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Tracking Air Pollution Changes Using Sentinel-5P Data in Khuzestan

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ABSTRACT

Air pollution represents a significant challenge in Middle Eastern countries and has notably impacted the western regions of Iran, specifically the province of Khuzestan. The identification of pollution production centers and the spatial distribution and patterns of pollution are crucial for effective management. Limited synoptic ground stations and challenging data accessibility make it difficult to precisely monitor air pollution across various regions. Remote sensing, however, offers a viable solution for obtaining reliable air pollution information through time series analysis. This study utilized Sentinel-5P satellite image products and data from synoptic stations in Khuzestan province. Leveraging the Google Earth Engine system, the research identified atmospheric pollutants including NO2, CO, UV-Aerosol, and SO2 over a period of one year from January 2022 to January 2023. Subsequently, maps displaying the concentration of atmospheric pollutants were generated, visually representing pollutant concentrations through color-coded layers. Monthly fluctuations in NO2, CO, UV-Aerosol, and SO2 levels were graphed, revealing seasonal variations in pollutant concentration. The results indicated that NO and CO showed higher concentrations during spring and summer, while UV-Aerosol exhibited peak concentrations in spring. Additionally, the months of September and October highlighted the highest concentration of SO2 in the central and southwest regions of Khuzestan province. The research findings further illustrated an increase in pollutant levels from central areas to the south and southwest regions of the province. Finally, ground data from synoptic stations were utilized to validate the results.

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1. Introduction

Air pollution (AP) poses a significant threat to public health, giving rise to new health and hygiene complications that result in increased costs for developing countries (Kazemi Garajeh *et al.,* 2023). Various factors contribute to air pollution, exerting detrimental effects on the health of living organisms (Safarianzengir *et al.,* 2020), and representing a crucial environmental issue, especially in technologically advanced and developing nations (Meetham *et al.,* 2016). Based on World Health Organization (2024) Pollution categorization is based on physical state (solid, liquid, gas) and emission sources (mobile, fixed, natural, man-made). Human activities, including industrial operations, transportation advancements, and chemical concentration, exert a significant influence on climatic conditions and atmospheric changes (Halder *et al.,* 2021*;* Halder *et al.,* 2023).

The most notable air pollutants encompass carbon monoxide (CO), sulfur dioxide (SO2), nitrogen dioxide (NO2), and aerosols (AI) (Tahmasbi *et al.*, 2009). The World Health Organization (WHO) has underscored that around 99% of the global population is subject to high levels of air pollution, resulting in approximately 7 million annual fatalities due to pollutant exposure and low- and middle-income countries suffering from the highest exposures(Saxena and Naik, 2018). Furthermore, air pollution poses a threat to individuals of all age groups, especially children (Vidotto *et al.*, 2012), leading to complications such as cardiovascular diseases (Cesaroni *et al.*, 2014) and reproductive disorders (Sager, 2019). Overall, air pollution is linked to premature mortality, particularly in highly industrialized countries (Ialongo *et al.,* 2020).

Key airborne pollutants encompass sulfur dioxide (SO2), carbon dioxide (CO2), carbon monoxide (CO), nitrogen oxides (NO2), ozone (O3), methane (CH4), volatile organic compounds, chlorofluorocarbons (CFCs), and suspended particles or aerosols (Saxena and Naik, 2018). Notably, nitrogen dioxide (NO2), carbon monoxide (CO), and aerosol optical depth (AOD) are pivotal in gauging air quality, given their substantial impact on the environment and human health (Caiazzo *et al.*, 2013).

In the past years, the western regions of Iran have been heavily affected by various air polluting phenomena, such as fine dust, due to their neighborhood with desert areas. One of the most damaged areas is Khuzestan province, which is in the danger zone for many days of the year (Ghaderi and Azizi, 2019 and 2020).

It's amazing to see the significant impact and potential of using remote sensing techniques in monitoring air pollution, as mentioned in the examples referenced. The capability to leverage satellite imagery, such as the Sentinel-5P data, to analyze and understand the changes in air quality and pollution levels brings to light an important aspect of environmental research and public health.

The research conducted by Safarianzengir *et al.* 2020, that focused on monitoring the carbon monoxide levels in Iran using Sentinel-5P satellite data offers valuable insights into the spatial distribution of air pollutants, particularly in regions undergoing significant environmental challenges. the results obtained from southwestern Iran indicate that a large part of the west of Khuzestan province with values of 0.33 mol/m2 more exposed to air pollution (carbon monoxide). They also stated that the highest amount of pollution occurs in the winter due to the use of fossil fuels and the phenomenon of air inversion. Meanwhile, summer pollutants are more dangerous to human health because they are based on nitrogen and sulfur (Safarianzengir *et al.,* 2020). By emphasizing the use of remote sensing and satellite imagery, the study aims to provide a comprehensive understanding of the concentration and distribution of pollutants, focusing on "CO", "SO2", "NO2", and "AI" in the meteorological stations of Khuzestan province for the period from January 2022 to January 2023.

