Available online at https://sanad.iau.ir/journal/jonass
Publisher: Maybod Branch, slamic Azad University
Journal of Nature and Spatial Sciences
ISSN: 2783-1604

Evaluating the Relationship Between Dust Concentrations and Nitrogen Dioxide Levels: A Comparative Study of Kerman and Isfahan- Iran

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A R T I C L E I N F O

Research Type:
Research article

Article history:
Received 15 Aug 2022
Revised 18 Sep 2022
Accepted 22 Dec 2022

Keywords:
Dust,
Nitrogen Dioxide Concentration,
Remote Sensing,
Google Earth Engine

A B S T R A C T

Background and objective: Air quality, particularly concerning dust and nitrogen dioxide (NO_2) levels, has become a significant environmental concern in urban areas like Kerman and Isfahan, Iran. This study aims to evaluate the relationship between dust concentrations and NO_2 levels with environmental factors, including land use, wind intensity, and vegetation cover (NDVI). By understanding these dynamics, the study seeks to inform effective air quality management strategies.

Materials and methods: Data on dust concentrations and NO_2 levels were obtained using Sentinel – 5P and remote sensing techniques and analyzed through Google Earth Engine (GEE). The study employed a comprehensive approach, incorporating satellite imagery for NDVI assessment and land use classification into five categories. Wind intensity was measured using meteorological data. Statistical analyses were conducted to evaluate the correlations between these variables.

Results and conclusion: The findings indicate a significant positive correlation between wind intensity and dust volumes, particularly in Kerman, where the highest dust concentrations are noted. In contrast, Isfahan exhibits higher NO_2 levels, mainly in industrial areas with limited vegetation cover. This study confirms both hypotheses: increased wind intensity correlates with higher dust levels, and greater vegetation cover is associated with lower NO_2 concentrations. The results highlight the importance of incorporating environmental factors into air quality assessments, providing a foundation for developing targeted air quality management strategies in both cities.

1. Introduction

In the past, environmental activities predominantly focused on the impacts of pollution on natural environments outside urban boundaries. Consequently, urban ecology and environmental health within

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Peer review under responsibility of Maybod Branch, Islamic Azad University

DOI: https://doi.org/10.30495/jonass.2024.999760

cities received limited attention. Most city dwellers would examine environmental issues outside urban areas, overlooking urban environmental dynamics. However, in recent times, it has become crucial to focus on urban environments, as city residents are now at the heart of some of the most pressing environmental challenges (Mokhtarisabet et al., 2024).

The rise in air pollutant concentrations beyond critical thresholds has triggered severe incidents worldwide (Mokhtari et al., 2017). These acute pollution events, which have caused widespread illness and mortality in urban populations, have served as warnings to the global community about the real dangers of air pollution. Consequently, these incidents have catalyzed positive actions in air pollution control (Sicard et al., 2023).

Air pollutants can be categorized into primary and secondary pollutants based on their chemical composition and origin. The United States Environmental Protection Agency (EPA) classifies six primary pollutants as key indicators for air quality. Primary pollutants, such as carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter (PM2.5 and PM10), sulfur dioxide (SO_2), and lead (Pb), are directly emitted into the atmosphere, posing significant public health risks. In contrast, secondary pollutants, like ozone (O_3), form through chemical reactions involving primary pollutants (Kaiser & Meyer, 2016).

Among nitrogen oxides, nitrogen monoxide (NO) and nitrogen dioxide (NO_2) are significant pollutants in urban air. NO_2 is a visible brown gas with a pungent odor, produced mainly through high-temperature fuel combustion. The primary sources of NO_2 emissions in the troposphere include industrial activities, motor vehicle traffic, and biomass burning. Natural sources, such as soil emissions, lightning, and wildfires, also contribute to NO_2 concentrations. In urban settings, vehicle emissions are a major factor in determining NO_2 levels, with both primary and secondary emissions influencing air quality (Shon et al., 2011). Developed countries have adopted strict regulatory standards to control NO_x emissions from vehicles, significantly improving urban air quality.

Another major environmental issue, particularly in arid and semi-arid regions, is dust. Dust storms are meteorological disasters that can disrupt human life in numerous ways. Their occurrence is higher in dry regions, particularly in parts of Asia, where they significantly affect living conditions (Middleton et al., 2019; Sokolik et al., 2020). The increasing severity of dust storms has prompted global concern and extensive research into their causes, primarily wind erosion and desertification (Ghane Ezabadi et al., 2021; Waggoner & Sokolik, 2010). Some researchers suggest that dust storms, exacerbated by climate change and drought, are among the most serious environmental hazards in dry and semi-dry regions (Jiao et al., 2021; Taheri Shahraiyni et al., 2015).

Dust storms are complex phenomena influenced by atmospheric interactions and primarily driven by strong winds, bare soil surfaces, and dry air. Desert winds create ideal conditions for dust emission, particularly in regions already affected by desertification and drought (Koohestani et al., 2021; Ghane Ezabadi et al., 2021). The socio-economic, environmental, and health impacts of dust storms are far-reaching. These storms reduce visibility, damage infrastructure, disrupt transportation, and degrade communication systems. In addition to economic losses, dust storms aggravate soil salinity, water scarcity, and desertification, thereby intensifying the environmental degradation of affected areas (Cao et al., 2015). Dust particles also carry allergens and pathogens, posing serious health risks to populations exposed to such events (Tong et al., 2023).

This study investigates and compares dust volume and nitrogen dioxide (NO_2) concentrations in two major Iranian cities, Kerman and Isfahan. Remote sensing technology, particularly satellite imagery from Sentinel-5, was employed to assess spatial and temporal variations in these pollutants. The analysis was further extended by correlating these pollution levels with land use patterns, wind intensity, and vegetation cover, measured using the Normalized Difference Vegetation Index (NDVI). The data were processed and modeled using the Google Earth Engine (GEE) platform, which enabled the comprehensive assessment of environmental conditions in these regions.

Remote sensing has emerged as a powerful tool in environmental monitoring, allowing for large-scale data collection and analysis over time (Yussupov & Suleimenova, 2023). In this study, the integration of satellite imagery and remote sensing techniques played a crucial role in understanding the interaction between dust concentration, NO_2 levels, and environmental variables, including land use and vegetation cover. By analyzing the temporal and spatial distribution of these pollutants, this research provides insights into the factors influencing air quality in both cities and highlights the potential for air quality management strategies in similar urban settings.

The primary objective of this study is to evaluate the relationship between dust concentrations and nitrogen dioxide (NO_2) levels with environmental factors such as land use, wind intensity, and vegetation cover (NDVI) in the cities of Kerman and Isfahan. This analysis aims to improve the understanding of air quality dynamics in these regions and provide a foundation for effective air quality management.

This study is analyzed by two main hypotheses:

- There is a significant positive correlation between wind intensity and the volume of dust in Kerman and Isfahan.
- Higher vegetation cover (NDVI) is associated with lower nitrogen dioxide (NO_2) concentrations in these cities.

2. Materials and Methods

2.1. Study Area

The city of Kerman is located between latitudes 30° 10′ and 30° 28′ N and longitudes 56° 18′ and 57° 53′ E. The average annual rainfall in Kerman, recorded between 1985 and 2004, is approximately 147 mm, with an average humidity of 31%. The temperature in the region fluctuates between -4°C and 40°C (Program and Budget Organization, 1995). Based on these climatic conditions, Kerman is classified as a semi-arid and arid region (Rahimi et al., 2017). Isfahan province, covering an area of 106,179 square kilometers, accounts for approximately 6.25% of the total area of Iran. It is situated between latitudes 30° 42′ and 34° 30′ N, and longitudes 49° 36′ and 55° 32′ E in central Iran. The city of Isfahan, located at 32° 38′ 30″ N and 51° 39′ 40″ E, is the third-largest city in Iran after Tehran and Mashhad. Isfahan province shares borders with ten other provinces: to the north with Markazi, Semnan, and Qom, to the south with Fars and Kohgiluyeh and Boyer-Ahmad, to the east with Yazd and South Khorasan, and to the west with Khuzestan, Chaharmahal and Bakhtiari, and Lorestan (Shafaqi, 2002) (Fig.1).

