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Investigating the Spatial and Temporal Variation of NO_2 Pollutant Obtained from Sentinel 5P Satellite in Cities of Yazd Province-Iran

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A B S T R A C T

Background and objective: Nitrogen dioxide (NO_2) is a significant air pollutant prevalent in industrialized and densely populated regions, including Yazd province. This study aims to assess the temporal and spatial variations in NO_2 concentrations in Yazd and its surrounding areas.
Materials and methods: Utilizing the advanced remote sensing capabilities of the Sentinel-5P satellite, we compiled monthly and seasonal distribution maps of NO_2 concentrations for Yazd province over a one-year period, spanning from April 1401 to March 1402. The Google Earth Engine (GEE) platform facilitated the processing and visualization of satellite data. Additionally, the influence of wind patterns and precipitation on the dispersion and concentration of NO_2 was systematically investigated.
Results and conclusion: The findings revealed that the highest concentrations of NO_2 occurred in spring, particularly in Yazd, while the lowest levels were recorded in winter, specifically in Bahabad city. It was observed that wind speed and direction had a limited impact on the distribution of NO_2 across the province. In contrast, rainfall demonstrated a significant relationship with NO2 concentrations; increased rainfall correlated with reduced pollutant levels. Overall, the study highlights the necessity for continuous monitoring of air quality and the implications of meteorological factors on pollutant dispersion in Yazd province.

1. Introduction

Air quality refers to the chemical status of the atmosphere at a specific time and place (World Health Organization., 2000). Scientific research has shown that significant climate changes have occurred throughout the Earth's history. Today, indicators reveal that human intervention in nature has accelerated these natural changes, contributing to natural disasters such as rising sea levels, global warming, deforestation, acid rain, ozone layer depletion, biodiversity loss, and air pollution (Goudie, 2018). Air pollution in cities is one of the byproducts of the Industrial Revolution, which began over three hundred years ago. With urbanization and industrial development, the intensity and amount of air

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pollution have increased over time (Zhang et al., 2022). Air pollution represents one dimension of environmental issues, not merely due to its presence but because of its high concentrations resulting from human activities, which cause serious health problems for humans (Manisalidis, 2020). Air pollution can have detrimental effects on internal organs such as the cardiovascular and respiratory systems, as well as external organs like the eyes and skin, which are directly exposed to pollutants (Manisalidis, 2020). The primary sources of air pollution in major cities are gases like carbon monoxide, sulfur dioxide, nitrogen oxides, hydrocarbons, and particulate matter. These gases, by themselves, may not pose a threat, but when their concentrations exceed certain thresholds—referred to as "threshold concentrations"—they are recognized as pollutants, negatively impacting human, plant, and animal health (Sillmann, 2021).

Research has shown that air pollution can lead to various adverse effects, including children's cognitive delays, anemia, increased mortality from heart attacks and strokes, genetic mutations, miscarriages, low birth weight, the extinction of plant and animal species, as well as economic and cultural damages, climate changes, water pollution, and reduced visibility (Edo, 2024). An essential aspect of controlling atmospheric pollution is determining the distribution and concentration of pollutants in different locations. Identifying and monitoring pollutants, their accumulation centers, and vulnerable areas is crucial for predicting and mitigating such occurrences. Various factors, including climatic elements like wind speed and direction, temperature, humidity, local geographic features such as building height and shape, topography, and traffic levels, all influence the dispersion of air pollution. Therefore, with the increasing severity of pollution in industrial cities, it is critical to provide suitable strategies for simulating and predicting pollution patterns in these cities, along with proposing effective methods to mitigate them (Bitta, 2018).

One of the most important methods for studying pollutants is satellite measurement. Remote sensing provides a broader and more comprehensive view of the study area (Jumaah, 2023). Shamshiri et al. (2014) used remote sensing data to assess dust conditions in Kermanshah province and applied the Ackerman, Miller, and TDI dust indices to highlight and map two dust events. The results showed that dust indices based on MODIS data vary between events. Rangzan et al. (2020), in a study on the spatial and temporal distribution of NO_2 gas in Khuzestan province using TROPOMI sensor data, concluded that areas with high NO_2 concentrations correspond to cities with high population density and industrial activities. Gharibvand et al. (2023), in a study examining the effects of the COVID-19 lockdown on NO_2 and O_3 pollutants in the industrial and polluted cities of Arak and Tehran, used Sentinel 5P data for these two pollutants during the lockdown period from November 19 to December 5, 2020, and compared them with data from the same period before the pandemic (November 19 to December 5, 2019). Their results showed that during the 2020 lockdown, NO_2 and O3 levels in Tehran decreased by 3.5% and 6.8%, respectively, while in Arak, NO_2 levels dropped by 20.97% and O3 by 5.67%.

In recent decades, advancements in technology have led to the widespread use of satellite-based air quality monitoring systems to study pollutants on various scales. Google Earth Engine (GEE) is a powerful platform capable of conducting large-scale geospatial analyses. It has computational capabilities for studying various issues such as natural disasters, climate monitoring, deforestation, food security, drought management, and environmental conservation (Gorelick, 2017). One of the platforms within GEE is the Earth Engine (EE), which allows users to access vast datasets in the EE data catalog. This catalog contains millions of datasets, including a complete set of Landsat-4, -5, -7, and -8, MODIS (Moderate Resolution Imaging Spectroradiometer), Sentinel-1, -2, -3, and -5P, atmospheric data, meteorological data, and more. The workspace allows users to quickly view, zoom in, and navigate, and also provides options for adjusting contrast, brightness, and transparency levels. Additionally, users can add multiple layers to the workspace for better temporal change analysis (Amani, 2020).