The emphasis on monitoring and understanding the changes in air pollutant concentrations over time in a region heavily impacted by various air pollution phenomena, such as the fine dust often associated with desert areas, underscores the critical need to address and mitigate the effects of increasing urbanization and population growth on air quality.

2. Materials and Methods

2.1 Study Area

The study area is situated at approximately 47°E and 30°N and encompasses Khuzestan province—the fifth most populous province in Iran spanning 640,057 square kilometers. Located in the southwest of Iran, it borders the Persian Gulf and the Arvand River. The province experiences a dry climate attributed to the arid winds originating from the adjacent Arabian Peninsula(Fig. 1), which contribute to its desert climate (Ghaderi and Azizi, 2021).

Khuzestan province generally exhibits a semi-desert climate with dry and hazy summers and is recognized for its high temperatures, particularly in Khuzestan and its adjacent coastal areas.

The region is characterized by two distinct terrains: mountainous and low-lying plains. The mountainous and elevated areas experience mild summers and cold winters, while the foothill areas exhibit a semi-desert climate. As one progresses southward and southwestward to the low-lying plains, the climate shifts from semi-desert to desert.

Overall, winters in this area are brief and mild, whereas summers are prolonged and hot. Vegetation in Khuzestan province is profoundly influenced by two critical climatic factors—temperature and humidity—resulting in three primary categories: forests and trees, natural plants and shrubs, and pastures, which collectively represent the predominant and distinctive vegetation types in the region. Notably, the province is home to approximately 500 thousand hectares of forest and 2.5 million hectares of pastureland.

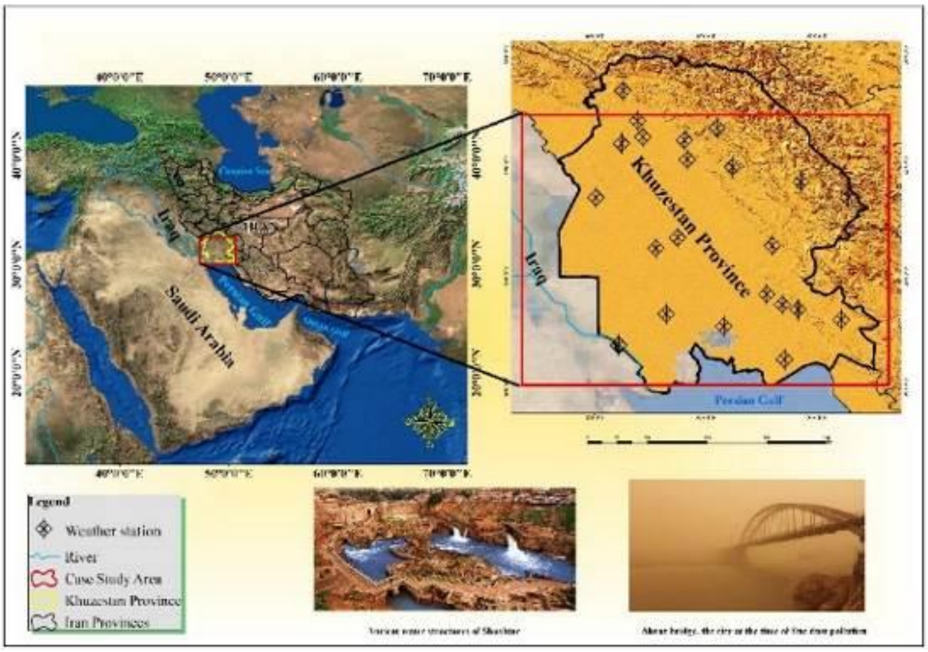

Fig. 1. Geographical location of the Study area

2.2 Data

The Sentinel-5P satellite, launched by the European Space Agency on October 17, 2017, is positioned at an altitude of 824 km, enabling high spatial and temporal resolution measurements of atmospheric layers. The satellite mission is primarily focused on monitoring air quality and atmospheric constituents. Equipped with sensors for ultraviolet, visible, short-infrared, and short-wavelength infrared bands, Sentinel-5P's monitoring capabilities extend to various air pollutants. This includes a sampling width of 50 km for wavelengths above 300 nm and 8 km for those below 300 nm (Purwadi *et al.*, 2020; Rohi *et al.*, 2020; Tahmasbi *et al.*, 2009).