Fig.1 – Study Area

2.2. Research Process Overview

The research process undertaken in this study follows a systematic and structured approach to ensure comprehensive analysis and accurate results. The methodology involves several key stages, starting from the selection of study areas (Kerman and Isfahan), to the collection and preprocessing of satellite data, and culminating in detailed modeling and analysis of air pollutants. The data collection phase includes retrieving information on nitrogen dioxide (NO_2) concentrations, dust volume, and environmental factors such as land use, wind intensity, and vegetation cover (NDVI), all gathered via Sentinel-5 satellite imagery.

Subsequently, the Google Earth Engine (GEE) platform was used to preprocess and analyze the data, enabling spatial and temporal evaluation of the pollutants. Finally, the interpretation of results focused on identifying correlations between environmental factors and pollution levels.

The flowchart (Fig. 2) below provides a visual representation of the research process, outlining each step in detail. This helps clarify the methodology followed in this study and highlights the sequential progression of tasks.

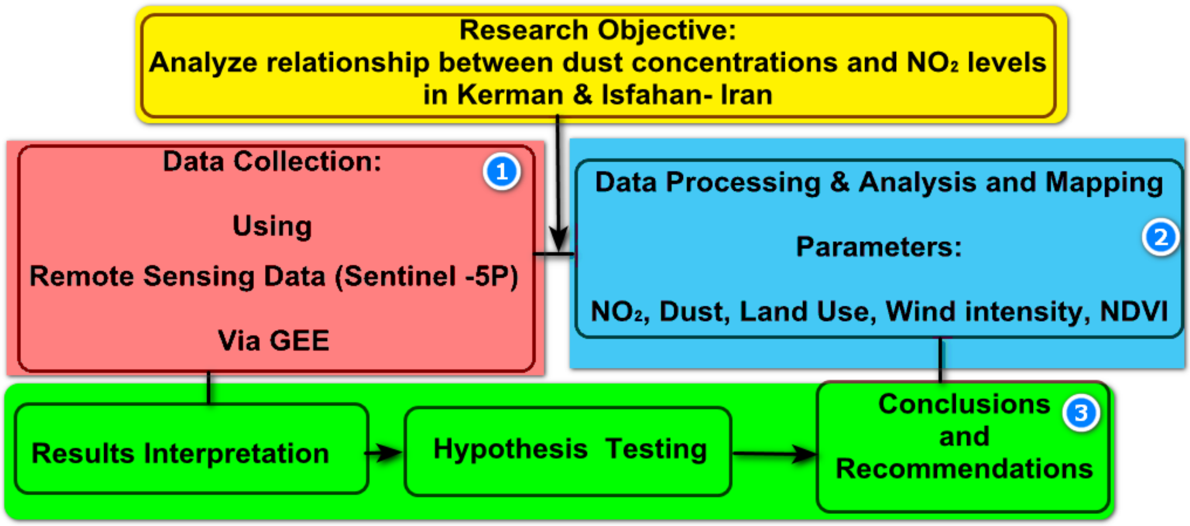

Fig.2- Flowchart of Research Process and Methodology for the Study

3. Results

3.1. Nitrogen Dioxide Concentration

The analysis of nitrogen dioxide (NO_2) concentration across Kerman and Isfahan was performed using Google Earth Engine (GEE), revealing significant spatial variability within both provinces.

In the central region of Kerman, the concentration of NO_2 is notably higher compared to other areas, as indicated by the red color on the corresponding maps. This suggests that urban activities, particularly in the city center, contribute to elevated levels of nitrogen dioxide. Conversely, the western parts of Kerman display a blue color, indicative of lower NO_2 concentrations, reflecting less anthropogenic activity and possibly better air quality in these regions.

Similarly, in Isfahan, the central areas, particularly those adjacent to industrial zones, exhibit high concentrations of NO_2, again represented by the red hue on the map. In contrast, the eastern regions of Isfahan are marked in blue, signifying lower levels of nitrogen dioxide. This pattern highlights the correlation between industrial activities and increased NO_2 concentrations in urban centers.

The maps generated (Fig.3) provide a clear visual representation of the distribution of nitrogen dioxide in both provinces, emphasizing the need for targeted air quality management strategies in high-concentration areas.

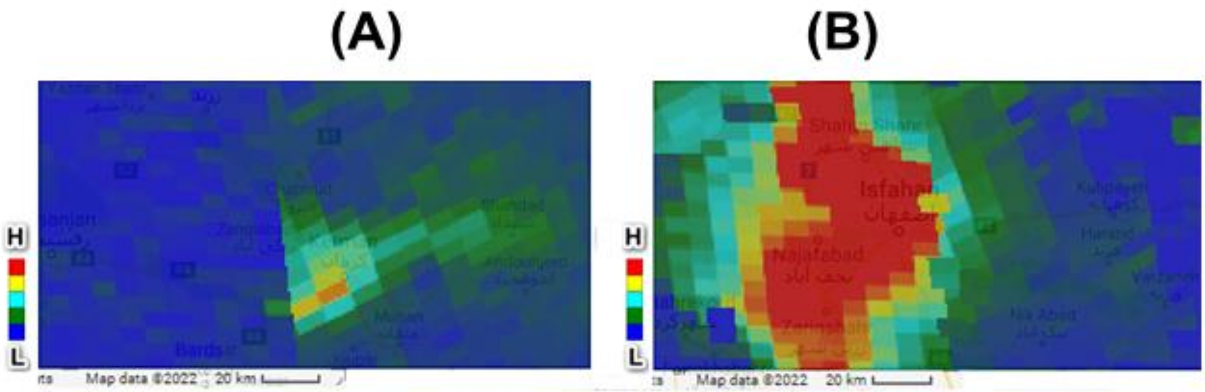

Fig.3 - Distribution of Nitrogen Dioxide Concentrations in Kerman (A) and Isfahan (B)

3.2. Analysis of NO_2 Concentration Trends

The time series graph depicted in Fig. 4 illustrates the concentrations of nitrogen dioxide (NO_2) in Kerman and Isfahan over a specified period, with key reference points marked by the red lines.

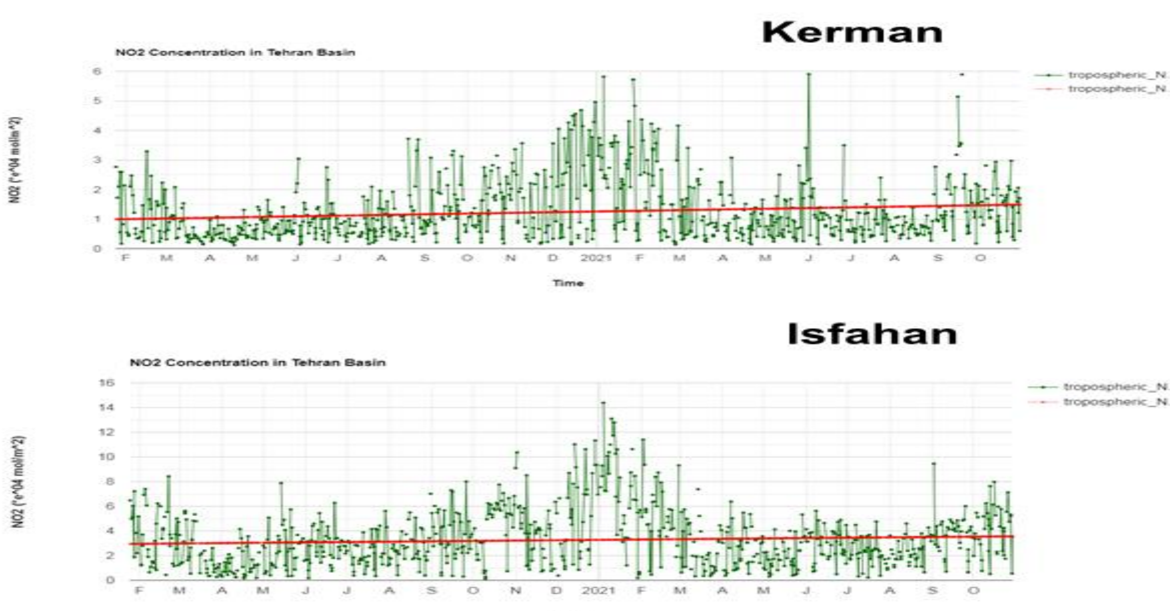

Fig.4 - Seasonal Trends in Nitrogen Dioxide (NO_2) Concentrations in Kerman and Isfahan

3.2.1. Reference Lines:

In Kerman, the red line starts at approximately 1 MOLIM (moles per square meter) and exhibits a gentle upward slope throughout the observation period. This suggests a gradual increase in NO_2 concentrations, indicating a potential trend of rising air pollution levels.

