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# Utilizing NASA Giovanni and Google Earth Engine for Dust Analysis in Northeast and East Iran: A 40-Year Study Using MODIS, MERRA-2, and Sentinel-5 Data to Assess Relationships with Wind and Vegetation

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## ABSTRACT

**Background and objective:** Dust storms have been a persistent environmental challenge in eastern and northeastern Iran, exacerbating air pollution and affecting human health, agriculture, and infrastructure. This study aims to analyze the spatial and temporal variations of dust levels over the last 40 years, with a focus on assessing the Enhanced Vegetation Index (EVI) and wind speed on dust intensity and distribution. The research uses satellite data to explore the relationship between environmental factors and the occurrence of dust storms, providing insights into the role of drought-induced vegetation loss in dust formation.

**Materials and methods:** This study utilized data from MODIS, MERRA-2, and Sentinel-5, processed through the NASA Giovanni and Google Earth Engine (GEE) platforms. Dust concentration levels were analyzed using satellite imagery and meteorological data. The relationship between wind speed, EVI, and dust levels was assessed by extracting time-series data for the study region. Temporal and spatial variations were analyzed to identify trends, with a particular focus on the influence of environmental factors such as, wind speed, and vegetation decline.

**Results and conclusion:** The results indicate a strong inverse correlation between vegetation cover and dust intensity, with declining EVI values corresponding to increased dust levels. Wind speed also significantly influenced dust distribution patterns, with higher speeds contributing to more severe dust storms. Over the 40-year period, a marked increase in dust levels was observed, particularly in areas where vegetation cover had diminished due to recurrent droughts. The findings highlight the critical role of wind and vegetation in controlling dust storms and suggest that improving vegetation cover could mitigate dust storm severity in the region.

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## 1. Introduction

Iran and neighboring countries, due to their extensive arid and semi-arid climate and improper use of water and soil resources, face meteorological phenomena such as wind erosion and the occurrence of dust (Duniway et al., 2019; Ebrahimi-Khusfi et al., 2020). Each year, population centers, industries, agricultural lands, and infrastructure in these regions are affected by dust. In recent decades, global warming and climate change have led to rising temperatures and declining rainfall, resulting in frequent droughts, reduced vegetation, and increased dust across the entire region (Azizi et al., 2012).

Wind erosion and the transport of suspended particles into the atmosphere occur under specific conditions such as excessive wind speed, the presence of particle-rich sources, dry soil surfaces, and low vegetation cover. When wind speed in desert areas exceeds a certain threshold (8 meters per second), depending on surface roughness, soil moisture, vegetation cover, and soil texture, fine particles are entrained into the atmospheric flow, creating suspended particles (Xuan et al., 2004). Iran, due to its proximity to large desert regions such as Syria, Jordan, Saudi Arabia, and especially Iraq, is affected by wind fields that transport dust particles into southern and southwestern Iran, and occasionally into central regions of the country.

Google Earth Engine (GEE) is a powerful cloud-based geospatial processing platform designed for analyzing large-scale environmental data. It integrates a vast collection of satellite imagery and geospatial datasets, allowing users to process, visualize, and extract information about the Earth's surface. GEE is especially effective for long-term environmental monitoring, offering tools for analyzing trends in land cover, climate patterns, and vegetation indices such as NDVI and EVI. Its ability to handle extensive datasets, combined with its coding interface, makes it an invaluable resource for research involving remote sensing and environmental modeling (Amani et al., 2020).

In the context of analyzing vegetation cover and its relationship with dust activity, indices such as the Enhanced Vegetation Index (EVI) and the Normalized Difference Chlorophyll Index (NDCI) are essential for monitoring vegetation health and density. EVI is particularly useful in regions with dense vegetation, as it improves sensitivity in high biomass areas, while NDCI provides insights into chlorophyll content and vegetation vitality (Xiong et al., 2023).

Extensive studies have been conducted in the last decade on the sources of dust and factors influencing its intensity in Iran and globally.

Papi et al. (2022) conducted a spatial-temporal analysis of remote sensing data to identify the sources of sand and dust storms (SDS) in Central Iran, an area characterized by prevalent SDS due to both natural and anthropogenic factors. The researchers employed a remote sensing approach, using 20-year time-series data from MODIS and TerraClimate products, and developed a model through multi-step masking to identify high-potential SDS sources. The study found that 5.3% of Central Iran is classified as high-potential SDS areas, with sandy sources comprising the largest share (60.9%) and frequent occurrences of SDS, particularly during spring and summer. The year 2008 recorded the highest SDS frequency, exceeding the 20-year average by 120%. While sandy and salt plain sources are primarily driven by natural factors, lakes and alluvial sources are significantly affected by human activities. Additionally, severe droughts were identified as exacerbating the frequency of SDS across all high-potential sources in Central Iran.

Namdari et al. (2022) analyzed the interaction between vegetation cover and dust activity in the Middle East using long-term Normalized Difference Vegetation Index (NDVI) and daily Aerosol Optical Depth (AOD) data from MODIS. The study focused on eight major dust hotspots identified from 20 years of AOD data (2000–2019). A spatiotemporal and statistical analysis revealed significant spatial variability in the relationship between NDVI and AOD across the region. During the period 2007–2013, AOD increased by 6% to 32%, while NDVI decreased by −0.9% to −14.3% in most hotspots, except in Yemen−Oman. The overall correlation between NDVI and AOD (−0.63) highlighted the significant influence of vegetation cover on dust intensity. The findings suggest that reduced vegetation cover is a critical factor in dust storm fluctuations and must be considered alongside wind speed and other climatic factors in dust management efforts across the Middle East.

Khusfi et al. (2020) investigated the seasonal and spatial variations of sand-dust events in the semi-arid regions of Central Iran Zone (CIZ) and their relationship with atmospheric conditions and vegetation cover. Using Ridge Regression (RR) analysis, the study assessed the impact of variables such as wind speed, precipitation, temperature, and Enhanced Vegetation Index (EVI) on the Dust Storm Index (DSI) across two periods (2001–2008 and 2009–2016). Results indicated an increasing trend in DSI during both periods, with a sharper rise in the second period, particularly near the Iran-Turkmenistan border. Surface wind speed had a significant positive correlation with DSI during summer and winter in the first period, while in the second period, the strongest correlation was found in spring, summer, and autumn. EVI had a negative relationship with DSI, but only in spring during the second period. Additionally, the dust rose analysis revealed that dusty winds primarily came from the northwest, southeast, and west, depending on the region. These findings contribute to better wind erosion management in semi-dry lands of CIZ by identifying key factors influencing dust emissions.