In Khuzestan province, 22 synoptic stations provide ground-level data. The challenges posed by the temporal and spatial variability of air pollutants, irregular ground-level sampling, and associated logistical costs underscore the limitations of acquiring comprehensive air pollution data across different regions. Remote sensing, especially through the usage of satellite images with nationwide coverage, has emerged as a valuable approach for investigating air pollution. Notably, this research leverages image products from the Sentinel-5P satellite for air pollution monitoring.

2.3 Method

Nitrogen dioxide, carbon monoxide and aerosol optical depth (AOD) are important for measuring air quality because these air pollutants are more harmful to the environment and human health (Halder *et al.,* 2023). And as a result, it is a serious threat to the health of society. Using remote sensing techniques is one of the most efficient methods to study pollution in the atmosphere (Cesaroni *et al.,* 2014; Li, 2020).

This research represents a non-interventional and descriptive-analytical study. The Google Earth Engine (GEE) system, utilizing the JavaScript programming language, was employed to monitor atmospheric pollutants. Image products linked to carbon monoxide (CO), sulfur dioxide (SO2), nitrogen dioxide (NO2), and UV-Aerosol pollutants from the Sentinel-5P satellite were selected and processed within the Google Earth Engine system.

For the continuous monitoring of atmospheric pollutants in the troposphere layer of the earth using the Google Earth Engine system, the polygon of the studied area was called. Then, the products related to atmospheric pollutants UV-Aerosol, CO, NO2, and SO2 were obtained according to the data recorded in the synoptic stations and ten days from November 1, 2022, to November 10, 2022. The map of the concentration of air pollutants was obtained separately with the average concentration of ten days and the concentration of pollutants was displayed with the method of color combination Dataset Visualization parameters.

Spatial maps displaying the concentration of air pollutants for each specific period (in this case, averaged over ten-day intervals) were created while utilizing a color-combination method to visually represent pollutant concentrations. Temporal and spatial changes were further observed through monthly charts spanning the one year, offering insight into the average concentrations of pollutants and aerosols over the course of the year. Ground-recorded data obtained from the 22 synoptic stations in Khuzestan province were utilized to validate observed trends in atmospheric pollutants, ensuring alignment and verification of the findings (Fig. 2).

The study's focus on validating the remote sensing data with ground synoptic stations demonstrates a robust and comprehensive approach. Combining the strengths of satellite-based observations with ground measurements helps ensure the accuracy and reliability of the findings, enhancing the overall credibility of the research.