For Isfahan, the red line begins at around 3 MOLIM and also follows a similar upward trajectory. The higher starting point compared to Kerman highlights that Isfahan experiences more elevated baseline NO_2 concentrations.

3.2.2. Fluctuations in NO_2 Levels:

The blue lines represent the actual measured concentrations of NO_2 throughout the monitoring period. In Kerman, the data reveals that the highest concentrations occur between January and March, reaching nearly 5 MOLIM². This seasonal peak suggests increased emissions, likely due to higher energy consumption during winter months, greater vehicular traffic, or industrial activities, all of which are common contributors to NO_2 emissions.

In contrast, Isfahan shows an exceptionally high NO_2 concentration in January, exceeding 14 MOLIM². This significant spike indicates a critical air quality issue, potentially attributable to intense industrial activities, vehicular emissions, or atmospheric conditions that exacerbate pollutant accumulation during winter.

3.3.3. Comparative Analysis:

The comparison of the two cities reveals that Isfahan consistently maintains higher NO_2 concentrations than Kerman throughout the year, as illustrated by the blue lines in relation to their respective red reference lines. This discrepancy could be due to Isfahan's larger industrial base and higher population density, leading to increased emissions from traffic and factories.

The trends in both cities underline the importance of targeted air quality management strategies. The peaks in NO_2 concentrations highlight critical periods that require monitoring and potential intervention to mitigate health risks associated with poor air quality.

Overall, the analysis of nitrogen dioxide concentrations in Kerman and Isfahan, as depicted in Fig. 4, underscores the varying challenges faced by these urban areas regarding air quality. The upward trends in NO_2 levels, particularly during specific months, signal a need for enhanced regulatory measures and public awareness campaigns aimed at reducing emissions. Continuous monitoring and research are essential to inform policies that protect public health and the environment from the adverse effects of air pollution.

3.3. Analysis of Dust (AEROSOL) Concentration in Kerman and Isfahan

The provided dust concentration maps for Kerman (A) and Isfahan (B) reveal notable variations in dust distribution across both provinces (Fig. 5).

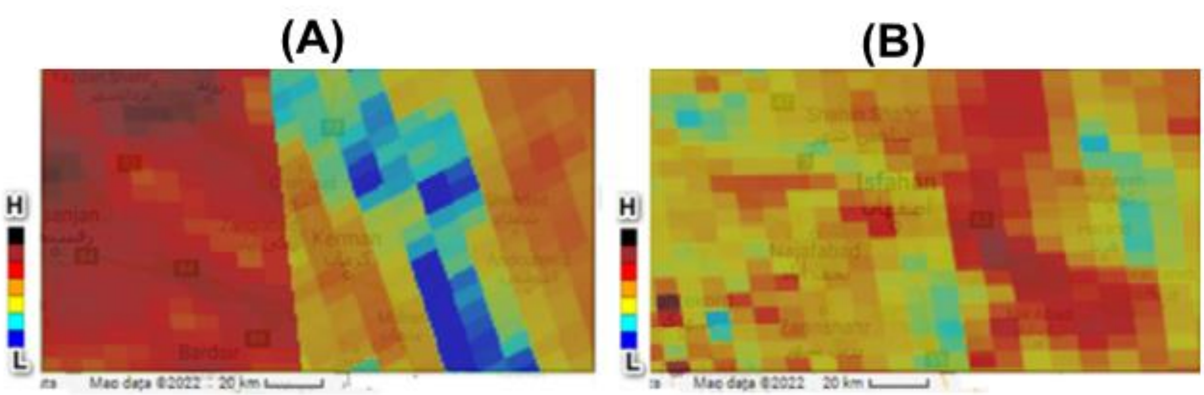

Fig. 5 - Spatial distribution of dust concentration in Kerman (A) and Isfahan (B) regions, showing higher dust levels in the northwestern parts of Kerman and the central and eastern parts of Isfahan.

Kerman (A):

The western and northwestern parts of Kerman, including regions like Rafsanjan and Zarand, exhibit the highest concentrations of dust, as indicated by the dark red areas. This pattern suggests that these regions are more prone to dust storms, likely due to arid conditions and minimal vegetation cover.

The blue areas in central Kerman, particularly around the city center, show significantly lower dust concentrations. These regions may benefit from better vegetation cover, urban infrastructure, or reduced wind speeds.

Isfahan (B):

In contrast to Kerman, Isfahan’s dust distribution shows higher concentrations in the central and eastern parts of the province, with red areas dominating these regions. These are likely industrial or desert regions where vegetation is sparse, and human activities or topography contribute to dust buildup.

The presence of yellow and blue patches in other parts of the province indicates relatively lower dust concentrations. The variation may be due to differing land use patterns, including agricultural areas or regions with more vegetation, which help to stabilize the soil and reduce dust generation.

In summary, both Kerman and Isfahan show spatial heterogeneity in dust distribution, with the highest concentrations localized in industrial or less vegetated regions. The varying topography, wind patterns, and land use likely play significant roles in the dust accumulation seen in both provinces.

This analysis highlights the need for targeted environmental management strategies to mitigate dust-related issues, particularly in regions identified as high-risk zones.

3.4. Analysis of UV Aerosol Index Changes in Kerman and Isfahan

The two graphs show the UV Aerosol Index Changes over time for Kerman and Isfahan, with the blue lines representing the aerosol thickness (dust concentration) variations and the red lines indicating the trend over time (Fig.6).