Yazd province is one of the industrial provinces of Iran, and air pollution has long been a concern for its citizens and authorities. In this study, among the various air pollutants, NO_2 gas was selected due to its direct link with vehicles, industries, and fuel consumption. Since no previous studies have employed modern methods to measure this pollutant, the importance of this research is evident. This study follows two hypothesis.

- Hypothesis 1: There is a significant negative correlation between rainfall and the concentration of NO_2 pollutants in Yazd Province. Increased precipitation leads to a decrease in NO_2 levels due to the washout effect of rain.
- Hypothesis 2: The dispersion of NO_2 pollutants is significantly influenced by wind patterns in Yazd Province. Areas with higher wind speeds will show lower concentrations of NO_2 pollutants compared to areas with calmer winds.

The goal of this study is to use remote sensing and Sentinel 5P satellite data, along with the Google Earth Engine platform, instead of costly ground-based measurement stations, to determine the concentration and distribution of NO_2 gas, one of the primary air pollutants in Yazd province. Due to the high accuracy of this method, the findings of this study can assist planners and policymakers in reducing air pollution.

2. Materials and Methods

2.1. Study Area

The study area for this research is Yazd Province, located in central Iran. Yazd covers an area of 72,156 square kilometers, accounting for approximately 37.4% of the total land area of Iran. Geographically, it lies between longitudes 52°45' to 56°30' E and latitudes 29°48' to 33°30' N. The province experiences an arid desert climate, characterized by an average annual rainfall of 108 millimeters, with temperatures ranging from a minimum of -20°C in winter to a maximum of 47°C in summer. The climate in Yazd is hot, dry, and highly variable, with significant temperature fluctuations between day and night as well as between winter and summer (Kiani, 2022).

2.2. Methods and Data Collection

The primary data source for this study was obtained through remote sensing using Sentinel-5 satellite imagery, analyzed via the Google Earth Engine (GEE) platform. To create maps illustrating urban air pollution, specifically the NO_2 pollutant, data from the Sentinel-5 sensor were utilized. These maps were generated on a monthly and seasonal basis for the entire year of 2022 (April 2022 to March 2023) to monitor the spatial and temporal distribution of the pollutant across different areas of Yazd Province.

In addition to air pollution maps, wind rose diagrams were generated on a seasonal basis for 2022 to analyze the impact of wind patterns on the distribution of pollutants throughout the province. These diagrams were sourced from the Iowa State University Mesonet website (https://mesonet.agron.iastate.edu).

Lastly, a rainfall variation chart for 2022 was produced using Sentinel-5 satellite data and the Google Earth Engine, illustrating the changes in precipitation over time and its potential influence on pollutant dispersion.

3. Result

3.1. Monthly Satellite Data on NO_2 Concentration from Sentinel-5

In this study, satellite images and charts depicting the monthly concentration of NO_2 gas were collected and analyzed. The process began by retrieving monthly satellite imagery and concentration graphs from Sentinel-5 for the entire year 1401. Subsequently, seasonal satellite images and charts reflecting NO_2 concentration variations were generated. The concentrations of NO_2 gas were estimated seasonally for different counties within Yazd province, and the results were summarized.

Figs 1 and 2 present the spatial distribution maps of monthly NO_2 concentrations and the variation charts for 1401. These figures illustrate the maximum and minimum concentrations of NO_2 for different months. In Figures 1 and 2, the months are labeled from April to March using English letters from A to F to represent the corresponding Persian months.