Yao et al. (2020) analyzed a May 2017 dust storm in East Asia using the MERRA-2 reanalysis dataset alongside ground-based and satellite observational data. The study assessed the accuracy of MERRA-2 in simulating dust processes. The findings showed that MERRA-2 data effectively matched other data sources (AERONET, Hamawari-8) in describing the spatiotemporal evolution of the dust storm. The Gobi Desert was identified as the primary source, with dust reaching high altitudes (above 500 hPa) due to vertical atmospheric motion. The event spanned across China, reaching the ocean and Japan. Despite some uncertainty in dust emission sources, MERRA-2 successfully simulated the dust event.

Bakker et al. (2019) evaluated the key northern African dust sources during boreal winter seasons from 2015 to 2017, focusing on their contribution to the Amazon Basin's nutrient supply. Using remote sensing data from SEVIRI, MODIS, VIIRS, and Sentinel-2, the study identified and classified dust sources based on geomorphological characteristics and quantified their dust mass emissions. The results revealed that palaeolakes, especially the Bodélé Depression, were the largest dust emitters, while alluvial deposits also contributed significantly, accounting for approximately 36% of the total dust mass. Interestingly, sand deposits were found to emit minimal dust, contrasting with previous findings.

Feuerstein and Schepanski (2018) aimed to enhance the prediction of atmospheric mineral dust distribution by improving the understanding of dust source behavior and variability. They localized dust sources in the Aïr Massif region of Niger using Sentinel-2 optical data and HydroSHEDS flow accumulation data to detect riverbeds and sand formations. This sediment supply map was then compared with dust source activation data from Meteosat satellites, confirming a strong link between meteorology, sediment supply, and dust activity. The study further incorporated the sediment data into a dust-emission model, demonstrating improved localization of dust sources and better representation of seasonal dust activity. This methodology can be applied to regional and global models for more accurate atmospheric dust load estimations.

In this study, remote sensing techniques play a crucial role in analyzing environmental variables. Data from MODIS (Moderate Resolution Imaging Spectroradiometer), MERRA-2 (Modern-Era Retrospective Analysis for Research and Applications), and Sentinel-5 have been utilized to investigate dust activity and its relationship with vegetation cover and wind speed over the last forty years. MODIS provides high-resolution imagery for tracking vegetation and aerosol optical depth, while MERRA-2 offers reanalysis data crucial for understanding atmospheric dynamics and dust transport. Sentinel-5, with its advanced atmospheric monitoring capabilities, aids in measuring gases such as $NO_2$ and $SO_2$, which are essential for assessing air quality and environmental health (Papi et al., 2022).

The aim of this study is to analyze the dust situation in eastern and northeastern Iran by examining satellite imagery over four decades and assessing key indicators such as wind and vegetation. Utilizing

NASA Giovanni and Google Earth Engine data, this research will investigate temporal and spatial changes in dust over the past forty years.

This study seeks to evaluate two hypotheses. 1. Wind speed and vegetation cover directly influence the intensity and distribution of dust in eastern and northeastern Iran. 2. A decline in vegetation due to frequent droughts has significantly increased dust levels in these regions over the last forty years.

Considering the adverse effects of dust on public health, especially respiratory problems, and the reduction of air quality, it is crucial to study the dust conditions in the vulnerable areas of eastern and northeastern Iran. This research will provide critical information for optimal natural resource management and strategies to mitigate dust-related damage.

## 2. Materials and Methods

### 2.1. Study Area

The study area is located between geographical coordinates 54°E to 32°N and 70°E to 39°N, covering an extensive region in the east and northeast of Iran. This area includes the provinces of North Khorasan, South Khorasan, and Khorasan Razavi, which form a critical environmental zone due to their proximity to arid and semi-arid regions. The area is bounded by Turkmenistan to the north, Afghanistan to the east, Central Iran to the west, and Sistan and Baluchestan province to the south (Fig. 1). This region exhibits a diverse range of topographical and climatological features. It encompasses both mountainous areas, such as the eastern extensions of the Alborz mountain range, and vast desert plains, including parts of the Dasht-e Kavir desert (Breckle, 2002). The elevation ranges significantly from lowland areas in the deserts to high mountainous regions, influencing the local climate and vegetation cover. The study area falls within an arid to semi-arid climatic zone, characterized by hot, dry summers and cold winters, with annual precipitation levels generally lower than 250 mm (Rahmdel et al., 2022). However, the precipitation is unevenly distributed, with the mountainous areas receiving more rainfall compared to the desert plains.

Fig. 1- Geographical coordinates of the study area 54,32,70,39

The prevailing winds in the region, particularly during the summer months, contribute significantly to the transport of dust and sand, making this area a major hotspot for dust storms. The region's vegetation cover, though sparse, plays a crucial role in stabilizing the soil and reducing dust emissions, particularly in the semi-arid regions. However, anthropogenic activities such as overgrazing, unsustainable land management, and water resource mismanagement have led to land degradation and increased the susceptibility of the region to desertification and dust storms. Moreover, this region holds a strategic environmental position, as it is located at the crossroads of several dust transport pathways. Dust originating from local sources within the region, as well as from neighboring deserts in Afghanistan and Turkmenistan, frequently affects the air quality and visibility. This makes the area particularly relevant for studying dust dynamics and the interaction between climatic factors, vegetation cover, and dust activity.

## *2.2. Research method*

Fig.2 illustrates the research process flowchart, outlining the key steps and methodologies employed throughout the study. In this study, multiple data sources were utilized to analyze dust, vegetation, and wind speed over the eastern and northeastern regions of Iran. The data were extracted from various remote sensing platforms, including NASA's Giovanni tool, GEE, and satellite datasets like MODIS (Moderate Resolution Imaging Spectroradiometer), MERRA-2 (Modern-Era Retrospective analysis for Research and Applications, Version 2), and Sentinel-5. Each of these datasets provided valuable information on different environmental factors that influence dust activity. Dust concentration maps and wind speed maps were analyzed in four time periods over four decades, while vegetation coverage maps (using the Enhanced Vegetation Index, EVI) were studied over two decades to explore their correlations with dust events (Ebrahimi-Khusfi et al., 2020; Shi et al., 2021).