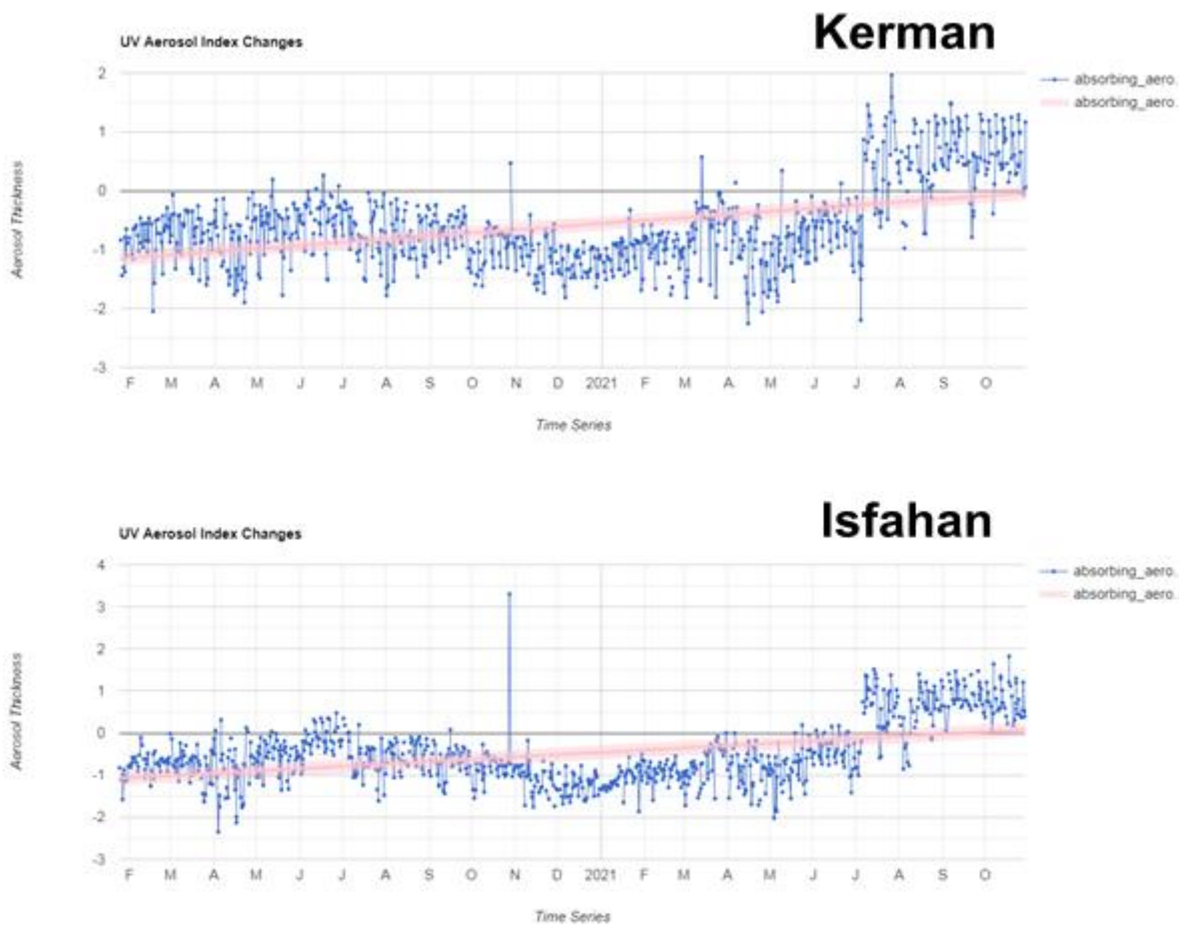

Fig.6 - Time series analysis of UV Aerosol Index changes in Kerman (top) and Isfahan (bottom) for 2021, illustrating daily fluctuations and an increasing trend in aerosol thickness, particularly in late summer and autumn months.

3.4.1. Kerman (Top Graph):

Trend: The red line, representing the general trend of aerosol thickness, shows a slight upward slope, indicating that the concentration of aerosols has increased over the course of 2021. This suggests a gradual rise in dust particles, likely influenced by increasing arid conditions, dust storms, or human activities.

Seasonal Variation: The blue lines display daily fluctuations in aerosol thickness.

There is a more stable aerosol level from February to July, with most values fluctuating close to the horizontal baseline of 0. This suggests relatively moderate aerosol levels during these months.

August to October shows the most significant spikes in aerosol levels, where values surpass 1 in thickness, indicating dust storms or other temporary events leading to higher concentrations of aerosols in the atmosphere.

Extremes: A few sharp dips below the baseline (e.g., in February and March) indicate lower-than-average aerosol levels, possibly due to rainy periods or reduced dust activity.

3.4.2. Isfahan (Bottom Graph):

Trend: Similar to Kerman, Isfahan shows a slight upward trend in aerosol thickness over time. However, the trend in Isfahan is more pronounced, starting from a higher baseline of about 1, compared to Kerman's baseline of 0. This suggests that Isfahan, on average, experiences higher dust concentrations throughout the year.

Seasonal Variation:

In January to July, the blue lines show more fluctuations, with the aerosol levels varying between -1 and 1. This indicates that Isfahan experiences regular fluctuations in dust concentrations, with periodic rises in dust levels.

August to October mirrors the pattern seen in Kerman, with a noticeable rise in aerosol thickness. The highest peak reaches over 3, indicating significant dust activity during these months.

Extremes: As seen in Kerman, Isfahan experiences dips below the baseline, especially in March and May, suggesting periods of reduced dust presence, potentially due to changes in weather conditions or decreased dust-generating activities.

3.4.3. Comparison:

Kerman shows a more stable and moderate pattern in aerosol thickness, with significant increases only in the latter half of the year.

Isfahan generally experiences higher aerosol levels year-round and exhibits larger fluctuations, particularly in the second half of the year, indicating more frequent dust events or higher dust loads during this period.

The UV Aerosol Index changes indicate a rising trend of dust concentration in both regions over 2021. Seasonal variations are evident, with late summer to autumn showing peak dust activity, likely due to dry conditions and wind patterns that contribute to dust storms. This analysis highlights the temporal dynamics of dust in Kerman and Isfahan and the potential need for dust management strategies, especially during high-risk months.

3.5. Wind Intensity Analysis in Kerman and Isfahan

Fig. 7 presents the spatial distribution of wind intensity across the provinces of Kerman (A) and Isfahan (B). This analysis helps in understanding how wind patterns vary within these regions, which can influence environmental and health outcomes, particularly due to dust movement.

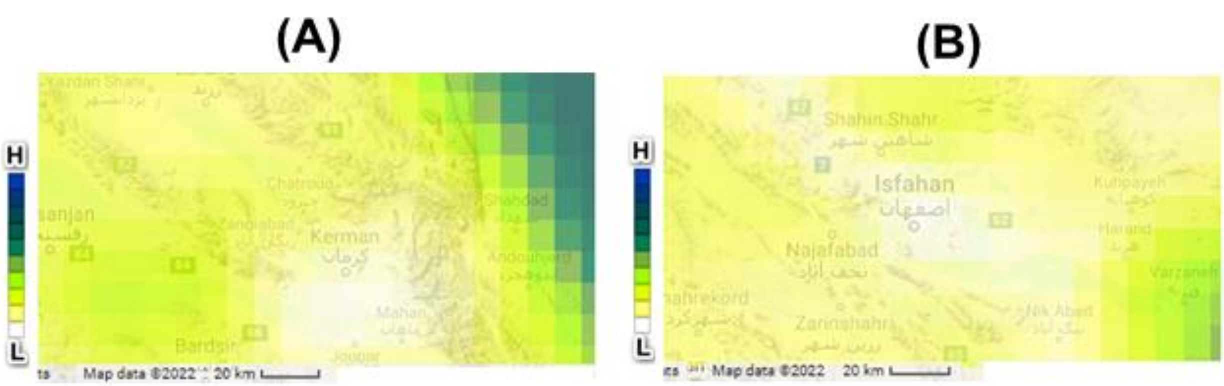

Fig. 7 - Wind intensity variations in Kerman (A) and Isfahan (B)

3.5.1. Kerman (A) Wind Intensity Analysis:

The map for Kerman shows that the eastern part of the province experiences the highest wind intensity, as indicated by the darker green shades. This region is characterized by strong winds that could lead to dust storms and atmospheric transportation of particles. As the wind patterns move towards the western parts of Kerman, the intensity decreases significantly, as represented by the lighter yellow shades. This suggests that the western part of the province experiences less wind activity, potentially contributing to fewer dust-related issues in that region.

3.5.1.1. Quantitative Analysis:

The eastern areas show higher wind intensity values, reflected in darker green shades on the map.

Central and western Kerman display a noticeable decrease in wind speed, with values likely around the lower end of the scale represented in lighter yellow hues.

This gradient in wind intensity across Kerman suggests regional variability in exposure to airborne dust, which could have implications for air quality and public health.

3.5.2. Isfahan (B) Wind Intensity Analysis:

In Isfahan, a contrasting pattern emerges. The eastern and central parts of the province exhibit lower wind intensity, as depicted by the light yellow tones. This suggests calmer weather conditions in these areas, where the wind is not strong enough to cause significant dust movement. However, the western part of Isfahan shows relatively higher wind intensity, as seen by the green hues. This increase in wind strength towards the west might contribute to higher dust concentrations in these areas, potentially affecting air quality.