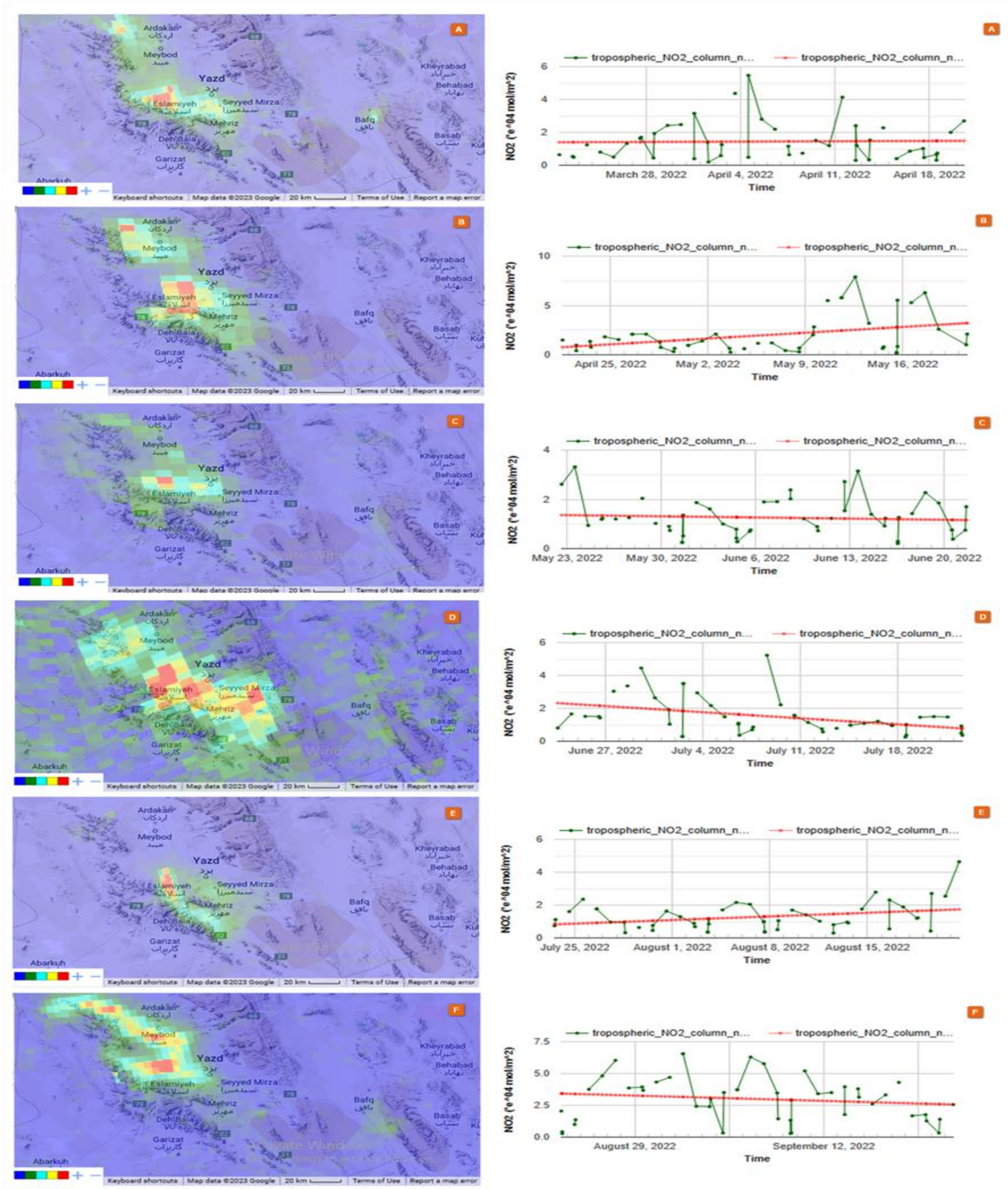

Fig. 1- Spatial Distribution Map and Concentration Chart of NO_2 Gas for the First Half of 1401 in Yazd Province

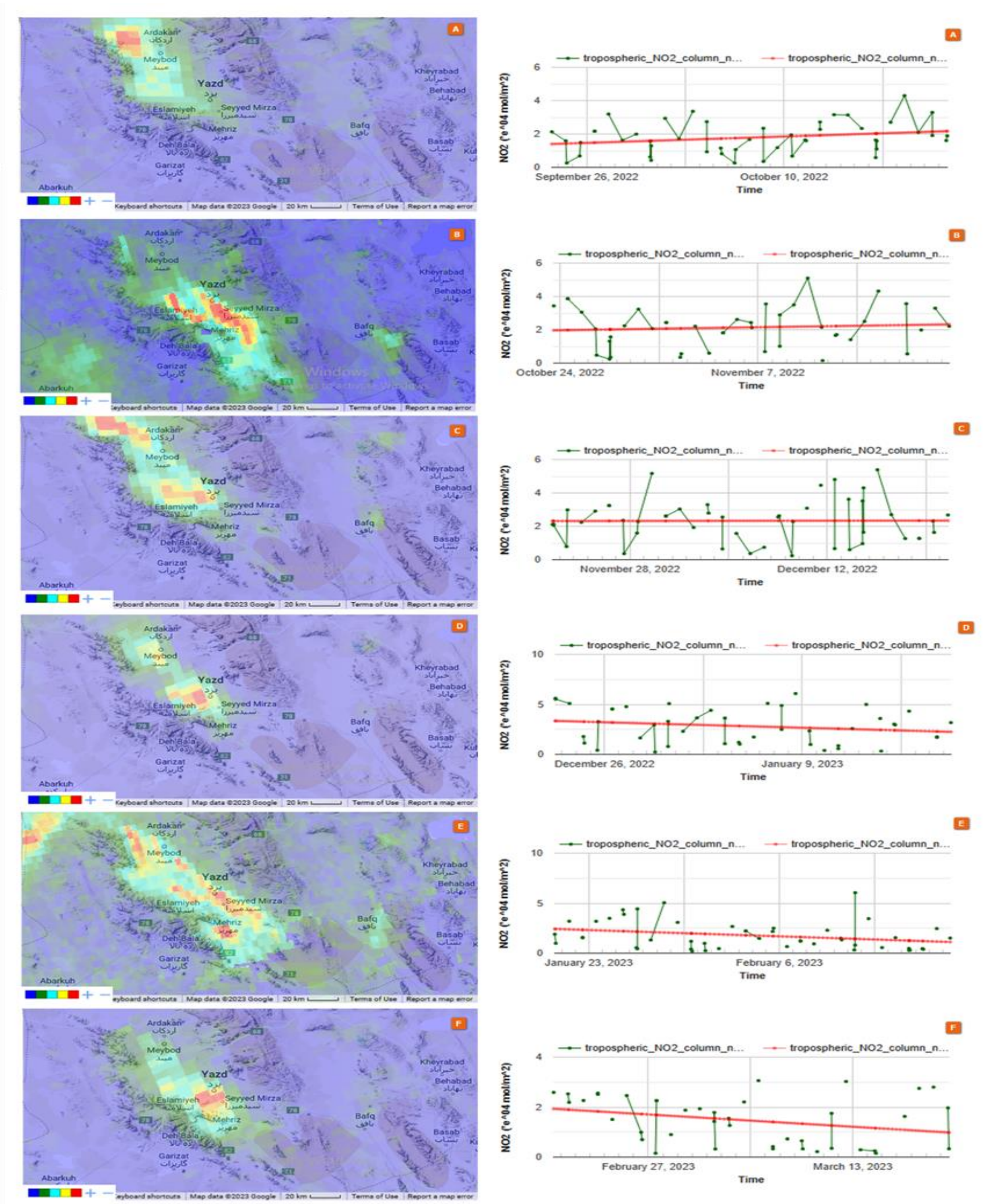

Fig. 2- Spatial Distribution Map and Concentration Chart of NO_2 Gas for the Second Half of 1401 in Yazd Province