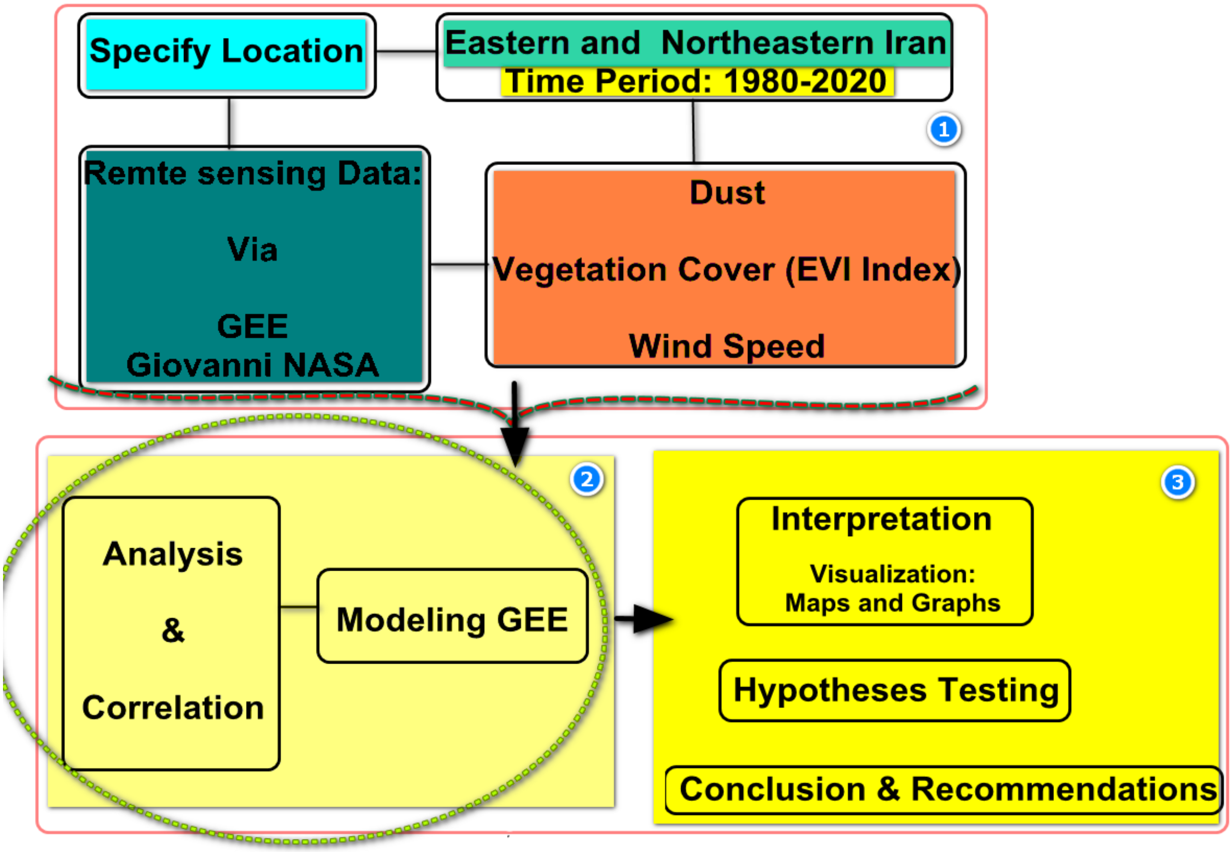


**Fig. 2 - Research process flowchart depicting the key stages and methodologies used in the study**

### *2.2.2. Study Period*

The study spans four decades, divided into distinct ten-year intervals, to examine the temporal variability of dust and wind. The selected periods provide insights into the decadal shifts in dust concentration and the evolving impact of climatic and environmental variables like wind speed and vegetation cover. This long-term analysis enables us to understand patterns and trends that may not be evident in shorter timeframes (Kok et al., 2021).

### *2.2.3. Dust Analysis*

Dust analysis was performed using data from NASA’s Giovanni tool, which provided high-resolution dust concentration maps for the study region. The dust data covered both spatial and temporal variations, helping to identify dust hotspots and periods of high dust intensity. The analysis included parameters such as Aerosol Optical Depth (AOD), which serves as a proxy for dust concentration. The selected periods allowed for the comparison of dust concentration changes across four decades and their relation to wind speed and vegetation cover (Berrick et al., 2008).

### *2.3.4. Vegetation Index Analysis*

The vegetation data were derived from MODIS using the Enhanced Vegetation Index (EVI), a key indicator of vegetation health and density. EVI data were used to examine how changes in vegetation coverage over two decades influenced dust activity. The study aimed to investigate the inverse relationship between dust concentration and vegetation cover, as regions with less vegetation are generally more susceptible to wind erosion and dust storms. EVI maps were analyzed over two distinct ten-year periods, aligning with the study's focus on long-term environmental changes (Priya et al., 2023).

### 2.3.5 Wind Speed Analysis

Wind speed is one of the critical factors affecting dust mobilization. Wind speed data were obtained from MERRA-2, which provided historical wind speed maps for the study region. These maps were analyzed across four decades to determine the role of wind intensity in dust emission and transport. The correlation between wind speed and dust concentration was a central focus, as stronger winds typically lead to increased dust activity, particularly in arid and semi-arid regions. The analysis also included seasonal variations in wind speed to capture the dynamic nature of dust storms (Gelaro et al., 2017).

### 2.3.6. Google Earth Engine (GEE) Data Processing

GEE was used for processing the satellite data and generating time-series analyses. The platform's ability to handle large datasets made it an ideal tool for studying the spatial and temporal patterns of dust, wind, and vegetation in the region. GEE allowed for the integration of MODIS, MERRA-2, and Sentinel-5 datasets, and facilitated efficient data extraction and analysis over the study periods. The use of GEE enabled the visualization of temporal shifts in dust activity and their correlation with climatic factors like wind and vegetation (Amani et al., 2020).

