**Comprehensive Analysis of Air Pollutants Behavior and**

**Wind Patterns in Vishakhapatnam**

*Thesis to be submitted in partial fulfillment of the requirements for the degree*

*of*

#### B. Tech

*by*

#### KOTHAPALLI SUVANJALI

**(19MI33010)**

Under the guidance of

**Prof. B.S.Sastry**

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## CERTIFICATE

This is to certify that we have examined the thesis entitled **Comprehensive Analysis of Air Pollutants Behavior and Wind Patterns in Vishakhapatnam,** submitted by **Kothapalli Suvanjali** (Roll Number: *19MI33010*) an undergraduate student of **Department of Mining Engineering** in partial fulfillment of the requirements for the degree of Bachelor of Technology. We hereby accord our approval of it as a study carried out and presented in a manner required for its acceptance in partial fulfillment for the Undergraduate Degree for which it has been submitted. The thesis has fulfilled all the requirements as per the regulations of the Institute and has reached the standard needed for submission.

### Supervisor

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**Place: Kharagpur**

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**Abstract**

Name of the student: **Kothapalli Suvanjali** Roll No: **19MI33010**

Degree for which submitted: **Bachelor of Technology**

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Thesis title: **Comprehensive Analysis of Air Pollutants Behavior and Wind Patterns in**

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Thesis supervisor: **Professor Bhamidipati Suryanarayana Sastry**

Month and year of thesis submission: **November 28th 2023**

This comprehensive study explores the intricate relationships between air pollutants, wind direction, monthly variations, and their collective impact on the Air Quality Index (AQI) and compliance with National Ambient Air Quality Standards (NAAQS). Leveraging historical air quality data encompassing diverse pollutants such as particulate matter (PM2.5 and PM10), nitrogen dioxide (NO2), sulfur dioxide (SO2), carbon monoxide (CO), and ozone (O3), Benzene (C6H6), Lead (Pb), Volatile Organic Compounds (VOCs) (Toluene, Xylene), alongside meteorological data including wind speed and direction, atmospheric temperature, relative humidity, rain fall, solar radiation, this research provides a holistic perspective on air quality dynamics.

The study employs various analytical tools, including box-and-whisker plots, correlation analysis, wind rose construction, and AQI/NAAQS assessments, to accomplish its objectives. Data preprocessing ensures the reliability and consistency of the datasets, addressing missing values, outliers, and temporal alignment issues.

Box-and-whisker plots offer insights into the distribution of wind directions concerning pollutant concentrations. These plots reveal how different pollutants vary with wind direction, providing valuable information on pollution source identification and dispersion patterns.

Monthly variations in pollutant concentrations are assessed through detailed graphical analyses. Plots depicting pollutant levels across different months unveil seasonal trends and their impact on air quality. These insights contribute to a more nuanced understanding of the temporal dynamics of air pollution.

Correlation analysis investigates the interplay between air pollutants, wind patterns, AQI, and NAAQS compliance. The study uncovers significant correlations between pollutants and AQI, shedding light on the pollutants that most strongly influence air quality. Furthermore, the analysis assesses whether specific wind patterns correlate with AQI fluctuations.

The construction of wind roses with respect to AQI and NAAQS compliance offers a spatial perspective on pollutant dispersion and their alignment with air quality standards. This visual representation aids in pinpointing areas of concern, identifying pollution hotspots, and assessing the impact of wind patterns on AQI and NAAQS adherence.

Ultimately, this research delivers actionable insights for environmental policymakers, regulatory agencies, and public health officials. By elucidating the intricate web of interactions between air pollutants, wind patterns, monthly variations, AQI, and NAAQS compliance, this study informs evidence-based decision-making. It guides targeted pollution control measures, enhances air quality management, and reinforces the importance of adhering to air quality standards to ensure the well-being of communities and the preservation of our environment.

**Chapter 1**

**1.0 Introduction**

This study delves into the dynamic interplay between air pollutants, wind patterns, and their collective impact on air quality, as measured by the Air Quality Index (AQI), and compliance with National Ambient Air Quality Standards (NAAQS). I explored these relationships through the analysis of historical air quality data, encompassing a spectrum of pollutants, including particulate matter (PM2.5 and PM10), nitrogen dioxide (NO2), sulfur dioxide (SO2), carbon monoxide (CO), and ozone (O3), Benzene (C6H6), Lead (Pb), Volatile Organic Compounds (VOCs) (Toluene, Xylene). Additionally, I incorporated meteorological data, particularly wind speed and direction, atmospheric temperature, relative humidity, rain fall, solar radiation, to gain a holistic understanding of air quality dynamics.

I have created a wind rose utilizing data on wind direction and wind speed, and subsequently conducted a statistical analysis to investigate the relationships between various air pollutants. This comprehensive approach allowed for a thorough exploration of how wind patterns and pollutant concentrations interact, shedding light on potential associations and dependencies.

Wind rose construction was employed to visualize and analyze historical wind patterns in a specific area of Visakhapatnam. This method involved dividing a compass rose into bins, counting the frequency of wind from each direction, and normalizing the data for easy interpretation. A polar plot was created to represent the wind data visually, with each segment's length indicating the wind frequency. This analysis helped identify prevailing wind directions, patterns, and their potential impact on factors like air quality and pollution dispersion. Wind roses served as valuable tools in various environmental and urban planning applications.