3.5.2.1. Quantitative Analysis:

The central and eastern areas of Isfahan show low wind activity, indicated by pale yellow shades.

Western Isfahan, on the other hand, experiences moderate to high wind speeds, as demonstrated by the green-colored areas.

This variation in wind intensity across Isfahan is important for understanding localized dust movement, especially in regions where industrial or agricultural activities may further aggravate dust levels.

3.5.3. Qualitative Implications:

The variation in wind intensity between Kerman and Isfahan can have several environmental and health-related implications. Higher wind speeds in eastern Kerman and western Isfahan may lead to the formation of dust storms, which can transport particulate matter over large distances. These particles may carry allergens, pollutants, and pathogens, increasing the risk of respiratory and cardiovascular diseases among the populations in these regions.

Additionally, the differences in wind patterns suggest that strategies for controlling air quality and minimizing dust-related health impacts should be region-specific. For example, mitigation efforts such as reforestation or dust barriers may be more critical in areas of higher wind intensity to reduce the health risks associated with airborne particles.

In summary, the wind intensity maps for Kerman and Isfahan highlight important regional variations in wind speed. While eastern Kerman experiences stronger winds, leading to a higher potential for dust storms, central and eastern Isfahan sees much lower wind activity. Western Isfahan, however, presents conditions more akin to those in eastern Kerman, with moderate to strong winds contributing to dust movement. These findings emphasize the need for tailored environmental and public health interventions in regions experiencing higher wind intensity to minimize the adverse effects of dust exposure.

3.6. Wind Speed Trends Analysis in Kerman and Isfahan

Fig. 8 shows the time series analysis of wind speed in Kerman (A) and Isfahan (B) from 2018 to 2021. These graphs provide insights into the temporal variations in wind speed, illustrating seasonal trends and fluctuations, as well as any long-term changes in wind behavior in both regions.

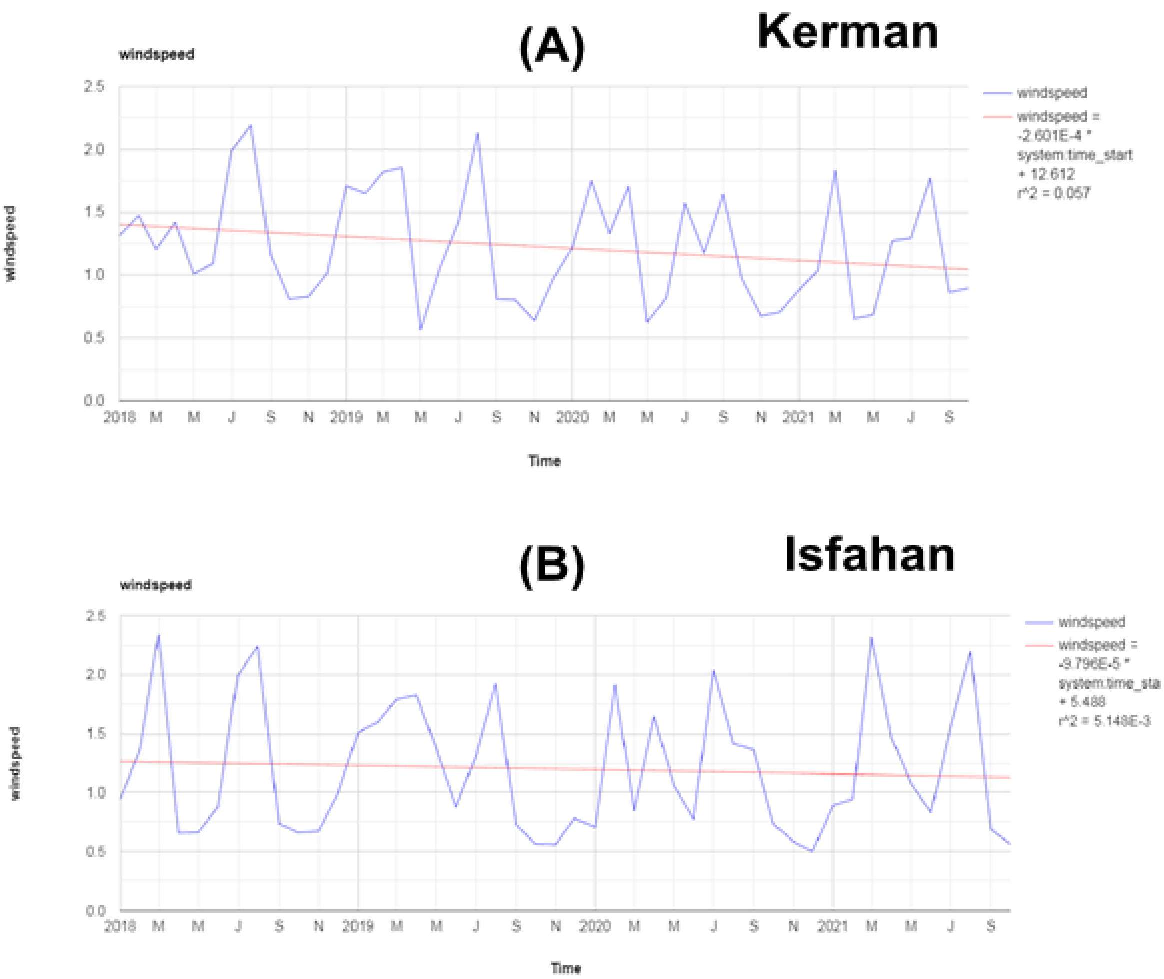

Fig.8: Time series analysis of wind speed in Kerman (A) and Isfahan (B)

3.6.1. Kerman (A) Wind Speed Analysis:

The wind speed data for Kerman fluctuates significantly over the analyzed period, with several peaks and troughs. The highest wind speed values, reaching up to 2.5 m/s, occur predominantly during the spring and early summer months. There are also noticeable drops in wind speed, particularly during the winter months, where the wind slows to around 1.0 m/s.

3.6.1.1. Quantitative Analysis:

Peak Wind Speeds: The highest wind speeds of around 2.5 m/s are observed during spring and early summer months, indicating a seasonal increase in wind activity during these periods.

Low Wind Speeds: The lowest wind speeds, around 1.0 m/s, occur during the winter months, particularly in late 2018 and 2020, suggesting calmer weather during these seasons.

Trend: The red trend line suggests a slight increase in wind speed over the analyzed period, though this trend is not very strong ($R^2 = 0.057$). However, it does indicate that Kerman's wind speeds might be gradually increasing over time.

3.6.2.2. Qualitative Implications:
The seasonal variability in wind speed suggests that dust storms and atmospheric particulate movement could be more prevalent in Kerman during spring and early summer. The calmer winter periods likely result in lower levels of dust and better air quality. The overall slight increase in wind speed could point to long-term environmental changes or shifts in regional weather patterns that could have implications for agriculture, public health, and infrastructure in the region.

3.6.2. Isfahan (B) Wind Speed Analysis:
The wind speed data for Isfahan follows a similar pattern to Kerman, with significant fluctuations and seasonal variations. However, the wind speed in Isfahan appears to be lower on average than in Kerman, with the highest recorded wind speed reaching just over 2.0 m/s. Like Kerman, the wind speeds in Isfahan are highest during the spring and early summer, with a noticeable decline in wind activity during the winter months.

3.6.2.1. Quantitative Analysis:
Peak Wind Speeds: The highest wind speeds in Isfahan reach around 2.0 m/s during the spring and summer months, slightly lower than the peak speeds observed in Kerman.

Low Wind Speeds: During winter, wind speeds drop to around 0.5-1.0 m/s, indicating relatively calm conditions.

Trend: The red trend line shows a very slight increase in wind speed over time, similar to Kerman, but with an even weaker trend ($R^2 = 0.148$), suggesting that wind speeds in Isfahan are also slowly increasing over time but at a slower rate.