### 2.3.7. Data Specifications

Table 1 summarizes the data specifications used in this study, including the source, temporal and spatial resolution, units of measurement, and variables analyzed. The table provides a clear overview of the datasets utilized for assessing dust concentration, wind speed, and vegetation indices in the study area.

**Table 1- Data Specifications**

| Variable | Units | Source | Temporal Resolution | Spatial Resolution | Begin Date | End Date |
|---|---|---|---|---|---|---|
| Dust Surface Mass Concentration | Kg $m^{-3}$ | MERRA-2 Model | Monthly | 0.5 x 0.625 | 1980-01-01 | 2020-12-31 |
| Surface Wind Speed | m $s^{-1}$ | MERRA-2 Model | Monthly | 0.5 x 0.625 | 1980-01-01 | 2020-12-31 |
| Enhanced Vegetation Index (EVI) | - | MODIS Aqua | Monthly | 0.5 | 2000-02-01 | 2021-01-31 |

- End Date and Begin Date: Indicate the time range for which the data were collected.
- Spatial Resolution: Specifies the spatial granularity of the data, with smaller values indicating higher resolution and more detailed spatial information.
- Temporal Resolution: Describes the frequency at which the data were recorded, with "Monthly" indicating that data were collected on a monthly basis.
- Source: Identifies the source of the data, including the MERRA-2 model for dust and wind data and MODIS Aqua for vegetation index data.
- Units: Provides the units of measurement for each variable, crucial for accurate interpretation of the data.
- Variable: Describes the specific parameter measured, such as dust surface mass concentration, surface wind speed, and the Enhanced Vegetation Index (EVI).

## 3. Results

### *3.1. Analysis of Dust Changes from 1980 to 2020*

The figure presents a sequence of four images (A, B, C, D) showing the spatial distribution and concentration of dust over the eastern and northeastern parts of Iran during four distinct time periods: 1980–1990 (A), 1990–2000 (B), 2000–2010 (C), and 2010–2020 (D) (Fig.3). These images are generated using satellite data and reveal the temporal and spatial evolution of dust intensity across multiple decades.

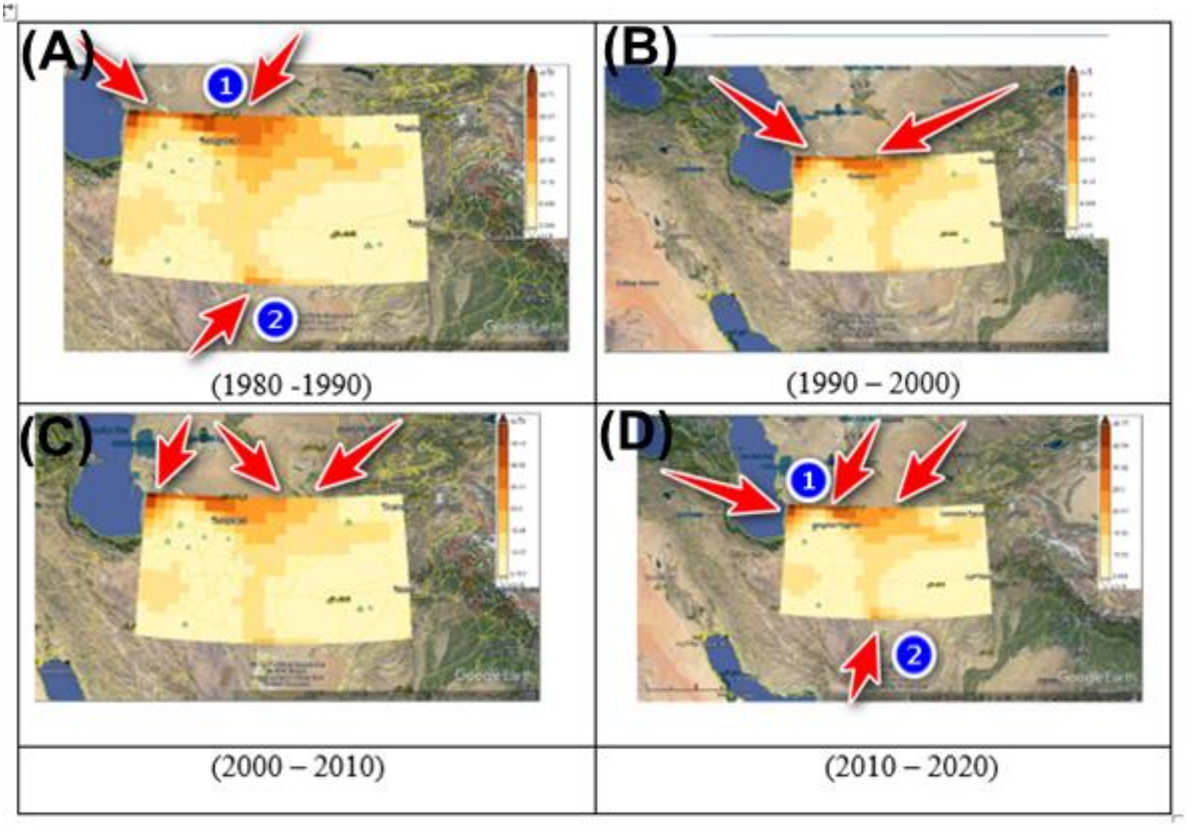


**Fig. 3 - Temporal and spatial changes in dust concentration across eastern and northeastern Iran over four decades: (A) 1980–1990, (B) 1990–2000, (C) 2000–2010, and (D) 2010–2020. Arrows indicate regions with significant dust activity during each period.**

### 3.1.1. (A) 1980–1990:

The first panel (A) depicts the dust concentration in the period from 1980 to 1990. Notably, the dust concentration is high in the northern parts, particularly in the regions adjacent to the Caspian Sea and Turkmenistan. Arrows (marked 1 and 2) indicate areas where significant dust accumulation is observed. The areas highlighted by arrow 1 are concentrated near northern Khorasan and Turkmenistan, indicating potential dust sources in these regions. The southern part (arrow 2) shows moderate dust intensity, suggesting that winds may carry dust particles southwards, impacting the central regions of Iran.