The highest NO_2 concentration during the year was observed in April and May, with values of 5.471 and 7.892, respectively. Conversely, the lowest concentrations were recorded at 0.2 and 0.17. The maximum NO_2 concentration showed an increasing trend, while the minimum concentration exhibited a declining pattern. In June, the peak concentration of NO_2 sharply decreased to 3.316, while the minimum concentration remained relatively unchanged at 0.2.

By July, NO_2 concentration surged again to 5.228, with the lowest concentration recorded at 0.249, indicating an upward trend. In August, the maximum concentration decreased to 4.637, while the minimum concentration slightly increased to 0.294. In September, NO_2 levels surged dramatically to 6.553, with the lowest concentration showing a marginal decline.

October saw a significant reduction in NO_2 concentration, with the maximum level falling to 4.302 and the minimum concentration remaining relatively stable at 0.259. November recorded another rise in NO_2, with concentrations reaching 5.099, while the minimum concentration continued its downward trend to 0.152. In December, a slight increase was observed, with the maximum NO_2 concentration rising to 5.391 and the minimum showing an upward trend at 0.23.

In January, the maximum concentration significantly increased to 6.082, while the minimum concentration rose slightly to 0.225. February showed a marginal decrease in NO_2 concentration, with a maximum of 6.045, and the lowest value fell to 0.203. Finally, in March, both maximum and minimum concentrations saw a sharp decline, with the highest concentration recorded at 3.06 and the lowest continuing its downward trend.

Overall, the highest NO_2 concentration throughout the year varied significantly, with the peak value occurring in May at 7.892. The lowest concentrations fluctuated only marginally, with the minimum value of 0.152 recorded in November, showing little variation compared to other months.

In the accompanying figures, the spatial distribution of NO_2 concentrations is represented using different colors to indicate levels from high to low (red, yellow, light blue, green, and dark blue). The following observations were made based on the spatial distribution:

- In April, the highest NO_2 pollution was observed in Yazd city, followed by Ardakan, Taft, Meybod, Bafq, Mehriz, and Abarkooh. The lowest pollution level was found in Bahabad.
- In May, the distribution pattern remained similar, with Yazd experiencing the highest NO_2 levels, followed by the same counties as April.
- June saw the highest pollution in Yazd, followed by Taft, Meybod, Ardakan, Bafq, Mehriz, and Abarkooh. Bahabad continued to experience the lowest NO_2 levels.
- In July, the highest concentrations were found in Yazd, Taft, and Mehriz, with a declining trend observed in Meybod, Ardakan, Abarkooh, and Bahabad.
- August showed a shift, with Taft experiencing the highest pollution, followed by Mehriz, Yazd, and the other counties in decreasing order of concentration.
- In September, the highest NO_2 concentrations were found in Yazd, Ardakan, and Meybod, followed by Taft, Bafq, Mehriz, Abarkooh, and Bahabad.
- In October, Ardakan and Meybod recorded the highest NO_2 levels, followed by Yazd, Taft, and other counties.
- November saw Yazd, Taft, and Mehriz with the highest NO_2 concentrations, with declining levels in Meybod, Ardakan, Abarkooh, and Bahabad.
- In December, the highest concentrations were recorded in Ardakan, Yazd, and Taft, followed by Meybod and other counties.
- January recorded the highest NO_2 levels in Yazd, Taft, and Meybod, with lower concentrations in Ardakan, Mehriz, Bafq, and the remaining counties.
- In February, the highest NO_2 concentrations were found in Yazd, Mehriz, Ardakan, and Meybod, followed by declining levels in other areas.

- Finally, in March, Yazd experienced the highest NO_2 pollution, with the remaining counties showing a gradual decrease in concentrations.

These spatial and temporal analyses provide insights into the variation of NO_2 levels across Yazd province, indicating areas with higher pollution levels and highlighting potential environmental and health impacts across the region.

3.2. Seasonal Satellite Data of NO_2 Concentration from Sentinel 5

Fig. 3 displays the satellite images and seasonal graphs of NO_2 concentration for the year 1400. As illustrated, the highest average concentrations during spring, summer, autumn, and winter were 7.892, 6.553, 5.391, and 6.082, respectively, while the lowest average concentrations were 0.17, 0.249, 0.152, and 0.155. Notably, the peak concentration occurred in spring, whereas the lowest was in winter.

In spring, the average concentrations in different counties ranked from highest to lowest are as follows: Yazd (0.575), Mehriz (0.343), Taft (0.324), Meybod (0.276), Ardakan (0.258), Abarkooh (0.257), Bafq (0.251), and Bahabad (0.165). As observed, the highest concentration in spring was recorded in Yazd, while the lowest was in Bahabad. Overall, the pollutant concentration remained relatively stable during spring, showing no significant fluctuations.