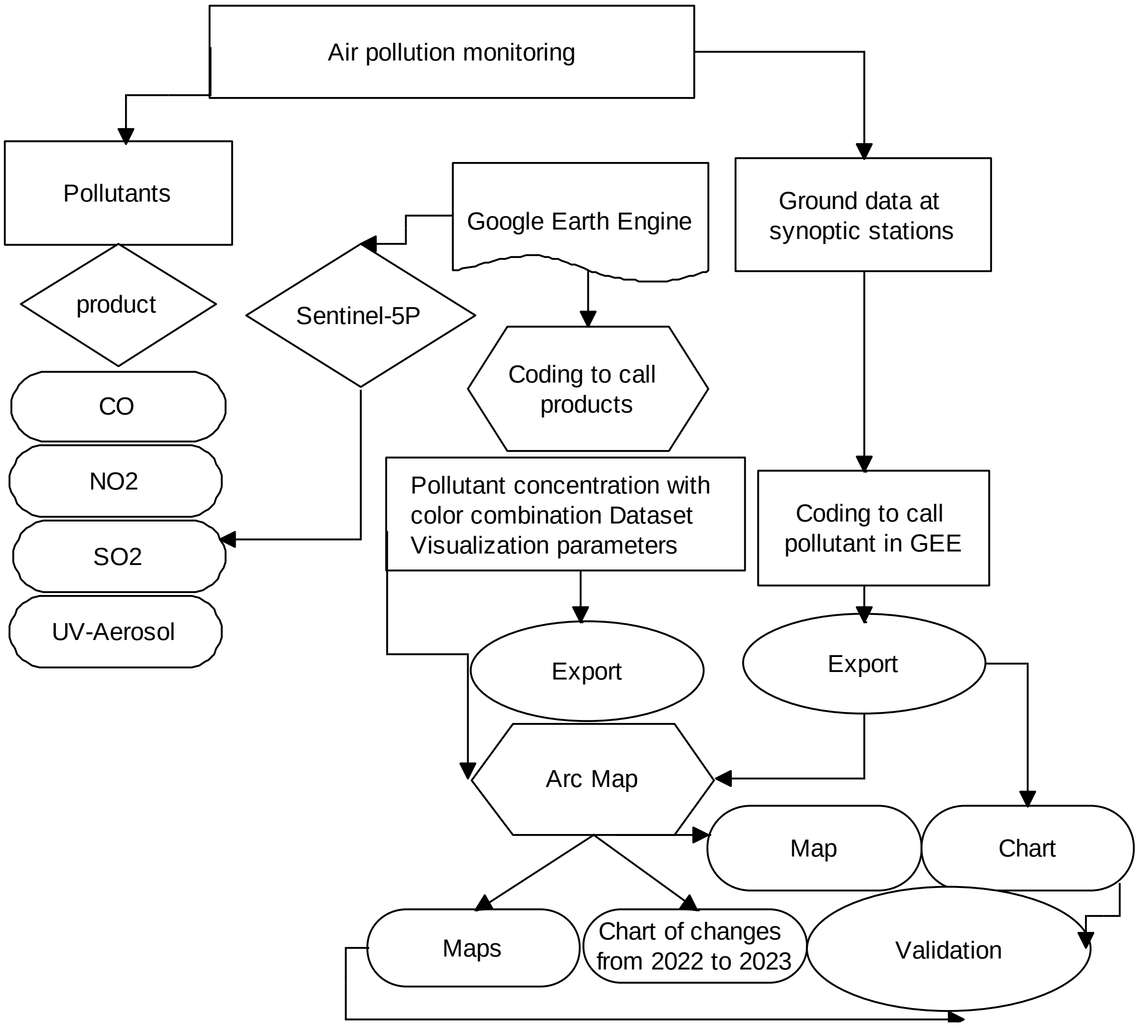

Fig. 2. An overview of the methodology used for AP monitoring

3. Results

The investigation into four specific pollutants in the study area, derived from Sentinel-5 images, has proven instrumental in identifying pollution centers and mapping the distribution and average concentration of pollutants across Khuzestan province, shedding light on the sources of pollution.

3.1 Geospatial Distribution

The visualization of the spatial concentration of pollutants has revealed significant patterns. Aerosol concentration, for instance, is notably pronounced in the central, western, and southwestern sectors of the province. Ground station data suggests that aerosol levels are higher in the western region, indicating potential origins from neighboring areas, potentially imported from Iraq. Meanwhile, heightened concentrations of nitrogen dioxide (NO2) in the province's center, as well as prominent levels of NO2 in the eastern portion of Iraq, have been observed. Carbon monoxide (CO) concentration presents notable peaks in populous and trafficked zones such as Ahvaz, Abadan, and Shadgan. Furthermore, sulfur dioxide (SO2) levels exhibit substantial concentrations in the western and southwestern regions of the province and the eastern Iraqi territory (Fig 3, 4).