### 3.1.2. (B) 1990–2000:

In the second panel (B), representing 1990 to 2000, the dust concentration appears to have expanded both in intensity and spatial coverage. The northern and central regions show a significant increase in dust activity, with the red arrows indicating the broadening of dust coverage. The central plateau of Iran experiences more dust during this decade, reflecting possible changes in regional climatic conditions such as reduced vegetation cover or increased wind speeds. The transition in dust distribution highlights growing environmental pressures during this decade.

### 3.1.3. (C) 2000–2010:

Panel (C), covering the period from 2000 to 2010, continues to show persistent dust activity. However, the concentration seems to be more pronounced in the central and southern regions. The arrows indicate the high emission sources in the north and central parts of the region, with dust transport extending into the southern provinces. This shift suggests a possible strengthening of wind patterns or changes in land use and surface conditions, which could contribute to the increased dust levels observed in the southern areas. The expansion of dust particles further southwards could lead to a higher impact on human health and agriculture.

#### *3.1.4. (D) 2010–2020:*

The final panel (D), from 2010 to 2020, demonstrates an even broader dust distribution. As indicated by arrows 1 and 2, the dust is observed in large amounts both in the north and south of the study area. Compared to the earlier periods, dust concentration appears more uniform, with higher levels in the southern regions as well. This suggests that environmental degradation or desertification might have intensified in the past decade. Additionally, the persistent dust observed in both the northern and southern parts reflects ongoing environmental challenges that may require targeted interventions, such as soil conservation and vegetation restoration, to mitigate the increasing dust hazards in the region.

#### *3.1.5. General Interpretation:*

Throughout the four decades, the dust distribution over the eastern and northeastern regions of Iran has shown both spatial and temporal changes. The intensity of dust, initially concentrated in the north, gradually expanded southwards, affecting larger areas by the final decade (2010–2020). These changes in dust patterns could be influenced by a combination of factors such as increased desertification, climatic shifts, and changes in wind patterns. Understanding these evolving dust patterns is critical for devising strategies to manage and mitigate their adverse effects on the environment and public health.

### *3.2. Wind Speed Changes Analysis (1980–2020)*

The provided series of images (A-D) shows the spatial and temporal variation in ground-level wind speed across the study area for four distinct decades: (A) 1980-1990, (B) 1990-2000, (C) 2000-2010, and (D) 2010-2020 (Fig. 4). The changes are represented by color scales, with higher wind speeds indicated by darker red colors and lower speeds represented by blue and green hues.

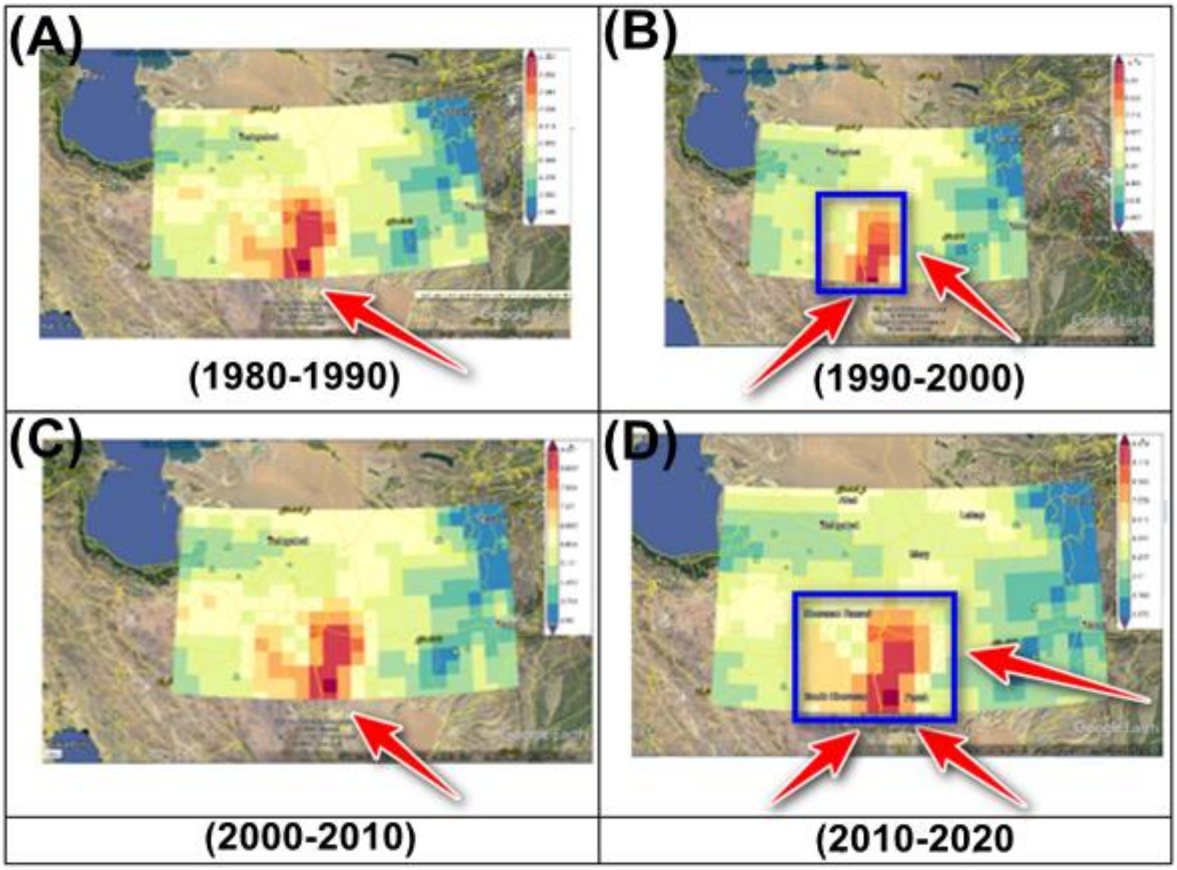


**Fig. 4 - Temporal and spatial changes in wind speed concentration across eastern and northeastern Iran over four decades: (A) 1980–1990, (B) 1990–2000, (C) 2000–2010, and (D) 2010–2020. Arrows indicate regions with significant dust activity during each period.**

### *3.2.1. (A) 1980–1990:*
The first decade (1980–1990) shows concentrated wind activity in the central southern regions of the study area, particularly around central areas such as the Lut Desert. This period highlights strong wind flows localized in the southern part of Khorasan and Sistan-Baluchestan provinces. Wind speeds in this region could contribute to higher levels of dust transport.