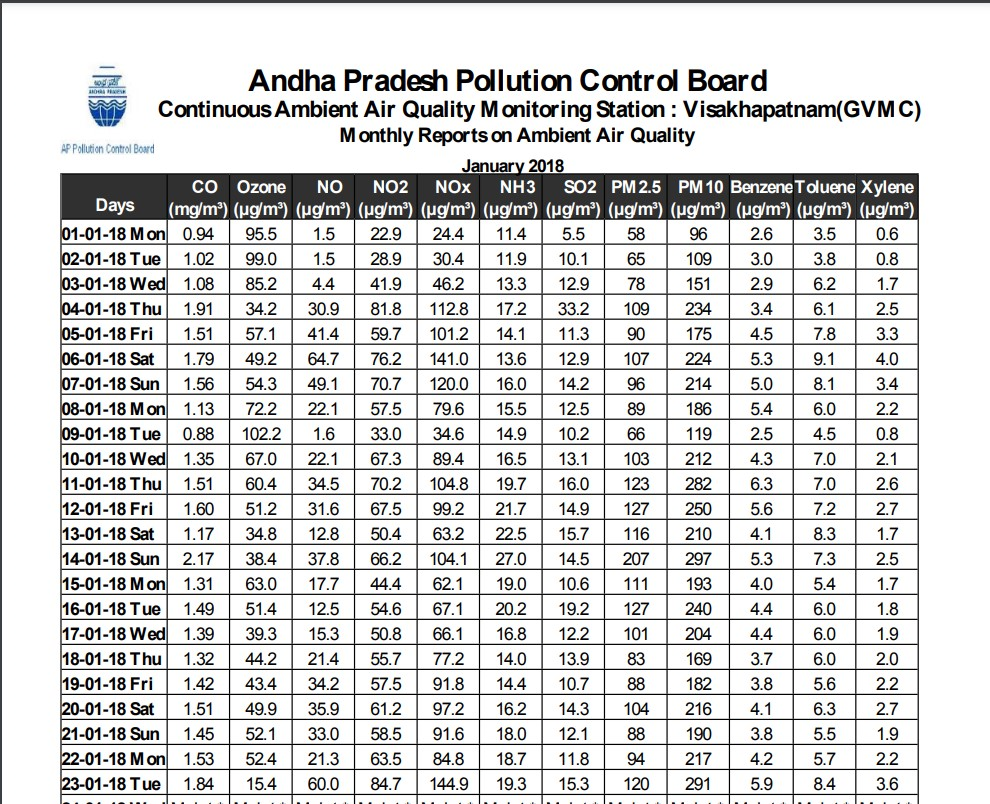
Correlation of air pollutants refers to the statistical analysis that measures the degree to which different air pollutants are related or associated. In a nutshell, it assesses whether changes in one pollutant coincide with changes in another. Positive correlation suggests that when one pollutant increases, the other tends to increase as well, while negative correlation implies that as one pollutant rises, the other falls. This analysis is crucial for understanding how multiple pollutants interact and can help identify common sources or factors influencing air quality variations.

I have generated a series of whisker plots using five years’ worth of air pollutant data obtained from the Andhra Pradesh Pollution Control Board's website. These plots offer a visual representation of how pollutant concentrations have fluctuated over this extended time frame, providing insights into long-term air quality trends in the region.

Whisker Plot of Wind Direction with Respect to Pollutants: This type of plot displays the distribution of pollutant concentrations based on different wind directions. It helps identify how pollutants vary depending on where the wind is coming from, which is valuable for pinpointing potential pollution sources and understanding how wind patterns affect air quality.

* 1. **Scope of work**

Collected daily day, month-wise data spanning five years from the Andhra Pradesh Pollution Control Board's website for Visakhapatnam (GVMC). **This is the original data from website:**



* 1. **Objective**

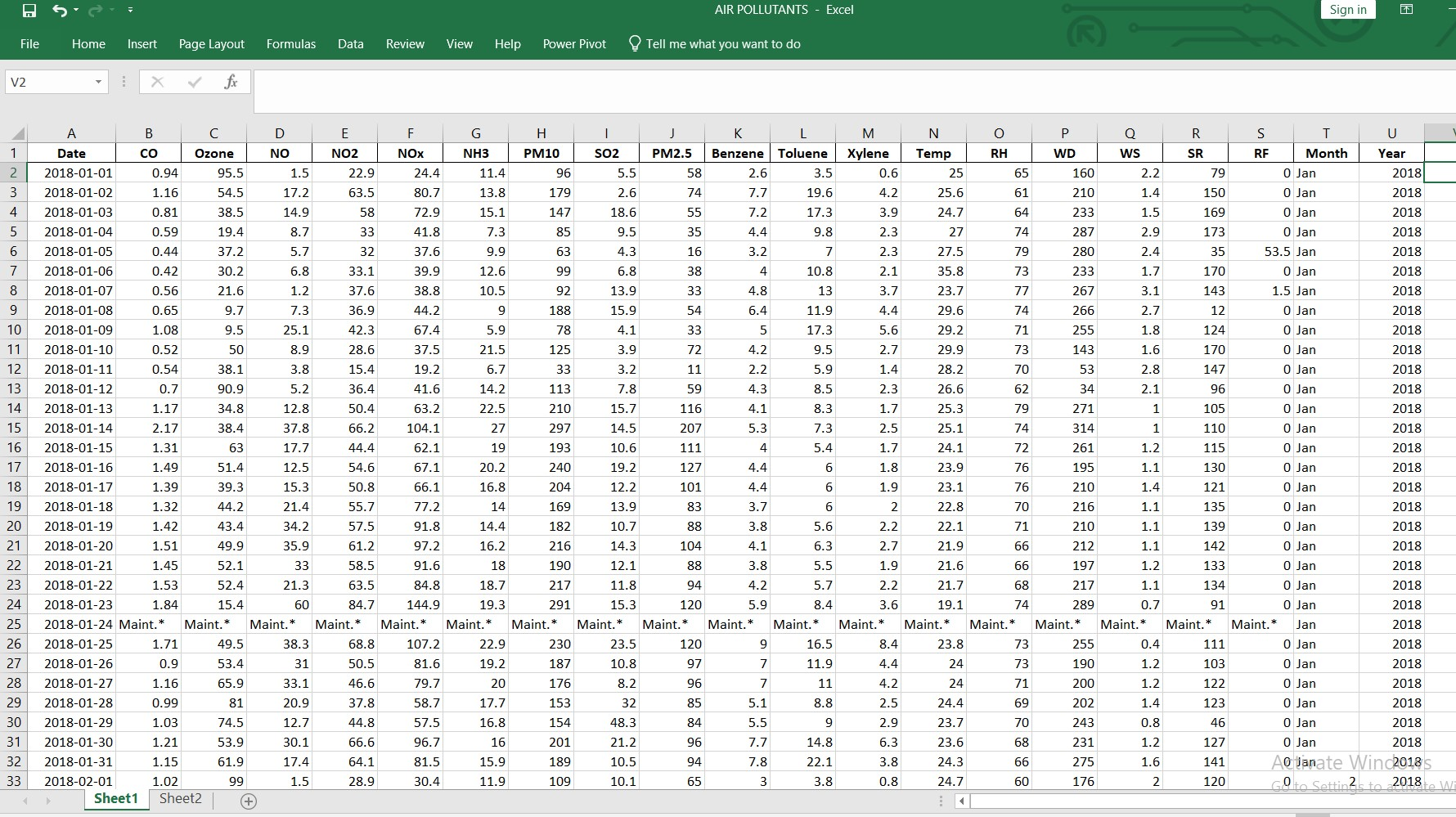
The objective of this project is to conduct a comprehensive analysis of air quality in Vishakhapatnam over a five-year period, involving the construction of wind rose, correlation analysis of air pollutants, and the creation of whisker plots to visualize data distribution.