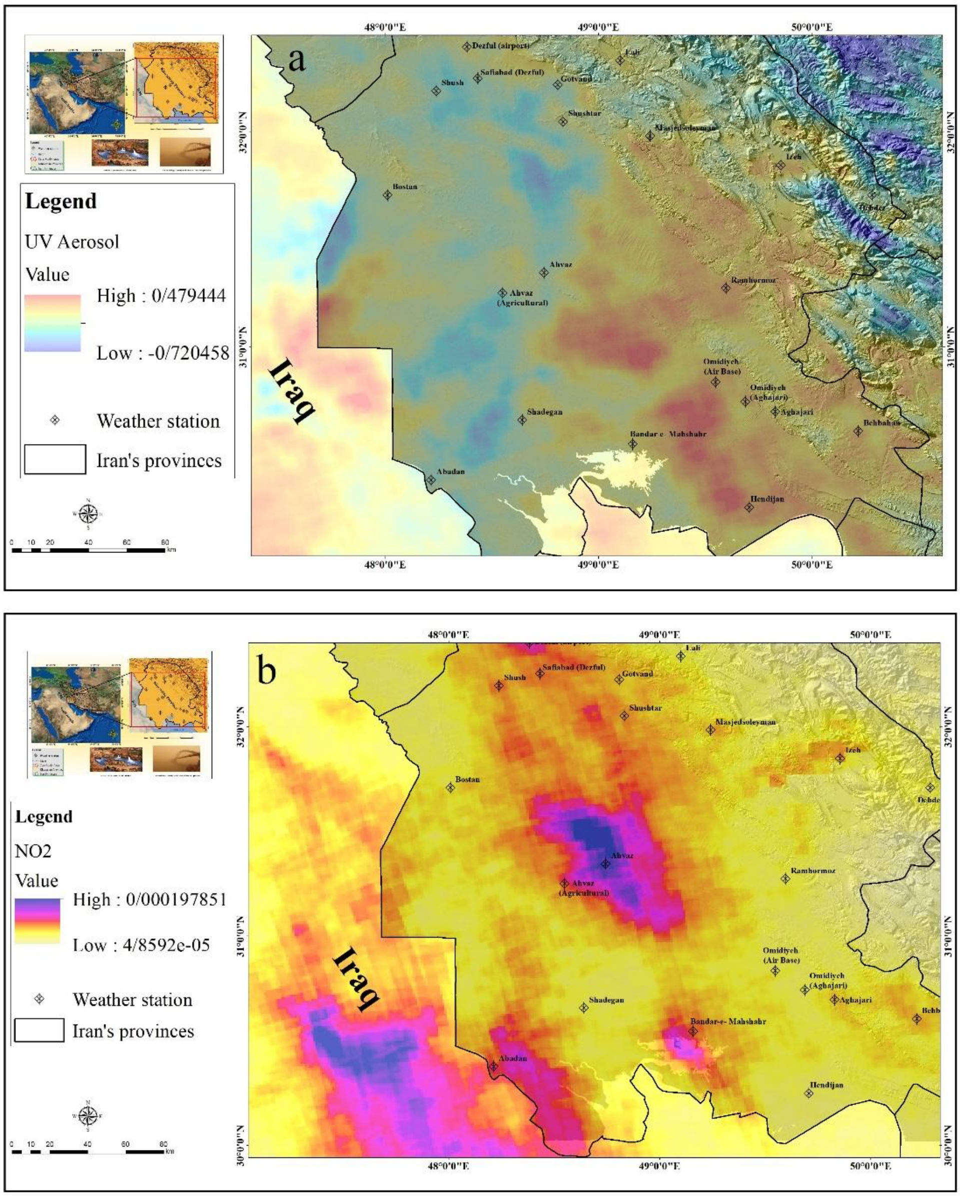

Fig. 3. a) UV-Aerosol pollutant distribution b) NO2 pollutant distribution

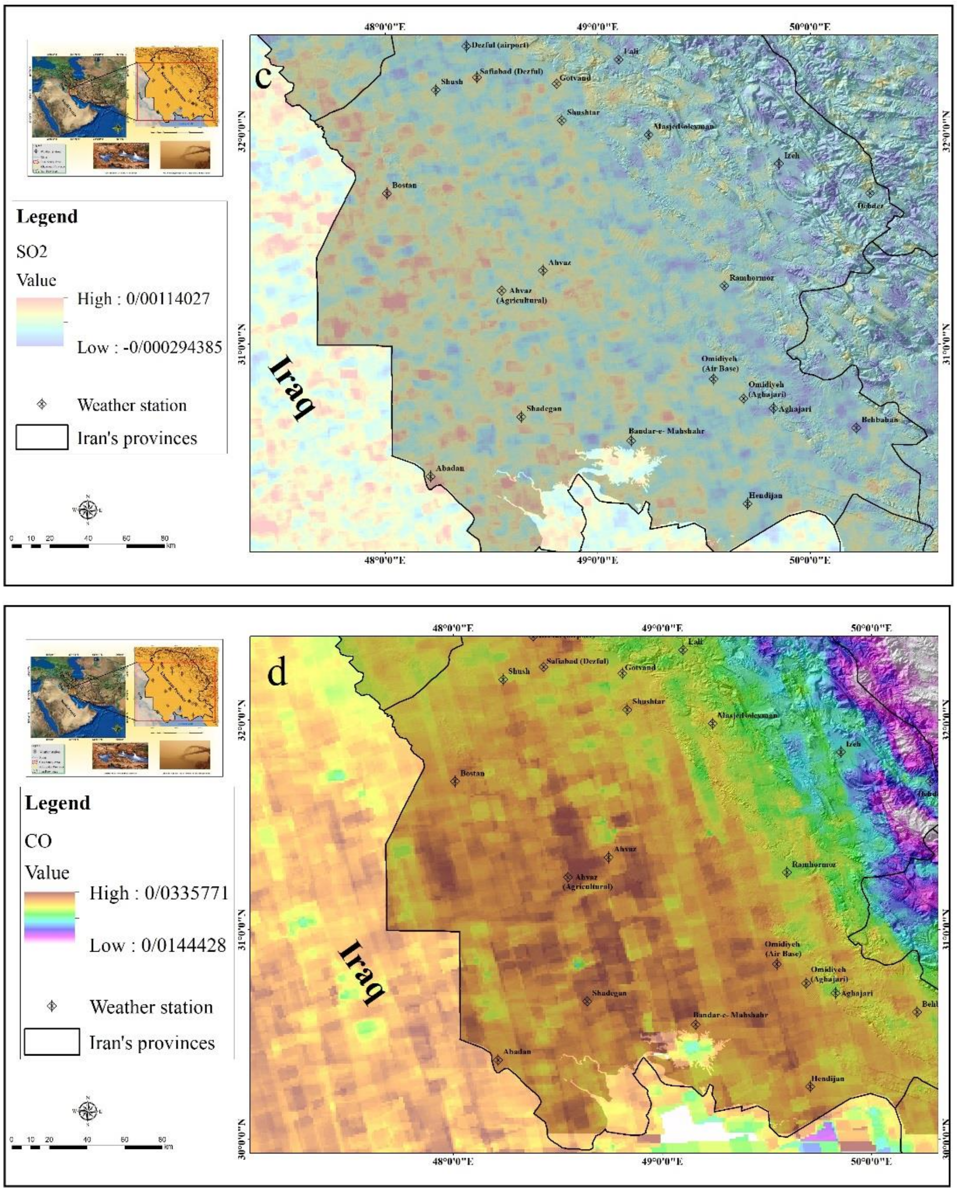

Fig. 4. c) CO pollutant distribution d) SO2 pollutant distribution.

3.2 Temporal Trends

The monthly variations of atmospheric pollutants offer further insights. Aerosol concentrations peaked during the spring season, particularly in May, resulting in significantly reduced horizontal visibility, reaching as low as 100 meters. Analysis of NO2 fluctuations indicates elevated concentrations during spring and summer, followed by a decreasing