3.6.2.2. Qualitative Implications:
Isfahan's lower average wind speeds suggest less potential for severe dust storms compared to Kerman. However, the seasonal fluctuations still indicate periods of higher wind activity during spring and early summer, which could lead to increased dust movement during these times. The slight upward trend in wind speed, though weak, may be indicative of broader regional climatic changes, though the impacts may be less pronounced than in Kerman.

3.7. Comparison Between Kerman and Isfahan:

Peak Wind Speeds: Kerman generally experiences higher peak wind speeds (up to 2.5 m/s) compared to Isfahan (up to 2.0 m/s). This indicates that Kerman is more likely to experience stronger wind events, which could lead to more significant dust storms.

Seasonal Patterns: Both regions exhibit similar seasonal patterns, with wind speeds peaking in spring and early summer and dropping in winter. This suggests that both provinces are subject to similar atmospheric conditions that drive seasonal wind patterns.

Trend Analysis: Both regions show a slight increasing trend in wind speeds over time, though the trend is slightly stronger in Isfahan. This could indicate a gradual change in regional wind patterns, potentially linked to climate change.

The analysis of wind speed data for Kerman and Isfahan reveals important seasonal variations and slight long-term increases in wind speed for both regions. Kerman experiences stronger wind events, which may lead to more frequent dust storms, particularly during spring and early summer. Isfahan, while having lower wind speeds overall, still shows similar seasonal patterns and is susceptible to increased dust movement during the windier months. These findings are crucial for developing region-specific mitigation strategies to manage dust-related environmental and health risks.

3.8 Analysis and Interpretation of Wind Rose for Kerman (A) and Isfahan (B)

Wind rose diagrams provide a visual representation of wind direction and frequency, helping to identify dominant wind flows in Kerman and Isfahan (Fig. 9).

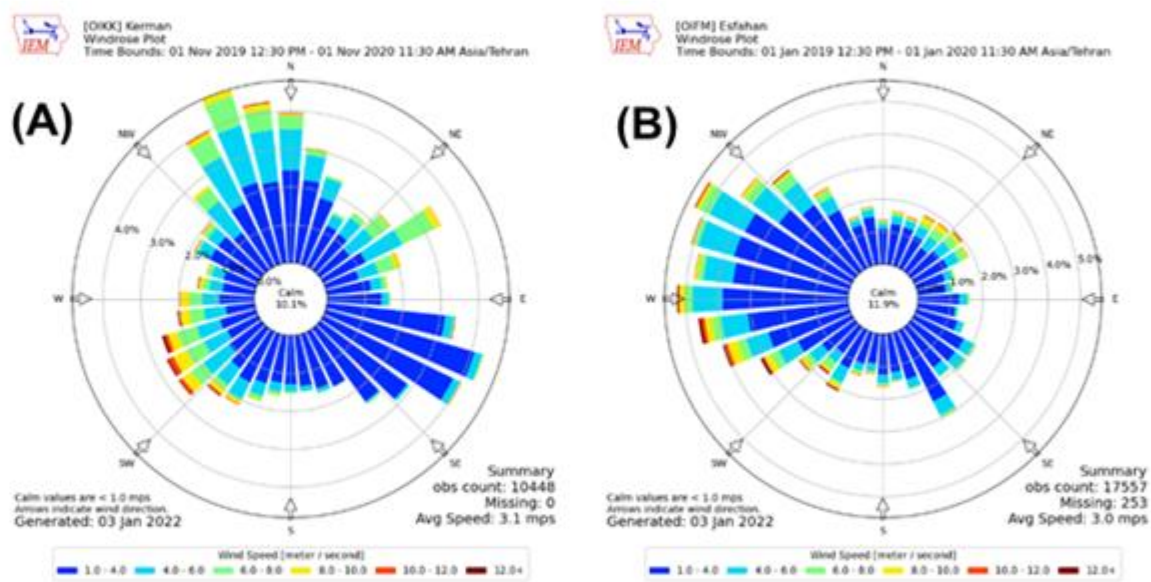

Fig. 9- Wind Rose Diagrams for Kerman (A) and Isfahan (B)

3.8.1. Dominant Wind Direction:

Kerman (A):
In Kerman, the dominant wind direction is from northwest to southeast. This means the wind predominantly blows from the northwest toward the southeast. This pattern may reflect geographical and topographical influences, such as the presence of mountains or natural wind pathways.

Isfahan (B):
In Isfahan, the dominant wind direction is from the west. This indicates that winds primarily flow from the west to the east. The influence of western winds might be due to geographical features such as mountains or wide plains in the western part of Isfahan.

3.8.2. Wind Frequency from Different Directions:

Kerman (A):
The wind frequency in Kerman is highest from the northwest. The taller bars in the wind rose chart for this direction indicate that winds blow more frequently from the northwest. This wind pattern likely reflects the effects of regional atmospheric systems and dominant airflows in the Kerman area.

Isfahan (B):
In Isfahan, wind frequency is higher from the west. This means that winds from the west are more frequent compared to other directions. This could be influenced by the topographical features and weather patterns prevalent in western Isfahan.

3.8.3. Calm Wind Frequency:

Kerman (A):
In Kerman, the percentage of Calm Wind is 10.1%, meaning that during 10.1% of the observed period, there were very low wind speeds or no wind at all. The relatively low percentage of calm winds suggests that Kerman typically experiences light to moderate wind conditions.

Isfahan (B):
In Isfahan, the percentage of Calm Wind is 11.9%, indicating that in 11.9% of the time, calm or nearly still conditions were observed. The calm wind frequency in Isfahan is slightly higher than in Kerman, which might reflect different climatic and geographical influences.

3.8.4. Wind Speed:

Kerman (A):
The wind rose for Kerman shows variations in wind speed from different directions, primarily from the northwest to southeast. Winds from the northwest tend to have moderate speed, possibly due to the influence of the terrain that slows or accelerates wind movement.

Isfahan (B):
The wind rose for Isfahan reveals that winds from the west generally have moderate to relatively high speeds. This indicates strong wind flows from the western direction, influenced by the regional geography and weather conditions.

3.8.5. Comparison Between Kerman and Isfahan:

Wind Direction:
The dominant wind direction in Kerman is from the northwest, while in Isfahan it is primarily from the west. This difference may arise from varying geographical, elevation, and natural characteristics of the two cities.

Wind Frequency:
Both cities experience significant wind activity, but Kerman has higher wind frequency from the northwest, while Isfahan sees more frequent winds from the west.

Calm Wind:
The percentage of calm wind in Isfahan (11.9%) is slightly higher than in Kerman (10.1%), suggesting that Isfahan experiences more still or light wind conditions compared to Kerman.

The analysis of wind rose charts for Kerman and Isfahan reveals distinct wind patterns for both cities. Kerman tends to experience northwesterly winds of moderate speed, whereas Isfahan experiences westerly winds with moderate to high speed. The difference in calm wind percentages reflects the unique atmospheric conditions in each city. This information is essential for urban planning, building design, and environmental management, providing insights into the wind dynamics in both regions.

3.9. NDVI Vegetation Coverage Analysis in Kerman and Isfahan

Fig. 10 shows NDVI (Normalized Difference Vegetation Index) imagery for the regions of Kerman (A) and Isfahan (B), highlighting the distribution and density of vegetation cover in both areas. NDVI values are used to assess the health and coverage of vegetation, where higher values indicate denser and healthier vegetation (represented in green), while lower values indicate sparse or no vegetation (represented in shades of brown and yellow).