In summer, the average concentrations from highest to lowest in the counties were as follows: Meybod (1.298), Yazd (0.928), Ardakan (0.619), Mehriz (0.434), Taft (0.338), Bafq (0.284), Abarkooh (0.192), and Bahabad (0.103). Consequently, Meybod exhibited the highest level of pollution during summer, followed by Yazd, while Bahabad recorded the lowest. In this season, the concentration of the pollutant showed an increasing trend, with the highest concentration noted in the month of Shahrivar (September).

In autumn, the average concentrations in the counties from highest to lowest were: Yazd (1.776), Meybod (1.195), Ardakan (0.556), Mehriz (0.502), Taft (0.460), Bafq (0.237), Abarkooh (0.154), and Bahabad (0.025). Again, Yazd and Meybod had the highest concentrations, while Bahabad had the lowest. The concentration of NO_2 in autumn exhibited a generally increasing trend.

In winter, the average concentrations ranked from highest to lowest in the counties were: Yazd (1.425), Mehriz (0.660), Meybod (0.563), Taft (0.541), Ardakan (0.346), Abarkooh (0.334), Bafq (0.233), and Bahabad (0.191). The highest concentrations were found in Yazd and Mehriz, while Bahabad had the lowest. As shown in Figure 3, the concentration of NO_2 in winter demonstrated a decreasing trend.

Using this tool, we examined the spatial and temporal distribution of NO_2 pollutants throughout the year 1400.

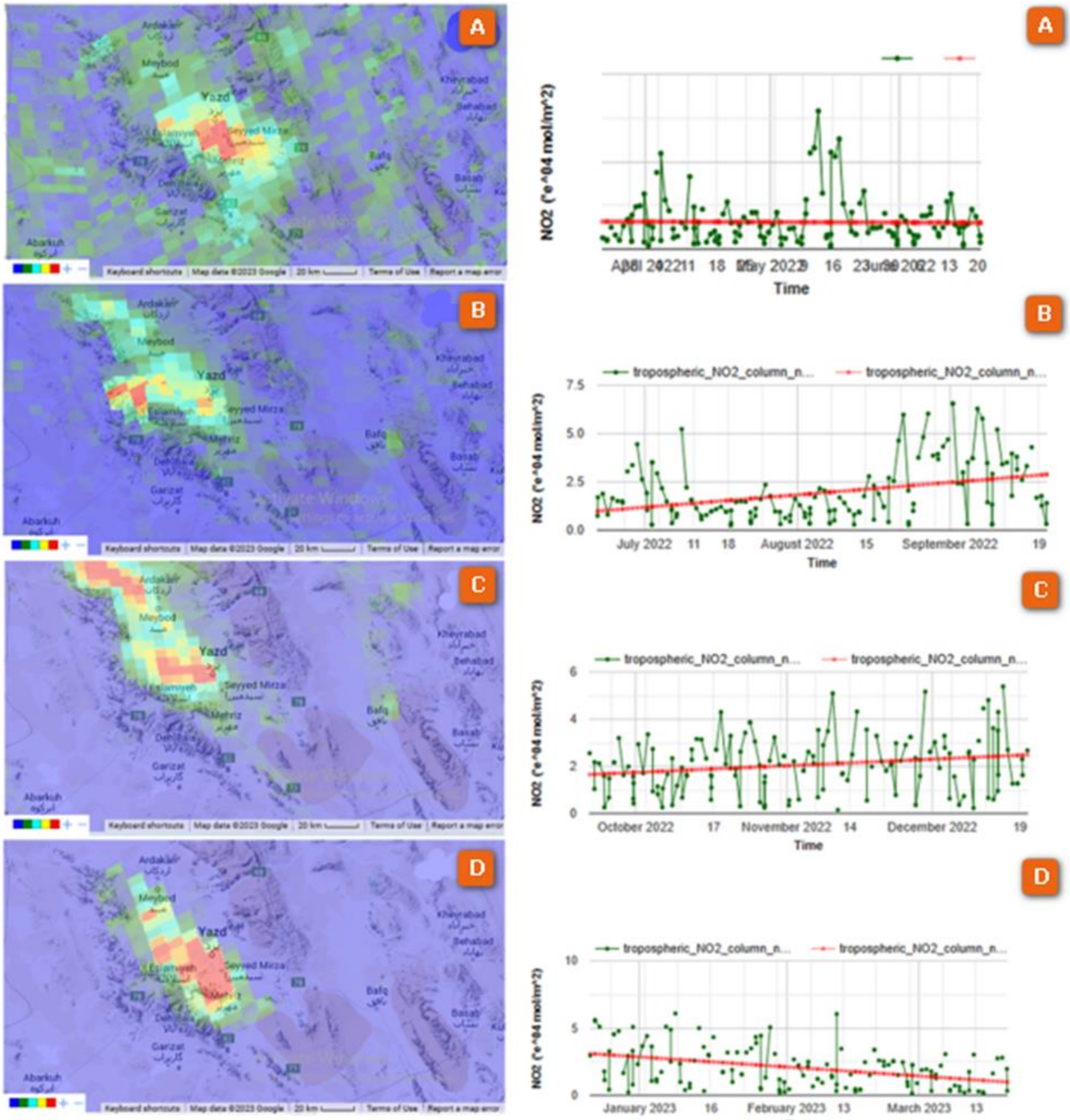

Fig. 3- Spatial distribution maps and charts of NO_2 concentration in different seasons of 2022 in Yazd Province: A) Spring, B) Summer, C) Autumn, D) Winter.

