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A Study of Seasonal and Temporal Variances in Ambient Air Quality of Highly Polluted Cities in Rajasthan

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ABSTRACT

The quality of the urban environment in tropical and subtropical densely populated cities is a complicated subject that has garnered a lot of attention in the current setting. Some of the most polluted cities in Rajasthan are Bhiwadi, Jaipur, Kota, and Udaipur, where the air quality has drastically declined over the previous ten years, according to an IQAir report. In order to determine the seasonal and temporal fluctuations in the concentrations of major air pollutants, such as carbon monoxide (CO), ozone (O3), nitrogen dioxide (NO2), sulphur dioxide (SO2), and particulate matter (PM10 and PM2.5), in an urban setting in Rajasthan, this study will examine the ambient air quality in severely polluted cities throughout the state. A comprehensive investigation of the seasonal and temporal variations in ambient air quality throughout Rajasthan's extremely polluted cities was made possible by the application of PCA and the K-Means Clustering Algorithm. We interpreted the intricate patterns of pollution oscillations by means of rigorous time-series analysis, providing insight into the dynamic interactions among meteorological conditions, sources of pollution, and regulatory actions. The results indicate that there were more seasonal variations during the summer, and that levels of particulate matter (PM10 and PM2.5) and nitrogen dioxide (NO2) in places like Jaipur, Bhiwadi, Kota, and Udaipur alarmingly rose above pre-pandemic levels. This highlights the significance of identifying and addressing the various challenges caused by air pollution at different times of the year and in different seasons. Furthermore, identifying the main sources of pollution and assessing the effectiveness of current legislation offer insightful information for focused actions.

Keywords : Air Pollution, Ambient Air Quality, Rajasthan, Seasonal Variations, Temporal Variations

I. INTRODUCTION

Energy-related activities, discoveries, and uses have led to the creation of many waste products, especially air pollutants, as a result of urbanisation, the green revolution, industrialization, communication, transportation, and pleasant living. The prospect of a multi-pollutant catastrophe is present in Rajasthani cities, where particle pollution is increasing and gaseous pollutants, such as ozone and nitrogen dioxide (NO_2), are starting to grow. This increases the state's public health risk. The latest analysis conducted by the Urban Lab at the Centre for Science and Environment (CSE) clarifies this [3].

The exploration of seasonal and temporal variations in ambient air quality, particularly within the highly polluted cities of Rajasthan, is of paramount importance, given the environmental and public health implications associated with increasing pollution levels in urban areas. Previous research has highlighted the detrimental effects of air pollution on respiratory health, cardiovascular disease, and overall well-being, emphasizing the need for comprehensive studies to elucidate the nuanced patterns of pollutant concentrations. Studies employing Statistical, Clustering and Machine Learning algorithms, have gained prominence for their efficacy in uncovering hidden structures and relationships within complex datasets. Researchers have successfully utilized Statistical Algorithms to identify key pollutants influencing air quality, providing valuable insights into the sources and contributors of pollution. Furthermore, the application of clustering algorithms has proven instrumental in discerning temporal patterns and grouping similar data points, aiding the formulation of targeted interventions and policy recommendations. This study aims to contribute to the growing body of literature by focusing on the unique challenges posed by the highly polluted cities in Rajasthan and employing a sophisticated blend of statistical and clustering algorithms to unravel the intricate dynamics of seasonal and temporal variations in ambient air quality.

II. LITERATURE REVIEW

A substantial amount of research has been conducted to understand the variation in air quality in megacities due to increased urbanization and population. The exploration of seasonal and temporal variations in air quality has garnered considerable attention from researchers, who have employed a diverse array of statistical, clustering, and machine learning algorithms. Seasonal and temporal variances in air pollution levels have been analysed by numerous researchers worldwide. According to the report of IIT Kanpur (2020), Jaipur, the capital city of Rajasthan, has identified that the level of air pollutants such as sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter with a diameter of 10 μm or less (PM10) tends to increase in the winter season, while the level of ozone significantly decreases [4]. The concentration of air pollutants in the summer season also follows a similar trend to that identified in the study conducted by Ravindra et al. (2020) [11].