* 1. **Methodology**

Data cleaning and air pollutant correlation analysis were conducted utilizing Python, while whisker plots were generated within an Excel spreadsheet.

Wind rose were created based on eight wind directions (N, NE, E, SE, S, SW, W, NW) to visualize wind patterns in Vishakhapatnam. The frequencies of wind occurrences in each direction were calculated. These frequencies were then normalized into percentages for accurate representation. The wind rose plots were carefully designed with color coding to illustrate wind speed categories.

**After modified data:**



**The Data consists of 1827 rows for all five years of each month-daily day wise.**

**Chapter 2: Literature Review**

**National Ambient Air Quality Standards (NAAQS):**

1. **Historical Development:**

Literature often covers the historical evolution of NAAQS, tracing its origins from early air pollution events to the establishment of the Clean Air Act in 1970. This includes discussions on the legislative framework and amendments that shaped the development of air quality standards.

1. **Criteria Pollutants and Standards:**

Detailed reviews explore each of the criteria pollutants (ozone, particulate matter, sulfur dioxide, nitrogen dioxide, carbon monoxide, and lead) regulated under NAAQS. This involves discussions on the scientific basis for setting standards, revision processes, and the establishment of primary and secondary standards.

1. **Health Impacts and Epidemiological Studies:**

Literature extensively reviews epidemiological studies assessing the health impacts of criteria pollutants regulated by NAAQS. This includes research on respiratory and cardiovascular effects, as well as long-term exposure studies linking air pollution to chronic diseases.

1. **Air Quality Monitoring and Measurement Techniques:**

A critical aspect of NAAQS is the development of robust monitoring techniques. Literature reviews cover advancements in air quality monitoring technologies, including satellite-based measurements, ground-level monitoring stations, and the integration of data from various sources.

1. **Regulatory Implementation and Compliance:**

Studies discuss the regulatory implementation of NAAQS at various administrative levels, exploring challenges, successes, and the role of regulatory agencies. This includes a focus on compliance monitoring, enforcement mechanisms, and the implications for industries.

1. **Air Quality Modeling and Assessment:**

Literature reviews delve into the use of air quality models to assess compliance with NAAQS. This includes discussions on modeling methodologies, their accuracy, and the incorporation of modeling into regulatory decision-making processes.

1. **Public Awareness and Communication:**

The effectiveness of NAAQS relies on public understanding. Literature explores the role of public awareness campaigns, communication strategies, and the integration of air quality information into public health initiatives.

1. **International Perspectives and Comparative Analyses:**

Comparative studies and international perspectives on air quality standards provide insights into the effectiveness of NAAQS in relation to global air quality management. This includes discussions on harmonization efforts and the adaptation of standards to diverse environmental contexts.

**Air Quality Index (AQI):**

1. **Historical Evolution and Development:**

Reviews often start with a historical perspective on the development of the Air Quality Index (AQI), tracing its origins and evolution from the early days of air quality monitoring to its current widespread use. This includes discussions on the establishment of AQI systems globally.

1. **Components of AQI:**

Literature delves into the components of AQI, which typically include various air pollutants such as ozone, particulate matter, sulfur dioxide, nitrogen dioxide, carbon monoxide, and sometimes additional pollutants. Studies discuss the selection of these pollutants, their health implications, and the development of AQI sub-indices.

1. **Health Impacts and Risk Communication:**

One of the central focuses of literature reviews is the correlation between AQI levels and health outcomes. Studies examine epidemiological evidence linking different AQI categories to health risks, including respiratory and cardiovascular effects. Additionally, research on the effectiveness of risk communication strategies associated with AQI is explored.

**The pollutants are:**

**Particulate Matter (PM2.5 and PM10):**

PM2.5 and PM10 are fine and coarse particles suspended in the air, respectively. They originate from various sources, including combustion processes, industrial activities, and natural sources. PM exposure is associated with respiratory and cardiovascular diseases. Literature emphasizes the health effects, sources, and regulatory measures for controlling PM levels.

**Nitrogen Dioxide (NO2):**

NO2 is a common air pollutant primarily emitted from combustion processes, such as vehicle emissions and industrial activities. Literature often explores its role in air quality, health impacts, and its contribution to the formation of ground-level ozone. NO2 is regulated due to its adverse effects on respiratory health.

**Sulfur Dioxide (SO2):**

SO2 is released during the burning of fossil fuels containing sulfur, like coal and oil. It contributes to acid rain formation and respiratory issues. Literature reviews cover its sources, health impacts, environmental consequences, and regulatory measures for limiting SO2 emissions.

**Carbon Monoxide (CO):**

CO is produced by incomplete combustion of carbon-containing fuels. It is known for its affinity to hemoglobin, reducing the blood's ability to carry oxygen. Literature reviews typically delve into the sources of CO, its health effects, monitoring methods, and regulations to ensure air quality standards.

**Ozone (O3):**

Ground-level ozone is a secondary pollutant formed by the reaction of precursor pollutants in the presence of sunlight. Literature explores ozone's sources, atmospheric chemistry, health impacts, and its role in smog formation. Ozone is regulated due to its adverse effects on respiratory health.