3.3. Examination of Wind Effects on the Dispersion of NO_2 Pollutant (Wind Rose)

Wind is responsible for the horizontal and vertical transport and dispersion of pollutants. The concentration of pollutants at the surface largely depends on the speed and direction of the wind and its attenuation. If the wind consistently blows in a specific direction, pollutants are transported in that direction. However, if the wind direction is variable, such as in calm conditions near the surface, pollutants are dispersed over a broader area. In locations where multiple pollution sources align with the wind direction, pollutants tend to accumulate in those areas.

The optimal locations for establishing polluting industries around cities are areas that are sheltered from the prevailing wind. For instance, in Yazd, where the dominant winds blow from the northwest, the best sites for factories are in the eastern and southeastern parts of the city. In general, wind speed decreases at the surface due to frictional effects, and it tends to increase with elevation above the ground.

Fig. 4 shows the wind rose diagram for Yazd Province across different seasons in 2022. As illustrated, the highest wind speeds in spring originated from the northwest and west of the province. The wind patterns in spring and summer are quite similar, although certain areas exhibited higher wind speeds in spring compared to summer. The lowest wind speeds were observed in autumn. In winter, the wind pattern followed that of spring and summer, but with reduced speeds compared to both seasons.

Overall, the dominant winds in Yazd Province come from the northwest and west, while the least wind activity is observed from the northeast and east. As shown in Fig. 1, the highest pollution levels are found in the central areas of the province. Considering the pollution map of the province and the wind rose diagram, the overall wind speed has not been sufficient to transport pollutants to adjacent counties. Therefore, the wind has played a minimal role in the dispersion of NO_2 pollutants in the province, resulting in a limited area of dispersion.

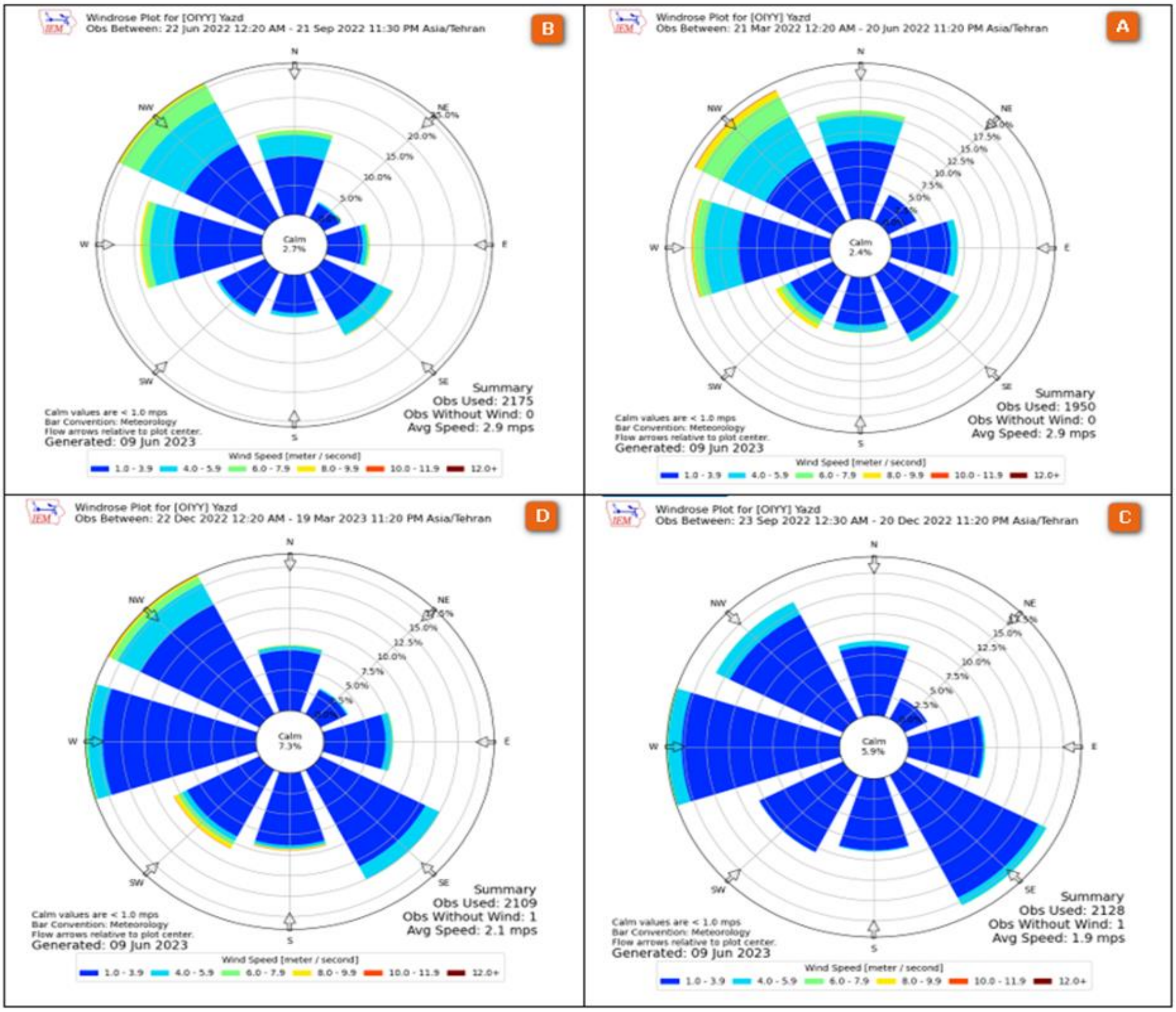

Fig. 4- Seasonal Wind Rose Diagram of Yazd Province in 2022. A) Spring, B) Summer, C) Autumn, D) Winter.