In the context of Temporal Variation, as per the study, air quality starts to improve in the early morning, remains best between the early morning and morning, and subsequently starts to degrade until the evening [13]. In 2023, Batra et al. examined the diurnal variation in air quality in Gurugram City. He utilized monitored air quality data and found that diurnal variations in air quality exhibited distinct patterns for different pollutants such as Oxides of Nitrogen (NOx), Carbon Monoxide (CO), and Particulate Matter (PM10). The study concluded that there was a decreasing trend in air quality from early morning to late night. In addition, the air quality starts degrading sharply from morning to late night [12]. Researchers have employed methods such as autoregressive integrated moving average (ARIMA) to model and forecast air quality parameters, providing valuable insights into the temporal dynamics of pollution levels

[5]. One prevalent approach is the utilization of statistical techniques, such as time-series analysis, to discern patterns in pollutant concentrations over different seasons and times. [10]. Clustering algorithms, including K-means and hierarchical clustering, have been instrumental in grouping similar data points and identifying distinct patterns of air quality variations. [9].

Principal Component Analysis (PCA) is another widely employed statistical technique for dimensionality reduction, aiding in identifying the most influential pollutants and their contributions to overall air quality variations. By extracting the underlying patterns and correlations, PCA enhances the interpretability of large datasets, thereby facilitating a more nuanced understanding of the intricate interplay between different pollutants. [8]. Machine learning algorithms such as decision trees [16], support vector machines [7], and neural networks [6] have also been applied in the study of air quality variations. These approaches are particularly useful for capturing complex relationships within datasets and for predicting pollutant concentrations based on various meteorological and environmental factors.

III.METHODOLOGY

A. DATA SET

The state of Rajasthan in India is renowned for its vast desert landscape, arid climate, and vulnerable ecosystems. It is located in the western portion of the nation between latitudes 23 30' and 30 11' North and longitudes 69 29' and 78 17' East [15]. The climate in Rajasthan is characterized by extreme heat and dryness throughout the year. During the summer months, the average temperatures soar between 30°C and 44°C, creating extremely hot and arid conditions. In contrast, during the winter season, temperatures range from 8°C to 22°C, and at times, mercury can plummet below the freezing point, reaching temperatures as low as 0°C, particularly during the night. The diurnal temperature range in this region is notable, with fluctuations as high as 14°C [14]. For this study, we collected air pollutant data from the Rajasthan State Pollution Control Board of the four most polluted cities in Rajasthan, namely Jaipur, Bhiwadi, Kota, and Udaipur, from January 2018 to July 2023. A summary of the dataset is provided below.

TABLE I. Data Summary

S.No.	Column Name	Unit Measure
1	From Date	
2	To Date	
3	PM2.5	(ug/m3)
4	PM10	(ug/m3)
5	NOx	(ug/m3)
6	SO2	(ug/m3)
7	CO	(ug/m3)
8	Ozone	(ug/m3)
9	City	

B. WORKING FLOW

The research methodology began with the collection and preprocessing of air quality data for cities in Rajasthan, focusing on parameters such as PM2.5, PM10, NOx, SO_2, CO, and Ozone. Seasonal and temporal analyses were conducted to extract seasonal averages and explore the temporal trends. Following this, exploratory data analysis visualizations provide insights into the distribution and patterns. Principal Component Analysis (PCA) was applied to reduce dimensionality, whereas K-means clustering was employed to group cities based on air quality similarities. The clusters were then analysed to identify common characteristics and trends. The results were interpreted, emphasizing the similarities and differences among cities. Python was utilized for coding, incorporating libraries such as Pandas, NumPy, Matplotlib/Seaborn for EDA, and Scikit-learn for PCA and K-means clustering.

C. SEASONAL VARIATION IN AIR QUALITY

Seasonal variation in air quality refers to fluctuations and changes in the composition of the air that we breathe throughout the year. This phenomenon is influenced by a combination of natural and anthropogenic factors, including weather patterns, geographical features, and human activity [2]. Rajasthan experiences distinct seasons characterized by hot summers, monsoon rains, and relatively cooler winters. Each season brings unique atmospheric conditions that affect the quality of air in the region. The major factors contributing to seasonal variations in air quality include temperature, wind patterns, and the prevalence of natural events such as dust storms.