**Benzene (C6H6):**

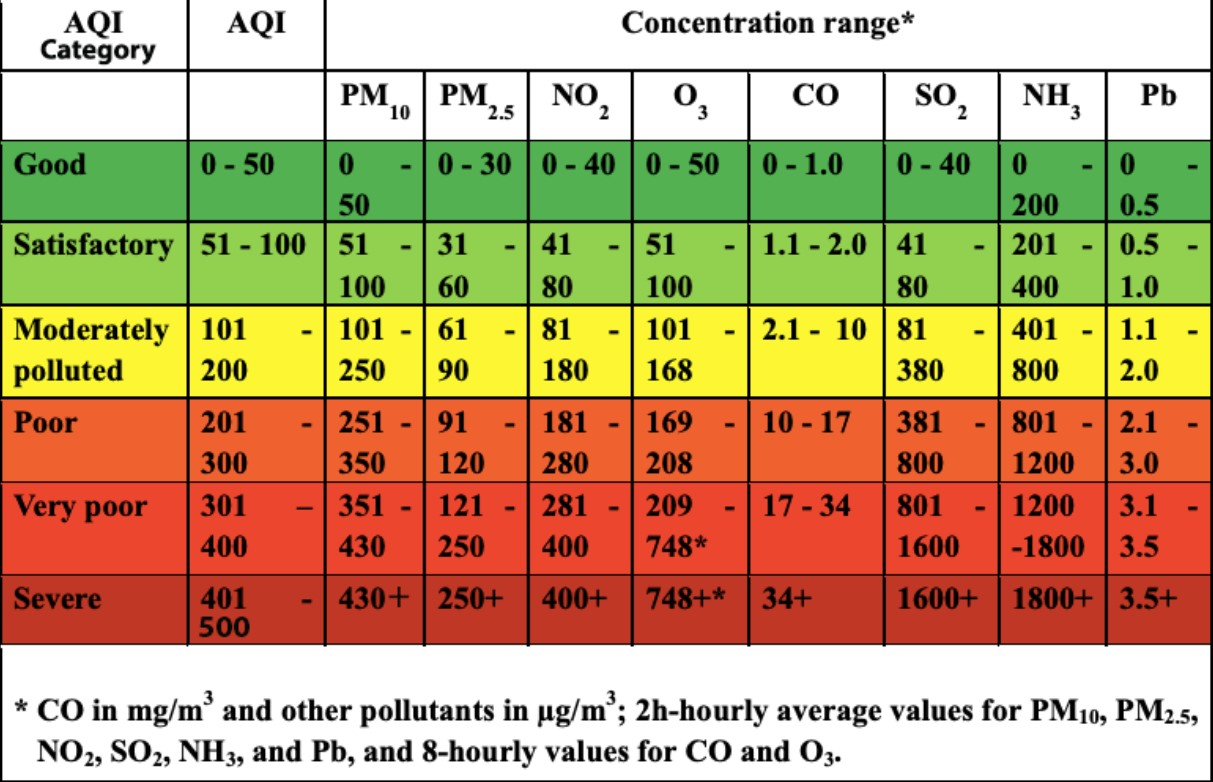
Benzene is a volatile organic compound (VOC) released from industrial processes and combustion. It is a known carcinogen and has both acute and chronic health effects. Literature reviews on benzene focus on exposure pathways, health risks, regulatory measures, and strategies for reducing emissions.

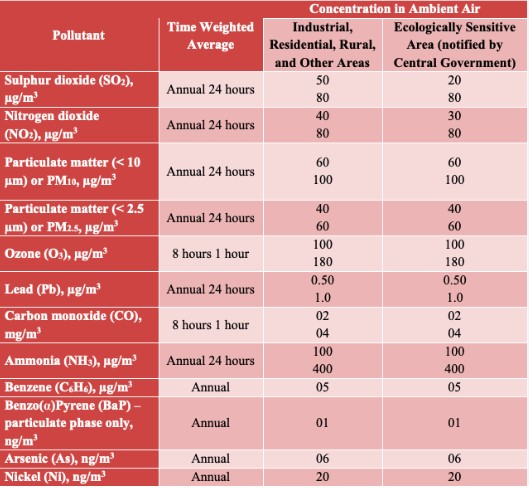
**Lead (Pb):**

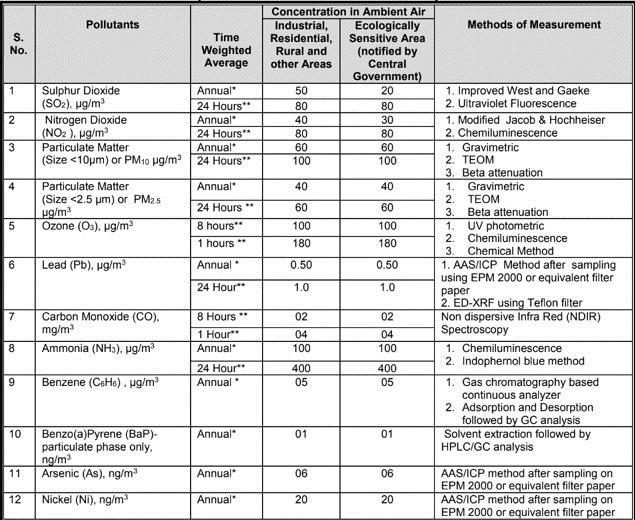
Lead can be released into the air from various sources, including leaded gasoline and industrial activities. Literature reviews on lead cover its historical use, health effects (especially neurotoxicity), environmental impacts, and regulatory efforts to reduce lead exposure.

**Volatile Organic Compounds (VOCs) - Toluene and Xylene:**

Toluene and xylene are common VOCs emitted from industrial activities, vehicle exhaust, and certain household products. Literature reviews often discuss their sources, health effects, environmental fate, and regulatory approaches to limit VOC emissions.







**Chapter 3: Data**

**Data Collection and Import:** Historical air pollutant data spanning five years (2018, 2019, 2020, 2021, 2022) was systematically gathered. This dataset was then efficiently imported into Python using the Pandas library to facilitate subsequent in-depth analysis.

All Data file, Plots and Code are available in this link: **https://github.com/KSuvanjali/BTP**

**Data Cleaning and Preprocessing:** The dataset underwent rigorous cleaning procedures using Python. Any missing values were either imputed or removed to ensure the integrity of the dataset. Outliers were identified and appropriately addressed through effective methods. Necessary transformations were applied to the data to enhance its quality and coherence. Utilizing Matplotlib and Seaborn, data distributions and anomalies were visually inspected, providing valuable insights into the dataset's quality and characteristics.

**Chapter 4: Data Analysis**

Machine learning techniques, particularly multiple linear regression, were employed to develop predictive models for air pollutant concentrations considering their correlations with various environmental variables. These models were designed to establish relationships between pollutants and key factors such as temperature, solar radiation, wind speed, relative humidity, rainfall, and wind direction using statistical analysis.

In simpler terms, *R^*2 measures the goodness of fit of the model. Higher *R^*2 values indicate a better fit, meaning that a larger proportion of the variability in the dependent variable is accounted for by the independent variables in the model.

*R^*2=0: The model does not explain any of the variability in the dependent variable.

*R^*2=1: The model perfectly explains the variability in the dependent variable.

**Equation:**

**CO = 2.30 +( -0.04) \* Temp + (-0.01) \* RH + 0.00 \* WD + 0.05 \* WS + (-0.00) \* SR + -0.00 \* RF**

For carbon monoxide, the equation suggests that its concentration is inversely related to temperature and relative humidity but positively related to wind speed.

**Equation:**

**Ozone = 205.50 + (-2.38) \* Temp + (-1.32) \* RH + (-0.08) \* WD + 0.97 \* WS + (-0.00) \* SR + (-0.06) \* RF**

The ozone concentration is negatively associated with temperature, relative humidity, wind direction, and rainfall but positively associated with wind speed.