3.4. Impact of Rainfall on the Dispersion of NO_2 Pollutant Gas

The impact of rainfall on the dispersion of air pollutants can be quite varied, depending on factors such as the intensity of rainfall, the types of pollutants, and the type of land surface. Generally, it can be stated that with rainfall, pollutants are washed from the air and settle on the ground.

Fig. 5 presents the rainfall chart for the study area obtained from Google Earth Engine. Overall, the trend of rainfall from Farvardin 1401 (March 2022) to Esfand (February 2023) of the same year has been increasing. As shown, there was no rainfall in the second half of Shahrivar (September) and early Mehr (October), while the highest rainfall was observed in Bahman (December) and Esfand (February).

Comparing the monthly concentration changes of NO_2 pollutant gas with the rainfall chart yields the following results: In Farvardin (March) and Ordibehesht (April), a decrease in rainfall corresponds with an increase in NO_2 concentration. In Khordad (May), where rainfall was nearly zero, no significant changes in pollutant concentration were observed. During summer, in Tir (June), an increase in rainfall was associated with a decrease in NO_2 concentration. However, in Mordad (July), a decrease in rainfall coincided with an increase in NO_2 concentration.

In Shahrivar (September) and the first half of Mehr (October), when there was no rainfall, no significant changes in pollutant concentrations were observed. In late Mehr (October) and early Aban (November), an increase in rainfall was linked to a decrease in NO_2 pollutants. At the end of Aban (November), with a decrease in rainfall, the concentration of NO_2 gas showed an increasing trend.

In Bahman (December) and Esfand (February), due to heavy rainfall, the concentration of NO_2 gas significantly decreased. Overall, it can be concluded that rainfall has a positive effect on reducing the concentration of NO_2 pollutant gas in the air.

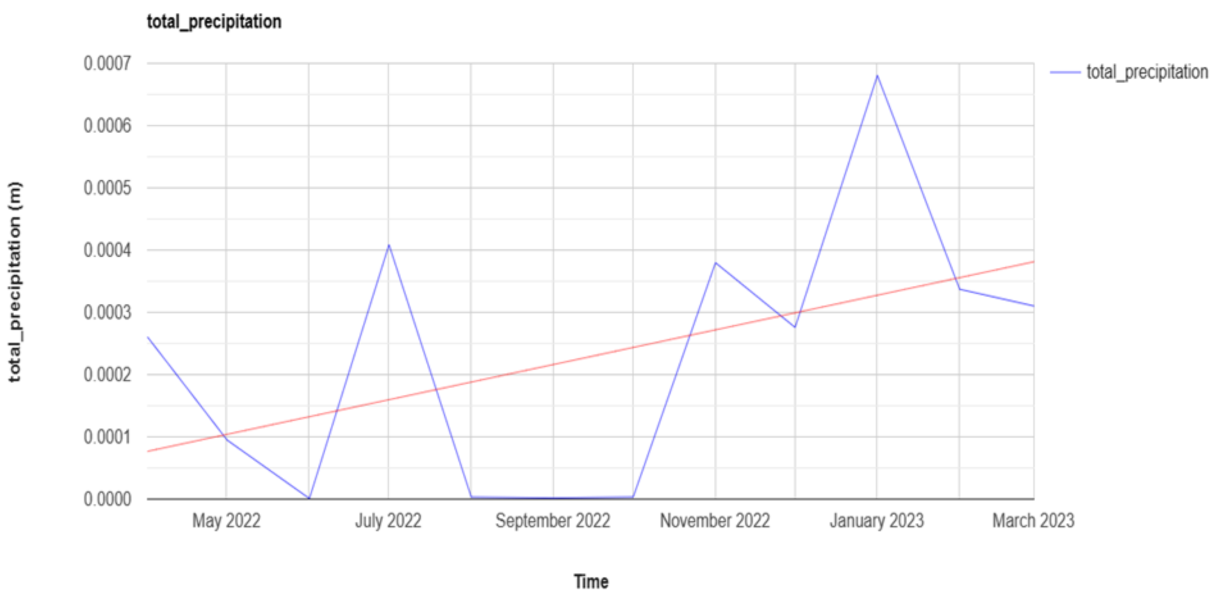

Figure 5: Rainfall over Time in Yazd Province during the Year 1401 (2022-2023)

4. . Discussion

The increasing concern over air quality and its impact on public health and the environment has led to extensive research on air pollutants, particularly nitrogen dioxide (NO_2). NO_2, a significant contributor to respiratory issues and other health problems, arises from various sources, including vehicle emissions, industrial activities, and natural phenomena. This study aimed to analyze the monthly and seasonal variations of NO_2 concentration in Yazd Province using satellite data from the Sentinel-5P, employing the Google Earth Engine platform. The findings provide valuable insights into the spatial distribution and influencing factors of NO_2 concentrations, contributing to the existing body of research on air quality management.