In our study, we analysed the seasonal variation of different major pollutants for four seasons, namely, Winter, Spring, Summer and Autumn, which are presented in graph format as follows:

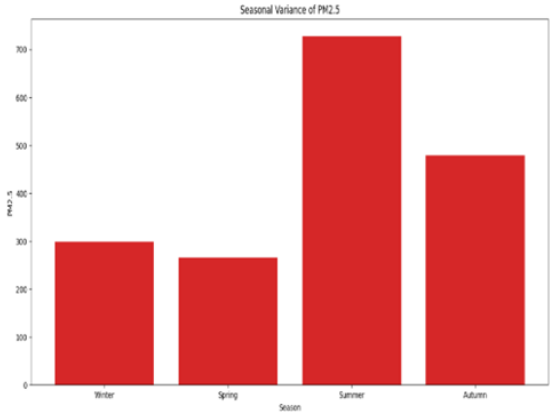

Figure 1(a): Seasonal Variations in PM2.5

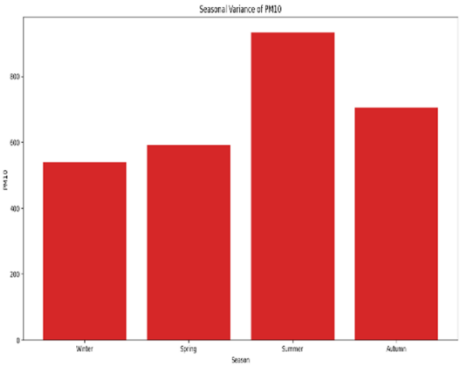

Figure 2(b): Seasonal Variations in PM10

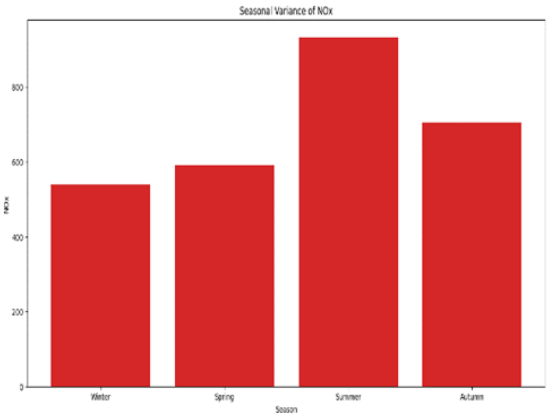

Figure 3(c): Seasonal Variations in NOx

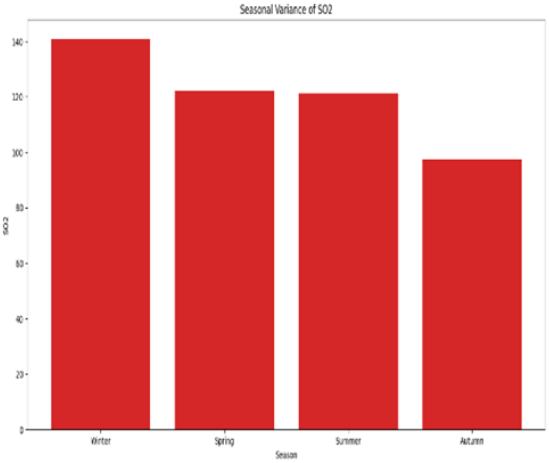

Figure 4(d): Seasonal Variations in SO_2

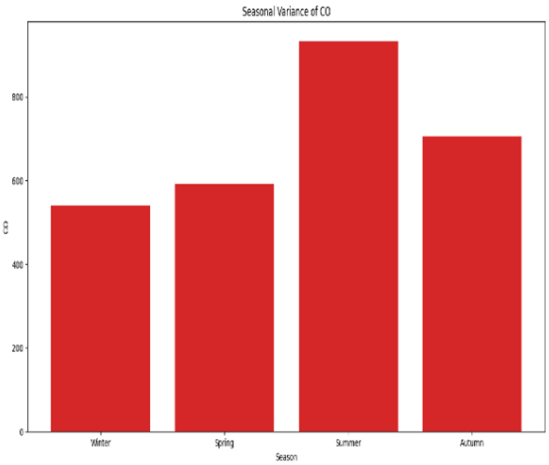

Figure 5(e): Seasonal Variations in CO

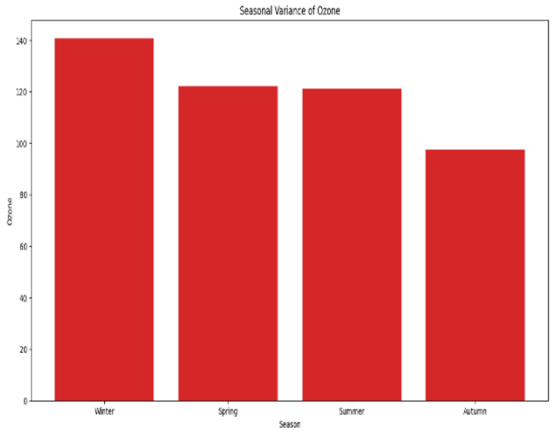

Figure 6(f): Seasonal Variations in Ozone

Figure 1. Seasonal Variation of different Air Pollutants

The temporal variance in air quality specifies "how the air quality variation took place with time."[1]. Temporal variations in air quality refer to changes in the composition and concentration of air pollutants over different periods, with a focus on daily patterns. In the context of Rajasthan, a region known for its diverse climatic conditions, understanding temporal daily variations in air quality is crucial. These fluctuations are influenced by various factors such as human activities, traffic density, industrial operations, and meteorological conditions. The significance of studying daily temporal variations lies in their direct impacts on human health and the environment. For instance, during peak traffic hours or specific industrial operations, pollutant levels may spike, leading to an increased exposure of the population. Analysing these daily variations helps in identifying high-risk periods and implementing targeted strategies to mitigate the adverse effects of air pollution.

In our study, we analysed the daily temporal variation of different major pollutants, which are presented in a graph format as follows:

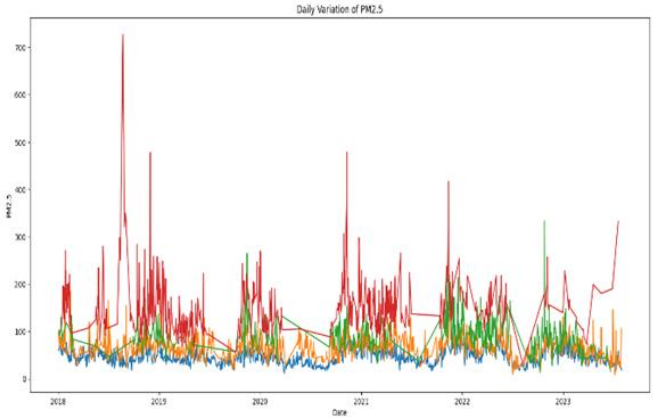

Figure 2(a): Daily Temporal Variation of PM2.5

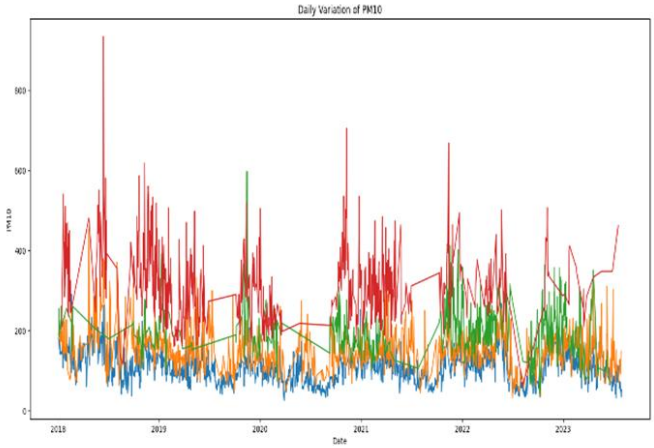

Figure 2(b): Daily Temporal Variation of PM10

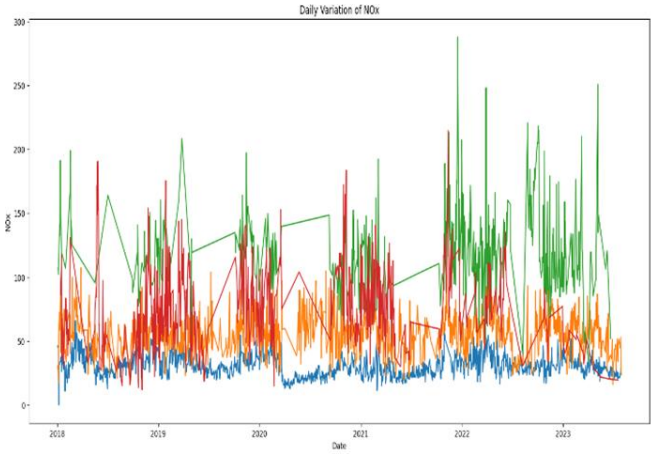

Figure 2(c): Daily Temporal Variation of NO_x

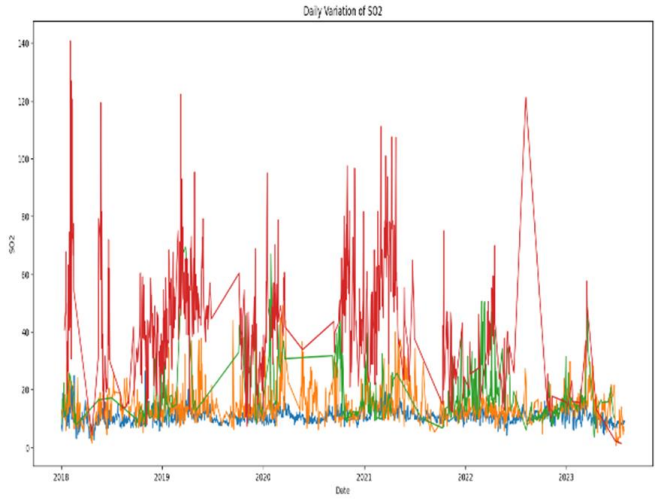

Figure 2(d): Daily Temporal Variation of SO_2

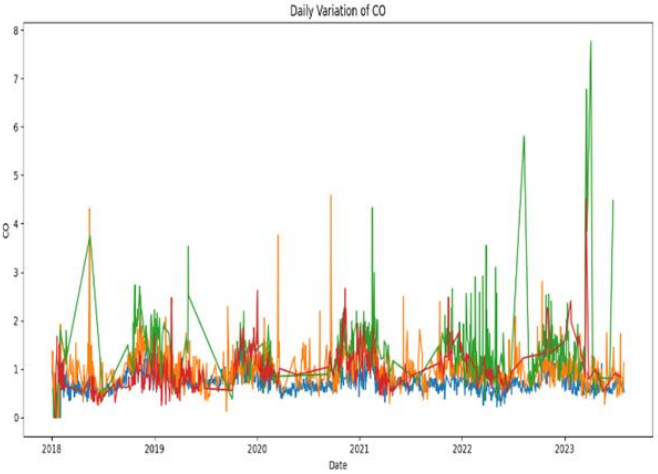

Figure 2(e): Daily Temporal Variation of CO

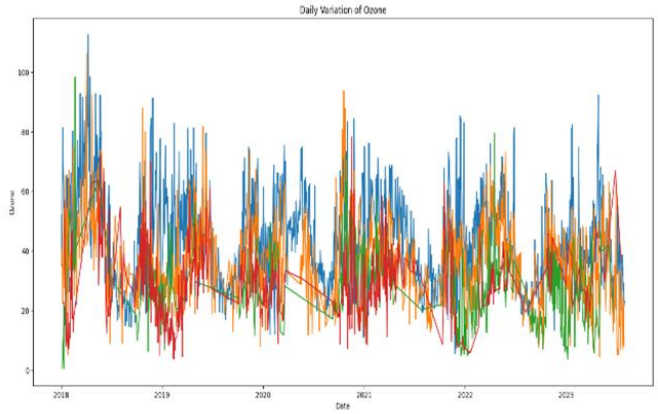

Figure 2(f): Daily Temporal Variation of Ozone

Figure 2. Daily Temporal Variation of Air Pollutants

IV.CONCLUSION

The study of seasonal and temporal variations in air quality in Rajasthan utilizing PCA and K-means clustering has yielded insightful findings that underscore the dynamic nature of air pollution in the region. The results revealed distinct patterns, allowing for the identification of cities with similar air quality profiles. The results obtained indicate that for air pollutants such as PM2.5, PM10, NOx, and CO, the seasonal variation is high during the summer season, whereas for SO_2 and ozone, it is higher in the winter.Comparably, in terms of temporal fluctuations, it is evident that the concentration of different air pollutants is higher during the day, or during office hours, because the rate of traffic and the concentration of various pollutants are lower at night, particularly between 1:00 AM and 12:00 AM. additionally It is essential to comprehend the health effects of bad air quality at particular times of year since this information serves as the foundation for focused public health initiatives. The significance of taking seasonal and temporal factors into account when developing successful environmental management techniques is emphasised by this study. The clusters that have been identified can act as a basis for customised policies that tackle the unique issues that each set of cities faces. As the health impacts of poor air quality continue to be a pressing concern, future research directions may involve exploring the long-term consequences on public health, integrating socioeconomic factors, and developing predictive models for timely intervention and mitigation strategies. Overall, this study contributes valuable insights to the ongoing discourse on air quality management, offering a foundation for evidence-based policies aimed at fostering healthier living environments in Rajasthan.

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