**Equation:**

**NO = 44.37 + (-1.09) \* Temp + (-0.05) \* RH + 0.03 \* WD + (-2.29) \* WS + 0.00 \* SR + (-0.01) \* RF**

Nitric oxide levels are negatively related to temperature, relative humidity, and rainfall but positively related to wind direction and wind speed.

**Equation:**

**NO2 = 125.28 + (-1.07) \* Temp + (-0.89) \* RH + 0.05 \* WD +( -0.70) \* WS + (-0.03) \* SR + 0.01 \* RF**

Nitrogen dioxide concentrations depend on temperature, relative humidity, wind direction, wind speed, solar radiation, and rainfall.

**Equation:**

**NOx = 169.71 + (-2.16) \* Temp + (-0.93) \* RH + 0.09 \* WD +( -3.00) \* WS + (-0.03) \* SR + 0.00 \* RF**

The concentration of nitrogen oxides is influenced by temperature, relative humidity, wind direction, wind speed, and solar radiation.

**Equation:**

**NH3 = 24.33 + 0.26 \* Temp +( -0.20) \* RH + 0.00 \* WD +( -2.23) \* WS + (-0.01) \* SR + 0.01 \* RF**

Ammonia levels are positively associated with temperature and rainfall but negatively associated with relative humidity, wind speed, and solar radiation.

**Equation:**

**SO2 = 25.97 +( -0.10) \* Temp + -0.12 \* RH + (-0.00) \* WD + -0.57 \* WS + (-0.01) \* SR + 0.04 \* RF**

Sulfur dioxide concentrations are influenced by temperature, relative humidity, wind speed, solar radiation, and rainfall.

**Equation:**

**PM2.5 = 279.97 + (-3.91) \* Temp + (-1.63) \* RH + 0.01 \* WD +( -3.17) \* WS + (-0.03) \* SR + (-0.36) \* RF**

Particulate matter (PM2.5) levels are negatively associated with temperature, relative humidity, wind direction, wind speed, solar radiation, and rainfall.

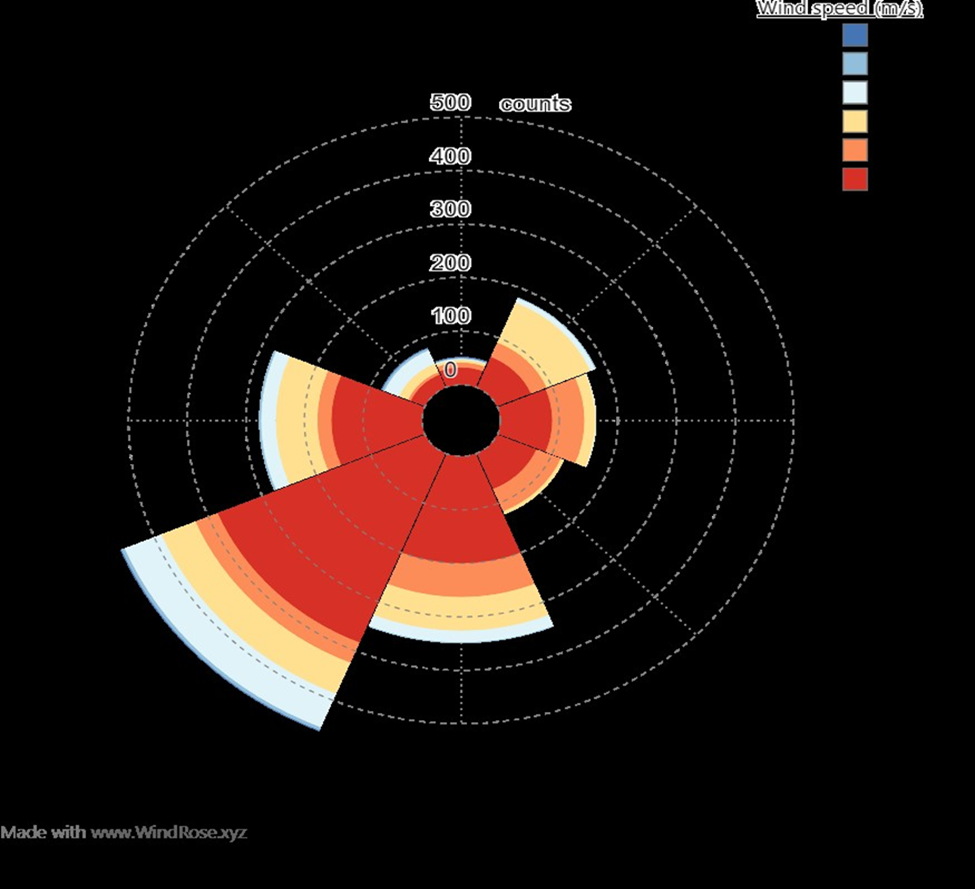
**Wind rose table:**

Top of Form

The table delineates that the colored values represent various ranges of wind speed measured in meters per second.