trend during the transition from summer to autumn. The average monthly changes in CO levels demonstrate a peak between May and September, with decreasing concentrations in March and April, reaching the lowest point in November. Similarly, SO2 concentrations showed varied trends, notably increasing during the spring and summer seasons (Fig 5-6).

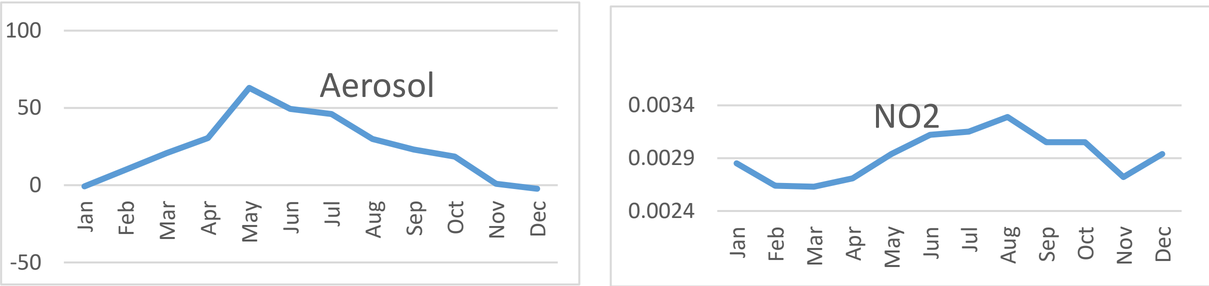

Figure 5. Chart of monthly UV-Aerosol, NO2 changes from January 2022 to January 2023.

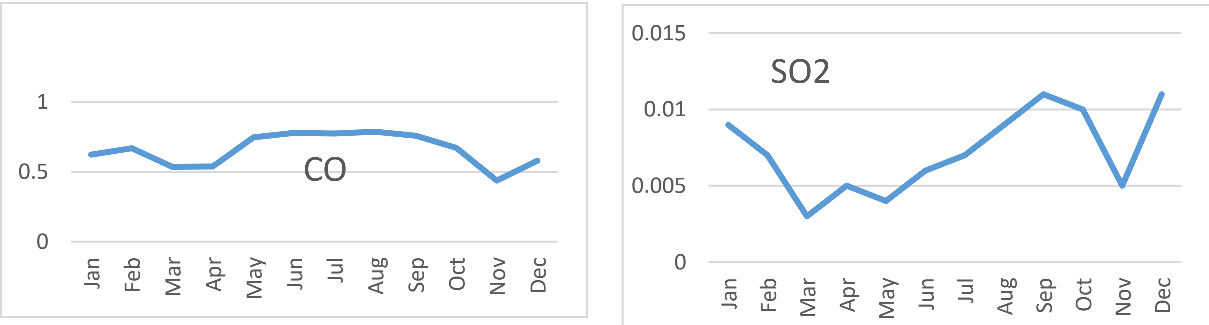

Figure 6. Chart of monthly CO, and SO2 changes from January 2022 to January 2023.