The analysis revealed significant monthly variations in NO_2 concentrations, with the highest levels recorded in April and May, reaching values of 7.892 $\mu g/m^3$ and 5.471 $\mu g/m^3$, respectively. The lowest concentrations were noted in November and December, with minimum values of 0.152 $\mu g/m^3$ and 0.23 $\mu g/m^3$. Seasonal data indicated that spring exhibited the highest average concentration of 7.892 $\mu g/m^3$, while winter recorded the lowest at 0.155 µg/m³. The results indicate that NO_2 levels are significantly influenced by both meteorological conditions and anthropogenic activities.

Furthermore, the spatial distribution maps demonstrated that Yazd city consistently experienced the highest levels of NO_2 pollution throughout the year. This aligns with the findings of Kiani et al. (2022), who identified urban areas as hotspots for pollutant concentrations due to their higher traffic and industrial activities. The observed trends in NO_2 concentrations are consistent with previous studies, such as those by Abbaszadeh et al. (2022) and Shami et al. (2020), which noted variations in pollutant levels during distinct periods influenced by external factors, including the COVID-19 pandemic.

The first hypothesis posited that there is a significant negative correlation between rainfall and the concentration of NO_2 pollutants in Yazd Province. The analysis of the rainfall data in conjunction with NO_2 concentrations supported this hypothesis. During periods of increased precipitation, particularly in Bahman (December) and Esfand (February), a marked decrease in NO_2 levels was observed. This phenomenon can be attributed to the washout effect of rain, which effectively cleanses the atmosphere of airborne pollutants, thereby reducing ground-level concentrations. The results align with existing literature, such as the works of Beig et al. (2021), which highlighted the role of rainfall in mitigating air pollution levels.

The second hypothesis suggested that the dispersion of NO_2 pollutants is significantly influenced by wind patterns in Yazd Province. The wind rose analysis indicated that the dominant winds in the region come from the northwest and west. However, the findings revealed that the wind speeds were not sufficiently high to facilitate significant dispersion of NO_2 pollutants. This observation suggests that while wind can transport pollutants, its limited speed and directionality in Yazd may hinder effective dispersion, leading to localized accumulation of pollutants in urban areas. This finding is corroborated by studies that emphasize the importance of wind patterns in pollutant transport and dispersion (Ravshanov et al., 2023).

The variations in NO_2 concentrations in Yazd Province were consistent with trends observed in other regions, as documented in recent studies. For instance, Abbaszadeh et al. (2022) noted a general decline in NO_2 levels during the pandemic period, illustrating the potential for reduced emissions in response to changes in human activity. In contrast, Kiani et al. (2022) reported an increase in SO2 concentrations in adjacent areas, highlighting the complex interplay of different pollutants and their sources.

Moreover, the results of this study underscore the need for comprehensive air quality monitoring strategies, combining remote sensing techniques with ground-based measurements to validate findings and enhance the understanding of pollutant dynamics.

5. Conclusion

This study aimed to monitor the spatial and temporal pollution caused by nitrogen dioxide (NO_2) in Yazd province using Sentinel-5P satellite imagery. The findings indicate that pollution levels in Yazd city are consistently elevated across all months, while Ardakan, Meybod, and Taft exhibit significant pollution during most months. Conversely, Bahabad, Abarkooh, and Bafq demonstrate the lowest levels of NO_2 concentration.

Seasonal analysis reveals that the highest average NO_2 concentrations occur in spring, particularly in Yazd, while the lowest are recorded in winter, specifically in Bahabad. It can be inferred that areas with elevated NO_2 levels are correlated with urban centers characterized by high population density, significant vehicular traffic, and industrial activities.

Moreover, the assessment of NO_2 pollution distribution in conjunction with prevailing wind patterns indicates that substantial pollutant concentrations often arise during periods of calm winds, deviating from normal atmospheric conditions. This suggests that pollutant accumulation is influenced by atmospheric stability, producing distinct patterns that are not aligned with typical wind flows. Therefore, understanding the sources of NO_2 emissions requires consideration of wind direction under stable atmospheric conditions.

Additionally, factors such as humidity, temperature inversions, rainfall, and solar radiation should be taken into account as they play crucial roles in pollutant dispersion. It is recommended that monitoring of atmospheric pollutants be conducted using satellite data, which provides a cost-effective and rapid approach compared to traditional methods. This technique offers extensive coverage of areas, making it particularly useful in Iran, especially in industrial and large urban centers, for identifying pollution hotspots and monitoring temporal distribution for effective pollution control and air quality improvement.

The study also underscores the potential of rainfall to physically wash airborne pollutants from the atmosphere. This process can significantly reduce concentrations of air pollution, especially NO_2. Observations indicate that months with decreased rainfall correspond to increased NO_2 levels. Generally, during the summer months, which typically experience lower precipitation, NO_2 concentrations are higher, whereas winter, characterized by significant rainfall, shows a marked decrease in pollutant levels.

However, it is crucial to note that while rainfall can wash NO_2 from the atmosphere into the soil and water sources, it may also lead to the formation of nitric acid through reactions with rainwater, resulting in secondary pollution effects. Thus, drawing definitive conclusions about the environmental impact of this process requires further analysis.

In conclusion, additional research is necessary to thoroughly investigate the positive or negative effects of rainfall on the dispersion of air pollutants and its subsequent impact on the environment. This will facilitate informed decision-making regarding air quality management and environmental sustainability.

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Consent to Publish (Author consent to publishing)

Authors Contributions (Authors contributed equally to the data collection, analysis, and interpretation. All authors critically reviewed, refined, and approved the manuscript.)

Code availability (Not applicable)

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