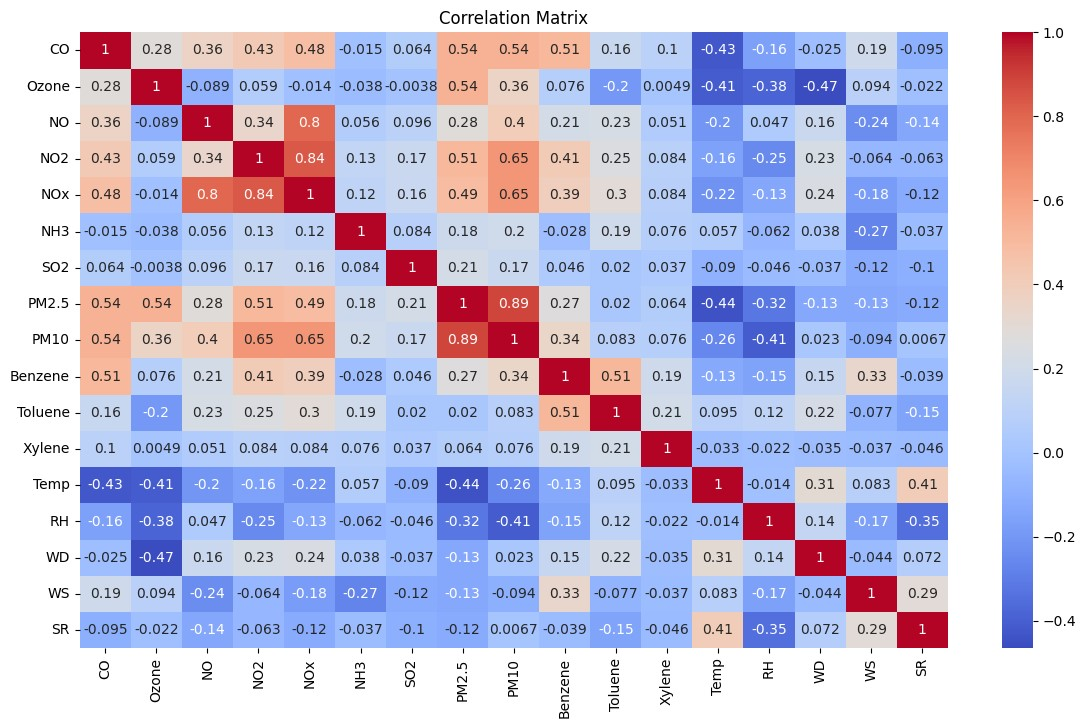
**Wind rose:**

Wind roses were created based on eight wind directions (N, NE, E, SE, S, SW, W, NW) to visualize wind patterns in Vishakhapatnam. The frequencies of wind occurrences in each direction were calculated. These frequencies were then normalized into percentages for accurate representation. The wind rose plots were carefully designed with color coding to illustrate wind speed categories.

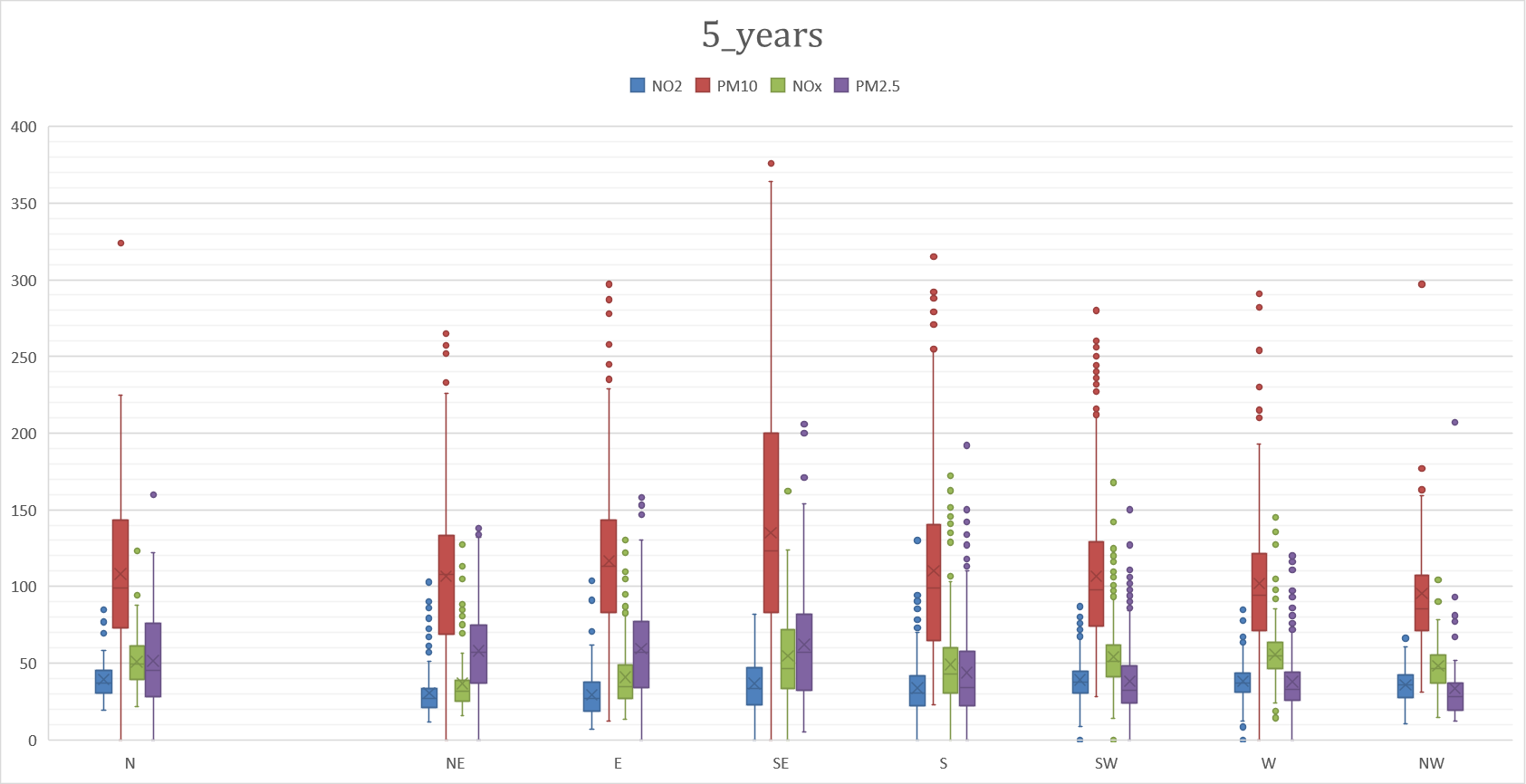
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**Correlation matrix:**