3.3 Validation and Ground Data

The application of ground data from meteorological stations within Khuzestan province effectively validated findings, especially in recording a dust event with reduced visibility in Ahvaz, Shadgan, Handijan, Abadan, and Omidiyeh on October 1-3, 2022, at specific hours. Utilizing the Google Earth Engine environment, a three-day graph and spatial map of aerosols were successfully aligned with ground station results, ultimately confirming the accuracy of the findings (Figs 7 and 8).

The implementation of remote sensing techniques in the study of air quality and pollution monitoring has not only facilitated convenience but also enhanced affordability. This research attests to the efficacy of these advancements in bolstering pollution monitoring and analysis.

This research affirms the substantial impact of utilizing Sentinel-5P imagery and remote sensing techniques in monitoring air pollutants. The comprehensive delineation of spatial and temporal variations in pollutants has illuminated crucial insights for understanding and addressing air quality challenges in Khuzestan province. Furthermore, the successful validation of findings using ground-based data underscores the robustness of this research approach.

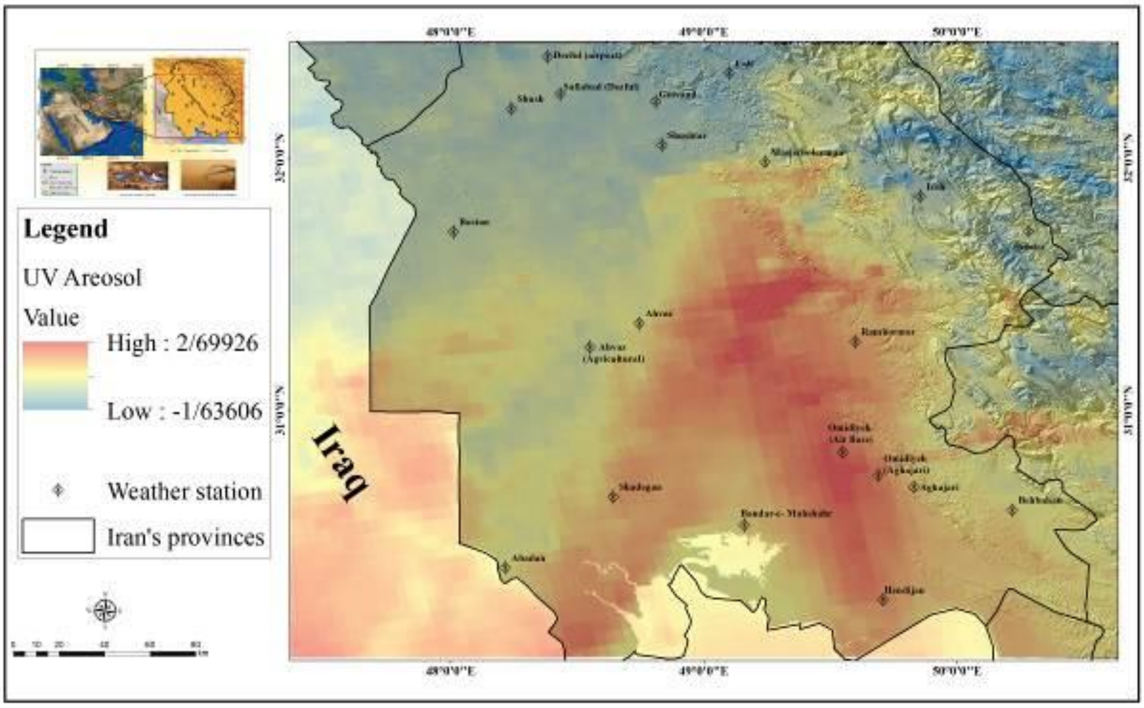

Fig. 7. Validation map of aerosols with synoptic station data

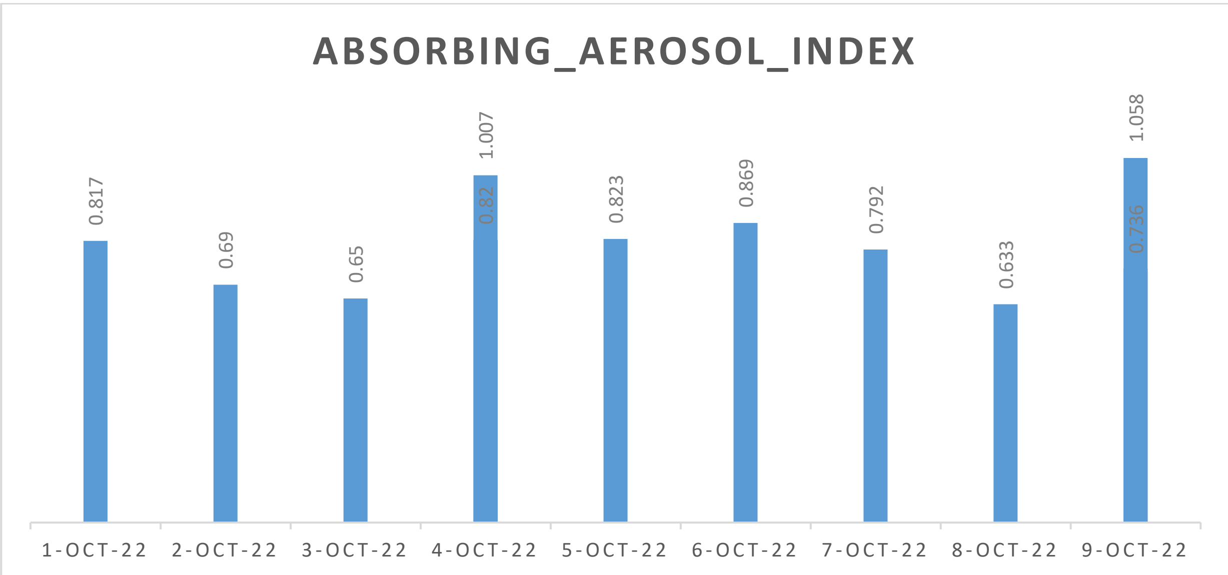

Fig. 8. Aerosols concentration chart according to synoptic station data

4. Discussion

The geographic positioning of Iran within subtropical high-pressure currents leads to the formation of hot and arid air masses, causing widespread dryness and dust storms in southwestern Iran. A combination of natural and human factors, such as droughts, dam construction, agricultural activities, and conflicts, exacerbate the severity of dust-related crises in Khuzestan province. Airborne particulate matter from neighboring countries like Saudi Arabia and Iraq also affects the region's air quality (Rivandi *et al.*, 2013; Rshnv, 2009;

Tahmasbi *et al.,* 2009).

Studies have shown a significant level of air pollution in the border areas with Iraq, especially in regions where oil resources are located. Changes in aerosol emissions from oil wells and refineries contribute to air pollution in Iraq. Exceeding permissible gas concentration levels due to air pollution can have adverse effects on human health and the environment, highlighting the need for effective air pollution monitoring and management strategies (Al-Mshhadani and Ubaidy, 2023; Kazemi Garajeh *et al.,* 2023; Halder *et al.,* 2023).

Remote sensing technology, combined with automated methods like the Google Earth Engine, offers more precise and insightful data for air pollution mapping and monitoring compared to traditional ground-based methods. Research on air pollution underscores the importance of studying air quality dynamics in shaping future planning and management strategies to ensure planetary well-being.

