in one factor led to a decrease in another (Cha & Kim, 2018; Chao & Min, 2022). NH_3 showed a negative correlation with most of the variables, especially particulate matter (PM), where it ranged with PM_{10} from -0.039 to -0.088.
- Temperature emerged as a significant meteorological factor, strongly influencing both AQI and particulate matter concentrations (Cha & Kim, 2018). In the study, the correlation between temperature and AQI ranged from -0.271 to -0.526, and the correlation between temperature and PM_{10} ranged from -0.285 to -0.528, while the correlation with the $PM_{2.5}$ ranged from -0.183 to -0.575.
- Humidity and rainfall also played important roles, as both contributed to the reduction of air pollution, particularly by lowering PM_{10} levels (Chao & Min, 2022). The correlation in the study between precipitation and PM_{10} ranged from -0.144 to -0.226.

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