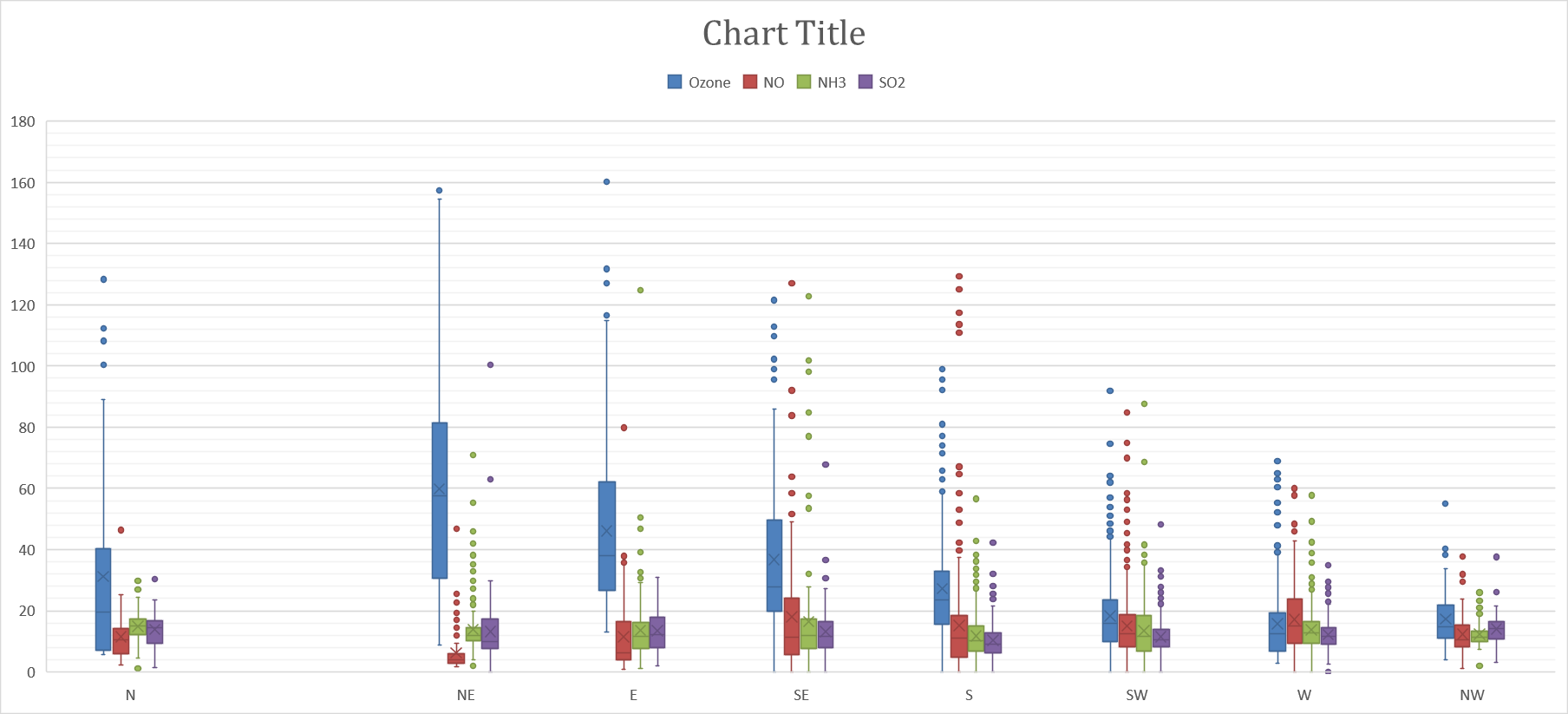
Correlation of air pollutants refers to the statistical analysis that measures the degree to which different air pollutants are related or associated. In a nutshell, it assesses whether changes in one pollutant coincide with changes in another. Positive correlation suggests that when one pollutant increases, the other tends to increase as well, while negative correlation implies that as one pollutant rises, the other falls. This analysis is crucial for understanding how multiple pollutants interact and can help identify common sources or factors influencing air quality variations.



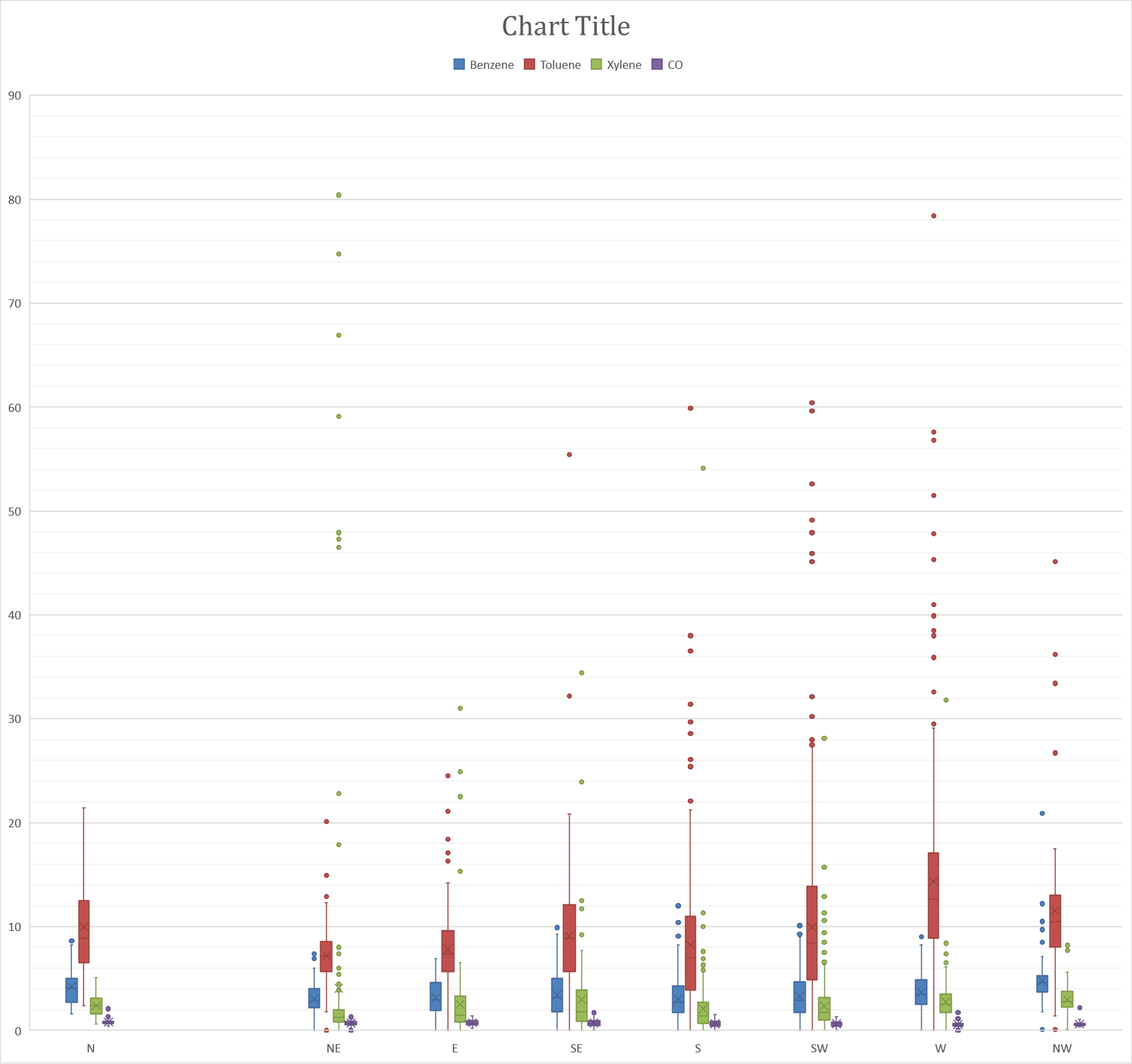
**Whisker Plots:**

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Graph-1(mu g/m^3)