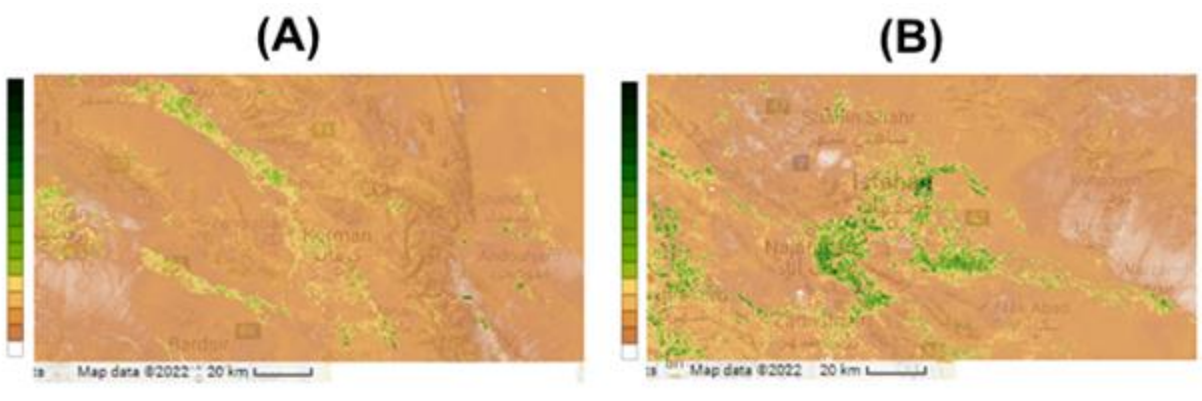

Fig.10 - NDVI (Normalized Difference Vegetation Index) imagery for Kerman (A) and Isfahan (B)

3.9.1. Kerman (A) NDVI Analysis:
The NDVI imagery of Kerman shows that vegetation is sparse across most of the region. The western and central parts of the area exhibit some clusters of green, indicating patches of vegetation, likely associated with agricultural areas or regions near water sources. However, a significant portion of Kerman appears to be arid or semi-arid, with vast areas showing low NDVI values, indicative of minimal vegetation cover.

3.9.1.1. Quantitative Analysis:
Vegetation Density: The regions with visible vegetation (highlighted in green) are scattered and mainly concentrated along river valleys and near mountainous regions, where water is likely more available.

Low NDVI Values: The predominant orange-brown color across most of the map suggests that the majority of the region has very low or no vegetation cover. These areas are likely desert-like, characterized by dry conditions with little to no plant life.

3.9.1.2. Qualitative Implications:
The sparse vegetation in Kerman highlights the challenges the region faces in terms of agricultural potential and land use. The limited areas of vegetation are crucial for local ecosystems, supporting biodiversity and agricultural activities. However, the vast arid regions suggest that any form of sustainable land management or reforestation would require significant water resources, which are likely scarce.

3.9.2. Isfahan (B) NDVI Analysis:
The NDVI imagery of Isfahan shows a higher density of vegetation compared to Kerman. The green areas are more extensive, particularly in the central and eastern parts of the region, indicating better vegetation coverage. This suggests that Isfahan has a more favorable climate or more accessible water resources, allowing for more widespread agriculture and natural vegetation.

3.9.2.1. Quantitative Analysis:

Vegetation Density: The higher density of green areas, especially in the central part of Isfahan, suggests that agricultural activities are more concentrated and potentially more productive compared to Kerman. The larger expanses of vegetation indicate better soil conditions and water availability.

Low NDVI Values: While there are areas with low NDVI values, particularly in the western part of the region, they are less extensive compared to Kerman. This indicates that more of the land in Isfahan is suitable for vegetation growth.

3.9.2.2. Qualitative Implications:

The greater vegetation cover in Isfahan suggests that the region has a more favorable environment for agriculture and supports a larger biodiversity. The presence of more vegetation also means that the area has a higher potential for carbon sequestration and could play a significant role in regional climate regulation. Additionally, this higher NDVI could reflect better water management practices or more favorable rainfall patterns compared to Kerman.

3.10. Comparison Between Kerman and Isfahan:

Vegetation Density: Isfahan clearly has a higher overall vegetation density compared to Kerman. This could be due to differences in water availability, rainfall patterns, or agricultural practices. Isfahan's more extensive green areas suggest that the region is more capable of supporting both natural ecosystems and agricultural activities.

Spatial Distribution: In both regions, vegetation is not uniformly distributed. In Kerman, vegetation is concentrated in limited areas, whereas in Isfahan, there is a broader and more consistent spread of vegetation.

Environmental Challenges: The arid landscape in Kerman poses significant challenges for agriculture and ecosystem management, while Isfahan, with its greater vegetation cover, likely faces fewer limitations in terms of land productivity.

The NDVI analysis reveals a stark contrast between the vegetation coverage in Kerman and Isfahan. Kerman is characterized by a predominantly arid landscape with sparse vegetation, while Isfahan shows a more favorable environment for plant growth, with higher vegetation density and wider coverage. These differences are likely due to variations in climate, water availability, and land use practices between the two regions. Understanding these patterns is crucial for developing region-specific strategies for sustainable land management, agriculture, and biodiversity conservation.

3.11. Land Use Analysis of Kerman (A) and Isfahan (B) Based on Five Classes

Fig. 11, shows the land use for Kerman (A) and Isfahan (B) that has been classified into five distinct categories: No Land Use (Yellow), Urban Land Use (Gray), Industrial Land Use (Red), Vegetation Cover (Green), Sparse Vegetation Cover (Light Green).

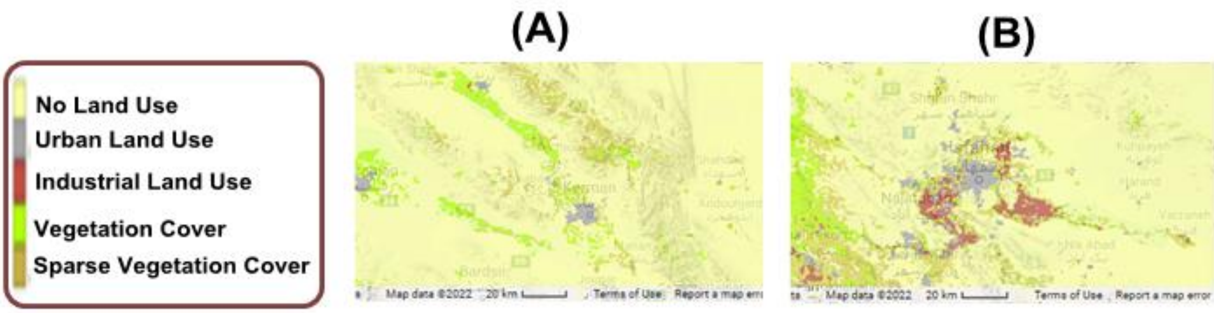

Fig.11- Land Use Classification for Kerman (A) and Isfahan (B)

3.11.1. Kerman (A) Analysis:

3.11.1.1. Quantitative Analysis:

No Land Use (Yellow): Kerman’s map is dominated by "No Land Use" zones, especially in the central and surrounding areas. This reflects the city's arid desert environment and large undeveloped regions.

Urban Land Use (Gray): Urban zones in Kerman are relatively small and scattered, mostly concentrated in and around the city center. The urban areas are less dense, showing a more spread-out and possibly lower population density compared to Isfahan.

Industrial Land Use (Red): Industrial land use is sparse in Kerman, with limited industrial areas mostly located near urban centers. These zones are small, indicating a lower industrialization level.

Vegetation Cover (Green): Vegetation cover appears mostly along riverbanks or agricultural areas, primarily concentrated in the northeast and along some parts of the city. However, these areas are limited due to the region's dry climate.

Sparse Vegetation Cover (Light Green): Sparse vegetation is more widespread in Kerman, representing areas of desert shrubland or minimal vegetation growth. These areas are a common feature of the region’s arid landscape.

3.11.1.2. Qualitative Analysis:

Kerman’s land use is largely dominated by undeveloped and sparsely vegetated areas, typical of a region with challenging environmental conditions for development. The limited industrial zones and scattered urban areas reflect a smaller economy and less concentrated population. Agriculture is constrained by water availability, resulting in minimal vegetation and green spaces.

3.11.2. Isfahan (B) Analysis:

3.11.2.1. Quantitative Analysis:

No Land Use (Yellow): While present, this category occupies a much smaller portion of Isfahan compared to Kerman. The city's land is more actively utilized for urban, industrial, and agricultural purposes.