### *3.2.2. (B) 1990–2000:*
From 1990 to 2000, the spatial distribution of wind speed changes, with the strongest wind concentration shifting slightly toward the central eastern part of the region. As indicated by the arrows and box, this decade highlights a significant wind corridor, suggesting an increase in wind activity near the northern part of the region. This could result from climatological shifts influencing the area's atmospheric circulation.

### *3.2.3. (C) 2000–2010:*
The wind pattern in the 2000–2010 period shows a persistence of high wind speeds over the same areas, particularly in the southern regions. The intensification in this area may suggest a sustained contribution of these winds to dust storms and the broader regional climate dynamics.

### 3.2.4. (D) 2010–2020:

In the latest decade, 2010–2020, the wind speeds remain high across the central and southern portions, with notable intensification in regions such as the Lut Desert. Additionally, regions in the central and northern part of Khorasan Razavi show increased wind speeds. The highlighted areas indicate regions with enhanced wind circulation, which could exacerbate dust activity in the area.

### 3.2.5. General Interpretation:

The four images (A-D) represent wind speed changes at ground level across the study area over four decades. These variations are critical in understanding the role of wind in the mobilization and transportation of dust particles. Regions with significant increases in wind speed, particularly in the southern and southeastern parts of the area, indicate heightened potential for dust storms, which directly impact air quality and environmental conditions. The shift in wind patterns over time demonstrates the dynamic nature of climatic conditions and their influence on dust dispersion across the region.

## 3.3. Analysis of Vegetation Density Changes with EVI Index (2000–2020):

The two images (A and B) represent the vegetation density in the study area based on the Enhanced Vegetation Index (EVI) for the periods 2000–2010 and 2010–2020, respectively (Fig. 5). EVI is used to assess the greenness and density of vegetation, reflecting the overall health of the plant cover. The arrows highlight areas of significant vegetation changes over these two decades.

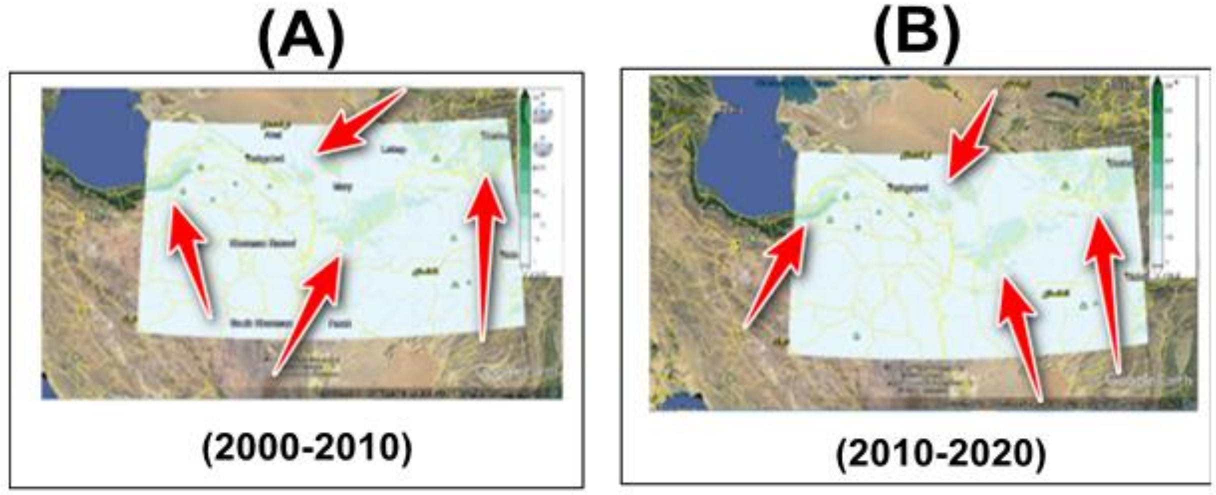


**Fig. 5 - Temporal and spatial changes in vegetation cover (EVI) concentration across eastern and northeastern Iran over two decades: (A) 2000–2010, (B) 2010–2020.**

### 3.3.1. A: Vegetation Density (2000–2010)

During this period, there is noticeable vegetation density in the northern and central parts of the region. The areas around the Alborz Mountains and near lakes like Urmia show higher vegetation densities. These areas are characterized by agricultural activities and natural vegetation, which positively contribute to the EVI values. The increased greenness in these areas suggests a stable or improving ecological condition during this decade. However, the southern and southeastern regions show less vegetation density, indicating either arid conditions or sparse vegetation.

### 3.3.2. B: Vegetation Density (2010–2020)

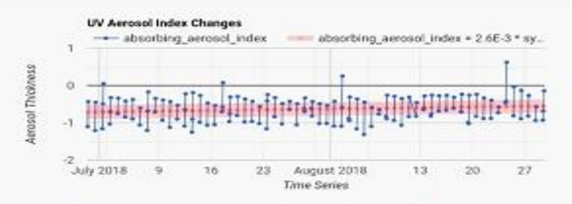
In the second decade, the vegetation density appears to have slightly decreased in some northern regions, especially near Urmia Lake. This decline might be attributed to environmental factors such as drought, water scarcity, and land degradation, which are common issues in this area. However, the central parts of the region still maintain a relatively high EVI value, which indicates that vegetation health has remained stable in these areas. Some parts in the east show slight improvement, which might suggest reforestation efforts or better land management practices.

### 3.3.3. General Interpretation of Vegetation Changes (EVI):

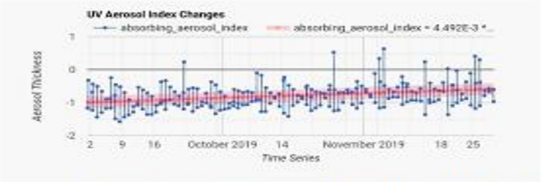
The two-decade analysis shows fluctuations in vegetation cover, with the northern areas experiencing a noticeable decline from 2010 to 2020. This decline could be linked to climate change effects such as reduced precipitation, increased temperature, and prolonged droughts. On the other hand, central parts of the region have remained more resilient, possibly due to better water resource management and agricultural practices. The overall trend emphasizes the sensitivity of vegetation in arid and semi-arid regions to environmental and climatic changes, which is crucial for understanding the dynamics of desertification and land degradation in the region.