In Khuzestan province, external and internal pollution sources contribute to unfavorable air quality conditions, with local sources like oil industries playing a significant role in perpetuating air pollution. The concentration of PM2.5 pollutants is particularly high in the province's southern and central sectors due to the density of industrial facilities, power plants, and vehicular emissions. Reducing emissions from these sources could help improve air quality in the region.

5. Conclusion

In conclusion, the findings of this study suggest that air pollution is a risk that can easily spread from one country to another due to the fluid nature of the air. The maps produced in this study demonstrate that Khuzestan province in Iran has been heavily impacted by environmental and human pressures, as well as pollution imported from neighboring countries and industrial activities. Living in this area has become increasingly difficult for its residents.

Previous research has shown that Sentinel 5 images with temporal and spatial resolution are effective for investigating air pollutants. The distribution of atmospheric pollutants in the south and southwest of Khuzestan province, particularly in areas such as Ahvaz, Abadan, Shadgan, Omidiyeh, and Handijan, is evident on the map of the southwest border of the country. Weather conditions, population density, and topography are all factors that influence the spread, concentration, and distribution of pollutants.

The validation map of aerosol centers in the southwest of Iran indicates that the eastern regions of Iraq have more aerosol centers. Additionally, changes in the average concentration of atmospheric pollutants from 2022 to 2023 show that NO2 and CO have their highest concentrations from May to October, while UV-Aerosol has its highest concentration in May, June, and July. Furthermore, September and October show the highest concentration of SO2 in the center of Khuzestan province and Ahvaz city.

Author contributions

Behnaz Ghaderi, Payam Alemi Safaval, and Zahra Azizi conceived the ideas and designed the methodology; Behnaz Ghaderi and Payam Alemi Safaval managed and analyzed the data; Mohammad Reza Tabesh and Zahra Azizi rewrote the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Data Availability Statement

Data will be made available on request.

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There are no items to report.

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Conflict of interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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