Urban Land Use (Gray): The urban areas in Isfahan are much denser, especially in the central and surrounding areas. The compact urbanization reflects a higher population density and more developed infrastructure.

Industrial Land Use (Red): Industrial zones are significantly larger and more prominent in Isfahan, particularly surrounding the city. The industrial land use is extensive, highlighting the city's role as an industrial hub.

Vegetation Cover (Green): Vegetation cover is more extensive in Isfahan, with green areas concentrated around the city and agricultural zones. The presence of agriculture and managed green spaces is more evident compared to Kerman, reflecting better access to water resources and irrigation.

Sparse Vegetation Cover (Light Green): While sparse vegetation is present, it is less dominant than in Kerman. Isfahan has more productive agricultural lands and vegetation, suggesting better environmental conditions for plant growth.

3.11.2.2. Qualitative Analysis:

Isfahan displays a much more balanced and developed land use pattern compared to Kerman. The larger and more compact urban areas reflect a higher population density, while the extensive industrial zones demonstrate the city’s economic strength in manufacturing. The agricultural lands are healthier and more widespread, benefiting from more favorable environmental conditions or advanced irrigation. Sparse vegetation is present but less prominent than in Kerman, further illustrating the city's more favorable conditions for growth and development.

3.11.3. Comparison Between Kerman and Isfahan:

Urban and Industrial Development: Isfahan clearly surpasses Kerman in both urban and industrial development. The densely populated urban areas and large industrial zones contrast with Kerman’s scattered and smaller-scale development.

Vegetation and Agriculture: Isfahan has far more extensive vegetation cover and productive agricultural zones, reflecting better environmental conditions for farming. Kerman, in contrast, struggles with sparse vegetation and minimal agricultural areas, highlighting the challenges of its desert-like environment.

No Land Use Zones: Kerman has a significantly larger proportion of its land categorized as "No Land Use," which highlights the vast, undeveloped, or desert-like areas surrounding the city. Isfahan has fewer undeveloped zones, indicating more active land use and development.

The land use patterns of Kerman and Isfahan are shaped by their respective geographical, climatic, and economic conditions. Isfahan’s well-developed urban and industrial zones, combined with its more productive agricultural land, make it a more economically vibrant city compared to Kerman, which faces greater challenges due to its arid climate and more limited land use. The comparison between the two cities highlights the importance of environmental conditions and infrastructure in shaping land use and development patterns.

4. Discussion

The primary objective of this study was to evaluate the relationship between dust concentrations and nitrogen dioxide (NO_2) levels with environmental factors such as land use, wind intensity, and vegetation cover (NDVI) in the cities of Kerman and Isfahan using remote sensing data (Sentinel-5P) via GEE. The findings from this study provide significant insights into air quality dynamics in these regions and lay a foundation for effective air quality management.

Our first hypothesis posited a significant positive correlation between wind intensity and the volume of dust in Kerman and Isfahan. The analysis confirmed this hypothesis, revealing that the highest dust concentrations were observed in Kerman, particularly in the western and northwestern areas, where wind intensity was also found to be the highest. This finding is consistent with previous studies that reported strong correlations between wind speed and dust storm events, particularly in arid and semi-arid regions (Francis et al., 2024). In Isfahan, while dust levels were comparatively lower, the eastern parts of the city still experienced considerable dust accumulation, which can be attributed to regional wind patterns. The observed relationship underscores the importance of monitoring wind patterns as a critical component of air quality assessments in these cities.

Our second hypothesis proposed that higher vegetation cover (NDVI) would be associated with lower NO_2 concentrations in Kerman and Isfahan. This hypothesis was also supported by our findings. The analysis indicated that areas with dense vegetation corresponded with lower levels of NO_2, particularly in Isfahan, where industrial activities are concentrated. These results align with prior research indicating that vegetation acts as a natural filter for air pollutants, effectively absorbing NO_2 and improving air quality (Xing & Brimblecombe, 2019). In contrast, urbanized and industrial areas with minimal vegetation cover demonstrated elevated NO_2 levels, reflecting the anthropogenic influences on air quality.

Additionally, the results indicated notable differences in land use patterns between Kerman and Isfahan. In Isfahan, industrial land use was prevalent, surrounding the urban core and contributing to higher NO_2 concentrations. This finding corroborates existing literature that emphasizes the role of industrial emissions in urban air pollution (Amegah & Agyei-Mensah, 2017). Meanwhile, Kerman exhibited a more varied land use distribution, with the concentration of dust primarily influenced by wind patterns rather than localized industrial activity.

The analysis of dust concentration maps highlighted the varying distribution of dust across both cities, with Kerman experiencing more significant dust events, particularly in its western regions. This discrepancy can be attributed to geographic and climatic factors, such as aridity and land degradation, which are prevalent in Kerman (Rahimi et al., 2015). The data collected on dust levels and their correlation with wind intensity and land use presents a critical foundation for future studies aimed at understanding the complex interplay between environmental factors and air quality.

In summary, this study enhances the understanding of the dynamics of air quality in Kerman and Isfahan, providing valuable insights for policymakers and environmental managers. The significant correlations observed between wind intensity, vegetation cover, and air pollutant concentrations underscore the need for integrated air quality management strategies that consider these environmental factors. Future research should focus on longitudinal studies to monitor these relationships over time and assess the effectiveness of implemented air quality management strategies.

5. Conclusion

This study aimed to evaluate the relationship between dust concentrations and nitrogen dioxide (NO_2) levels with environmental factors, including land use, wind intensity, and vegetation cover (NDVI) in the cities of Kerman and Isfahan. The analysis confirmed both hypotheses: first, that there is a significant positive correlation between wind intensity and the volume of dust; and second, that higher vegetation cover is associated with lower NO_2 concentrations.

The results indicated that Kerman experiences higher dust concentrations, particularly in its western regions, primarily due to increased wind intensity. In contrast, Isfahan exhibits elevated NO_2 levels, especially in industrial areas with minimal vegetation cover. The significant disparities in land use and environmental factors between the two cities highlight the complex interplay between natural and anthropogenic influences on air quality.

These findings contribute to the growing body of literature on urban air quality management, emphasizing the importance of integrating environmental factors into air quality assessments and policy-making processes.

Based on the findings of this study, the following recommendations are proposed:

Enhanced Monitoring: It is essential to implement continuous monitoring systems for dust and NO_2 levels in Kerman and Isfahan. Such systems should integrate meteorological data to provide real-time insights into air quality dynamics.

Vegetation Management: Urban planning should prioritize the increase of green spaces and vegetation cover, particularly in areas with high NO_2 concentrations. This approach can mitigate air pollution and improve overall air quality.

Windbreaks Implementation: Establishing windbreaks and barriers in regions prone to dust storms could help reduce the impact of wind on dust dispersion. This could be particularly beneficial in Kerman, where dust levels are significantly high.

Public Awareness Campaigns: Increasing public awareness regarding the sources and health impacts of air pollution can foster community engagement in pollution reduction initiatives and encourage sustainable practices.

Policy Development: Policymakers should consider the findings of this study in developing air quality management strategies that address the specific needs and conditions of Kerman and Isfahan. Collaborative efforts among government agencies, researchers, and local communities are vital to successfully implement these strategies.

Further Research: Future studies should investigate the long-term trends of dust and NO_2 concentrations, considering seasonal variations and the effects of climate change. Expanding the research to include additional cities with similar environmental conditions could also enhance the understanding of regional air quality dynamics.

By implementing these recommendations, stakeholders can work towards improving air quality in Kerman and Isfahan, ultimately enhancing public health and environmental sustainability.

Acknowledgements

The authors would like to express their gratitude to all individuals and institutions who provided valuable support and guidance throughout the course of this research.

Declarations

Funding Information (Private funding by authors)

Conflict of Interest /Competing interests (None)

Availability of Data and Material (Data are available when requested)

Consent to Publish (Authors consent to publishing)

Authors Contributions (All co-authors contributed to the manuscript)

Code availability (Not applicable)

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