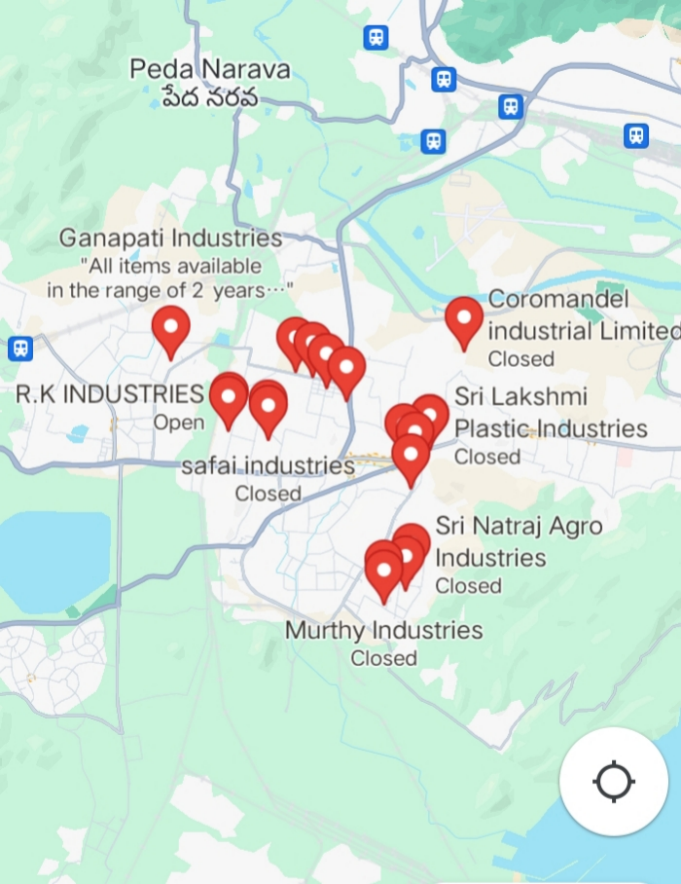
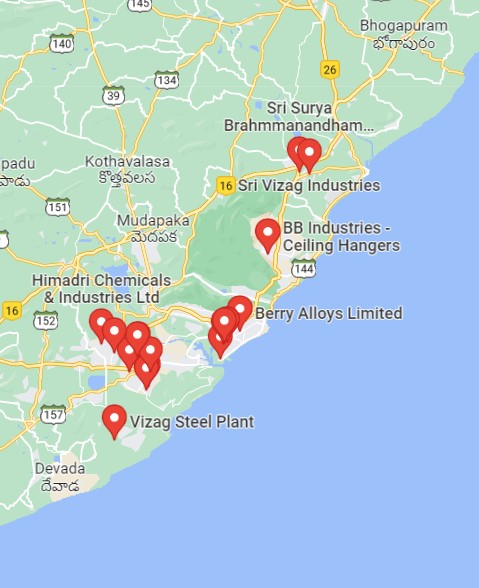
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Graph-2(mu g/m^3)

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Graph-3(mu g/m^3)

* Investigate potential sources in the southeast direction that could contribute to higher PM10 levels. This might include industrial facilities, construction sites, traffic patterns, or other localized emission sources (Graph-1,2,3).
* Consider prevailing wind patterns in the region. The fact that PM10 is higher in the southeast direction suggests that pollutants from sources in that direction are being transported towards Vishakhapatnam. Understanding local wind patterns is crucial for interpreting the transport of pollutants (Graph-1,2,3).
* There is a correlation between PM10 levels and other pollutants like NO2 and PM2.5 etc. in the southeast direction. A strong correlation might suggest common sources or shared influencing factors contributing to the observed pattern (Graph-1,2,3).
* In Graph 1, elevated concentrations of air pollutants are observed in the southeast (SE) direction, aligning with the wind rose data indicating predominant winds from the SE. Additionally, significant wind flow from the southeast (SE) suggests a potential transport of pollutants towards Vishakhapatnam. Notably, industrial areas are situated in the SE direction, where volatile compounds such as benzene, toluene, and xylene may contribute to the observed concentrations in Vishakhapatnam (GVMC).



**Chapter 5: Conclusions:**

This comprehensive study has provided valuable insights into the complex interplay between air pollutants, wind patterns, and seasonal variations in Vishakhapatnam. The analysis covered a spectrum of pollutants, including particulate matter (PM2.5 and PM10), nitrogen dioxide (NO2), sulfur dioxide (SO2), carbon monoxide (CO), ozone (O3), Benzene (C6H6), Lead (Pb), and Volatile Organic Compounds (VOCs) (Toluene, Xylene). By incorporating meteorological data, such as wind speed and direction, atmospheric temperature, relative humidity, rain fall, and solar radiation, a holistic understanding of air quality dynamics was achieved.

The wind rose analysis revealed prevailing wind patterns, aiding in the identification of potential pollution sources and understanding the dispersion of pollutants. Correlation analysis provided insights into the relationships between different pollutants, helping to pinpoint common sources or influencing factors. Whisker plots offered a visual representation of pollutant concentrations over five years, highlighting long-term trends and fluctuations.

The investigation into higher PM10 levels in the southeast direction suggested potential sources in that area, emphasizing the importance of considering local wind patterns in interpreting pollutant transport.

In conclusion, this research contributes to evidence-based decision-making for environmental policymakers, regulatory agencies, and public health officials. By unraveling the intricate relationships between air pollutants, wind patterns, and seasonal variations, the study provides actionable insights for targeted pollution control measures, enhanced air quality management, and reinforces the significance of adhering to air quality standards.

**Future Work:**

1.Extend the seasonal variation analysis to other pollutants to identify if similar patterns exist. This can provide a more holistic understanding of seasonal air quality dynamics in Vishakhapatnam.

2.Implement air quality modeling techniques to simulate the dispersion of pollutants during the identified high pollution months. This can provide a predictive understanding of pollutant transport and concentration patterns.

3.Training an ANN model to predict concentrations of specific air pollutants (e.g., PM2.5, NO2, SO2) based on meteorological parameters (temperature, humidity, wind speed, etc.). This can aid in forecasting pollutant levels, supporting early warnings, and real-time air quality management.

**Chapter 6: References:**

* CPCB, 2000.Air quality status and trend in India.Parivesh Newsletter, Vol. 4(3). Central Pollution Control Board, New Delhi, India.
* CPCB. 1996. Environmental protection in NCT of Delhi: pollution sources, environmental status, laws and administrative mechanism.
* <https://pcb.ap.gov.in/UI/quality_monitoring.aspx>

1. http://cpcb.nic.in/

2. <http://www.epa.gov/>

3. http://www.envis.nic.in/