## 3.4. Comprehensive Analysis of Aerosol Variability (01/06/2018 – 20/02/2021)

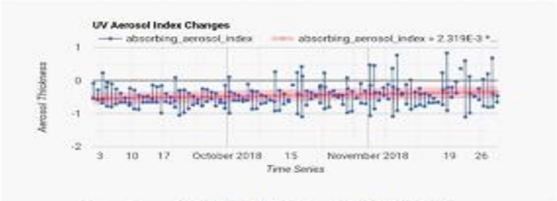
This section provides a detailed comparative analysis of aerosol concentration and distribution during different seasons from June 2018 to February 2021 (Fig. 6). The assessment focuses on qualitative and quantitative changes, comparing aerosol patterns across specific time frames within each season.



(Summer season) 2018/06/30 – 2018/08/01



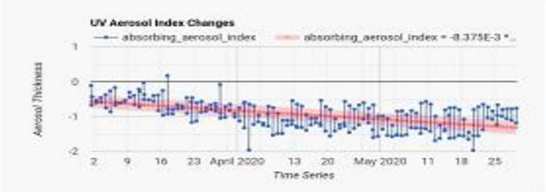
(Autumn season ) 2019/09/30 – 2019/11/01



(Aautumn)2018 /09/30 – 2018/11/01

(Winter season) 2019/12/01 – 2020/02/29

(Winter season) 2018/12/01 – 2019/02/28

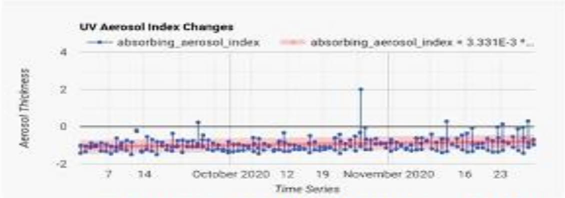


(Spring season) 2020/03/01 – 2020/05/30

(Spring season) 2019/03/01 – 2019/05/30

(Summer season) 2020/06/01 – 2020/08/30

(Summer season) 2019/06/01 – 2019/08/29



(Autumn season) 2020/09/01 – 2020/11/30

**Fig. 6 - Chart of dust changes in the study area seasonally and quarterly periods from 01/06/2018 to 20/02/2021 (Maps taken from Google Earth Engine site)**

### *3.4.1. Summer 2018 (30/06/2018 – 01/08/2018)*

During this period, the distribution and concentration of aerosols followed a relatively uniform pattern. There was a slight increase in aerosol spread, indicating some environmental variability but not drastic changes. The overall concentration remained consistent with a minor increase, likely influenced by regional weather conditions during the summer months.

### *3.4.2. Autumn 2018 (30/09/2018 – 01/11/2018)*

Aerosol distribution during this period was relatively stable, with higher concentrations compared to summer. Toward the end of this timeframe, there was a slight increase in aerosol spread, suggesting a potential correlation with seasonal changes like reduced rainfall and drier conditions leading to more suspended particles in the air.

### *3.4.3. Autumn 2019 (30/09/2019 – 01/11/2019)*

In this period, aerosol concentration and distribution fluctuated more significantly than in autumn 2018. Although the values increased toward the end of the period, the overall pattern showed more variability, which might be related to fluctuating weather patterns. Factors such as intermittent rainfall or wind events could explain these fluctuations in aerosol presence.

### *3.4.4. Winter 2018-2019 (01/12/2018 – 28/02/2019)*

During this winter period, the aerosol distribution remained uniform, similar to the summer season. However, unlike the summer season, aerosol concentration gradually decreased toward the end of the period. This trend might be attributed to increased precipitation and lower wind activity, which often help in reducing the suspension of particulate matter in the air.

### *3.4.5. Winter 2019-2020 (01/12/2019 – 29/02/2020)*

The winter of 2019-2020 showed similar aerosol behavior as the previous winter period. The distribution followed a stable pattern with a decrease in aerosol concentration toward the end of the season. This can be linked to wintertime climatic conditions, where cooler temperatures and moisture in the air lower the prevalence of airborne aerosols.

### *3.4.6. Spring 2019 (01/03/2019 – 30/05/2019)*

Spring 2019 demonstrated a significant decrease in aerosol concentration. Early in the season, aerosol levels were relatively high, but as the season progressed, there was a notable decline. This could reflect increased vegetation and wet conditions reducing the aerosol suspension. By the end of the period, concentrations had decreased to their lowest levels.

### *3.4.7. Spring 2020 (01/03/2020 – 30/05/2020)*

Similar to spring 2019, spring 2020 saw a significant drop in aerosol concentration. Aerosol levels were at their peak early in the season but dropped considerably toward the end. This sharp decrease could be attributed to weather patterns such as rainfall and increased vegetation cover, leading to a reduced rate of aerosol resuspension.

### *3.4.8. Summer 2019 (01/06/2019 – 29/08/2019)*

In summer 2019, aerosol concentration and distribution followed a more consistent pattern compared to the summer of 2018. Aerosol levels increased slightly compared to the previous summer but saw a minor decline toward the end of the period. This trend might reflect the influence of climatic conditions, where hotter temperatures and wind contributed to aerosol spread, but other factors kept concentrations relatively stable.

### *3.4.9. Summer 2020 (01/06/2020 – 30/08/2020)*

Unlike the previous summer periods, aerosol concentration in summer 2020 was almost non-existent, as reflected in the graphs. The only noticeable increase occurred in July, but overall, the levels were remarkably low. This unusual trend might indicate a significant environmental or atmospheric change that reduced aerosol production or resuspension during this period.

### *3.4.10. Autumn 2019 (01/09/2019 – 01/11/2019)*

Aerosol concentration remained low overall during autumn 2019, although there was a slight increase in concentration toward the end of the period. This minimal variation suggests that while the season experienced stable aerosol levels, certain environmental factors may have caused a small uptick in aerosol spread as the season progressed.

### *3.4.11. General Interpretation*

The analysis of aerosol concentration and distribution across the years 2018 to 2020 indicates both seasonal variability and year-on-year changes. Seasonal patterns demonstrate that aerosol concentrations tend to decrease during colder and wetter periods (winter and spring), whereas summer and early autumn show higher levels, particularly in drier and windier conditions. Comparing 2018 and 2019 reveals a slight increase in overall aerosol activity, which declined significantly by 2020, especially during the summer months. This comprehensive analysis highlights the influence of climatic and environmental factors on aerosol distribution, suggesting a complex interaction between meteorological patterns and airborne particulate matter. Understanding these dynamics is crucial for assessing air quality and predicting potential future changes.

## 4. Discussion

In this study we used NASA Giovanni and remote sensing data through GEE for Dust Analysis in Northeast and East Iran. In this study, the spatial and temporal variations of wind speed, vegetation cover (using EVI), and dust particle concentrations in the eastern and Northeastern regions of Iran were analyzed. The results indicate that wind speed and vegetation cover have significantly impacted the intensity and dispersion of dust, confirming our first hypothesis. Areas with higher wind speeds, particularly in arid regions, experienced greater amounts of dust. These findings are consistent with the work of Li et al. (2020), which showed that arid regions with stronger winds are a major source of dust production in the Middle East.

The results also reveal a significant reduction in vegetation cover over the past four decades, particularly in areas that have experienced frequent droughts. This decrease in vegetation aligns with the findings of Al Ameri et al. (2019), who showed that severe droughts in arid regions lead to vegetation degradation and increased dust levels. These findings also confirm our second hypothesis; the reduction in vegetation due to droughts has been a major factor in the increase of dust levels in these areas over the past 40 years.

In this study, areas with lower EVI showed higher levels of dust. This indicates that reduced vegetation cover has led to a decrease in the soil's ability to maintain surface stability and an increase in dust. Similar studies, such as those by Song et al. (2024), have also concluded that vegetation plays a crucial role in controlling dust particle dispersion in arid regions.

Wind speed in the eastern regions of Iran is higher than in the northeastern regions, which aligns with the results of our meteorological models. Eastern Iran, with stronger winds and less vegetation cover, experiences higher amounts of dust. These findings are consistent with the results of Zhang et al. (2023), who examined the direct relationship between wind and dust dispersion in arid regions worldwide.

The results indicate that with the reduction in vegetation due to droughts, dust levels in the eastern and northeastern regions of Iran have increased. Additionally, the analysis of wind patterns shows that areas with stronger winds, particularly during drier seasons, have experienced higher dust levels. These results highlight the importance of managing natural resources, especially vegetation, to mitigate the effects of dust in these regions. The findings of this study align with previous research in this field and illustrate the severe impacts of climate change and natural resource degradation on increasing dust levels in arid regions of Iran.

## 5. Conclusion

In this study, we utilized NASA Giovanni and GEE platforms to analyze the spatiotemporal variations of dust intensity and distribution across eastern and northeastern Iran over a 40-year period. Key climatic and environmental variables, including wind speed and vegetation cover, were examined to understand their relationship with dust storms in these regions.

Our findings confirm the first hypothesis that wind speed and vegetation cover significantly influence the intensity and distribution of dust storms. Areas experiencing higher wind speeds and lower vegetation cover were associated with more frequent and severe dust events. This supports prior research by Liu et al. (2024), who found similar trends in arid regions. Moreover, the study highlights that vegetation, particularly in regions prone to drought, plays a critical role in mitigating dust intensity by stabilizing the soil and reducing erosion.

The second hypothesis, suggesting that the decline in vegetation due to prolonged droughts has led to increased dust levels, was also supported. Over the past four decades, consistent decreases in vegetation cover, as shown through EVI analysis, were strongly correlated with the rise in dust intensity, particularly in arid areas. This finding is in line with studies such as Song et al. (2024), which emphasize the relationship between desertification and dust activity in dry regions.

In addition, the temporal analysis revealed that dust activity has increased significantly during the latter decades of the study, particularly in regions experiencing the most severe droughts. These results suggest that future climate conditions, if not addressed, will likely exacerbate dust storm frequency and severity, posing increased risks to both the environment and human health.

Based on the findings of this study, several recommendations are proposed for mitigating dust storms and their impacts in eastern and northeastern Iran:

Vegetation Restoration Programs: Given the critical role of vegetation in controlling dust storms, efforts should be made to rehabilitate degraded lands through afforestation and reforestation initiatives. Drought-resistant plant species, capable of thriving in arid environments, should be prioritized to maximize the stabilizing effects on the soil.

Sustainable Water Management: With the strong link between drought and dust storms, sustainable water management strategies must be implemented to reduce the adverse effects of water shortages on vegetation. Policies aimed at preserving groundwater resources and optimizing irrigation systems can help prevent further degradation of green cover in these regions.

Wind Erosion Control Measures: In areas most affected by high wind speeds, the installation of windbreaks, barriers, and protective vegetation should be implemented to reduce soil erosion. These measures have proven effective in other regions and should be adapted to the local conditions of Iran's dust-prone areas.

Enhanced Climate Monitoring: Continuous monitoring of climatic variables such as wind speed, vegetation cover, and precipitation patterns is essential for early detection and mitigation of dust storm events. Utilizing remote sensing technologies, such as those used in this study, can provide valuable insights for developing more effective dust storm management policies.

Policy and Community Engagement: Engaging local communities in dust mitigation efforts is crucial. Awareness campaigns and educational programs on the impacts of dust storms and the importance of sustainable land use practices can lead to greater community involvement and long-term success in reducing dust activity.

In conclusion, the results of this study underscore the importance of integrated environmental management strategies in controlling dust storms in arid regions of Iran. By addressing both climatic and anthropogenic factors, future policies can mitigate the negative impacts of dust storms, improve air quality, and promote sustainable development in these vulnerable regions.

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**Consent to Publish** (Authors consent to publishing)

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

**Code availability** (Access code to the web-based software of Google Earth Engine Dust study of the study area in East and Northeast of Iran ) https://code.earthengine.google.com/f0293c476336680a215933a0211df297

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