Monitoring Trends of SO_2 level Using Time-Series Sentinel-5 Images Based on Google Earth Engine

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Abstract. This research delves into an extensive examination of Sulphur dioxide (SO_2) column density patterns within the Tashkent region, Uzbekistan, employing advanced spatial analysis techniques facilitated by Google Earth Engine (GEE) and leveraging high-resolution Sentinel-5P satellite data. The investigation spans the critical years of 2019 and 2023, meticulously scrutinizing monthly maximum and mean SO_2 values to elucidate nuanced temporal trends and spatial distributions. The comprehensive analysis divulges a multifaceted narrative of air quality dynamics, particularly unveiling pronounced spatial heterogeneity in SO_2 emissions across the Tashkent region. Notably, the southern expanse emerges as a focal point of heightened SO_2 concentration, prominently linked to the extensive presence of industrial complexes and manufacturing facilities. Moreover, a distinct circular pattern of elevated SO_2 concentrations concentrically encircling the capital city, Tashkent. This spatial anomaly is attributed to a numerous of anthropogenic factors, prominently including the combustion of fossil fuels within greenhouse infrastructures, compounded by the escalating vehicular emissions stemming from the increasing urban populace and its concomitant resource consumption patterns.

1. Introduction

In the pursuit of sustainable development and environmental stewardship, monitoring air quality has emerged as a critical endeavor, resonating with the Sustainable Development Goals (SDGs) set forth by the United Nations. Specifically, SDG Goal 11, which aims to ensure sustainable cities and communities, and SDG Goal 13, targeting climate action, underscore the imperative of mitigating air pollution and its detrimental impacts on human health and the environment [1].

In recent years, advances in remote sensing technology have revolutionized the monitoring and assessment of atmospheric pollutants, with sulfur dioxide (SO_2) being of particular concern due to its adverse effects on respiratory health and its role in acid rain formation [2]. Platforms like TROPOMI (TROPOspheric Monitoring Instrument) have provided invaluable insights into global SO_2 emissions, offering high-resolution data that enable detailed analyses of pollutant distribution and trends [3,4].

A wealth of literature has underscored the efficiency and efficacy of remote sensing, especially utilizing data from the Sentinel-5P satellite, in monitoring air quality parameters such as SO_2 concentration. Sentinel-5P, part of the European Union's Copernicus program, offers unprecedented spatial and temporal coverage, facilitating comprehensive assessments of pollutant levels on a global scale [5,6].

Moreover, the utilization of Google Earth Engine (GEE) has emerged as a cornerstone in the monitoring and visualization of air quality metrics, including SO_2 column density [7]. GEE's robust capabilities in processing large-scale geospatial data sets, coupled with its user-friendly interface, have streamlined the analysis process, enabling researchers to derive actionable insights with unparalleled efficiency [8,9].

The Central Asian region, including Uzbekistan and the Tashkent region, faces unique challenges [10–12] concerning air quality management. Rapid industrialization, coupled with urbanization[13] and population growth, has accentuated pollution levels [14], necessitating concerted efforts for environmental monitoring and mitigation [15,16]. Central Asian countries have recognized the significance of collaborative endeavors in addressing shared environmental concerns [17–

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19], fostering initiatives for regional cooperation and knowledge exchange in air quality monitoring and management [20].

Both naturally occurring mechanisms and man-made ones allow Sulphur dioxide to reach the Earth's atmosphere. It influences everything from short-term pollutants to the climate. It is involved in chemistry both locally and globally. Anthropogenic sources account for the majority of SO_2 emissions, with just around 30% coming from natural sources. Sentinel-5P/TROPOMI enables the resolution of minute features, such as the identification of tiny SO_2 plumes, by sampling the Earth's surface with a revisit time of one day and a spatial resolution of 3.5 x 7 km. mole/m^2 (mol per square meter) is the unit of measurement used [21,22].

In this research, we aim to leverage the wealth of data provided by Sentinel-5P satellite observations and the analytical capabilities of Google Earth Engine to conduct a detailed assessment of sulfur dioxide (SO_2) levels in the Tashkent region of Uzbekistan. Our primary objective is to elucidate the spatial and temporal patterns of SO_2 emissions, particularly focusing on the southern industrial zones and the circular concentration around Tashkent city, shedding light on the sources and dynamics of air pollution in the region [23].

Future research endeavors may expand the scope of analysis to encompass additional air pollutants, such as nitrogen dioxide (NO_2) and particulate matter (PM2.5), enabling a comprehensive assessment of air quality dynamics and pollutant interactions.

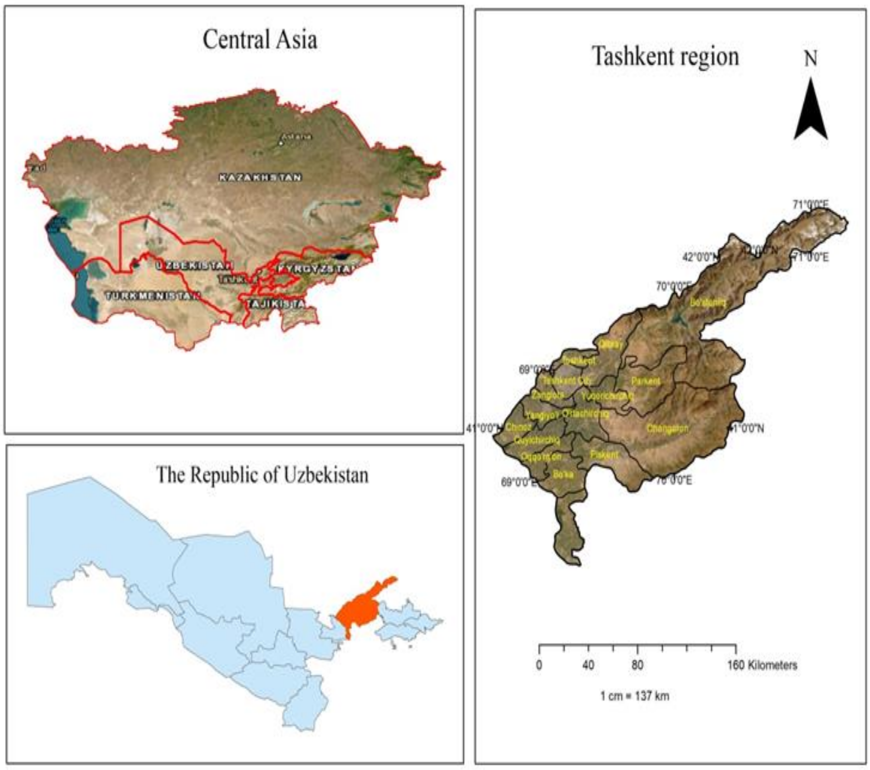

Fig. 1. Location of the study area

2. Methodology

2.1 *Study Area*

The Tashkent Region has boundaries with the Kyrgyz Republic to the northeast, the Republic of Tajikistan to the south, the Namangan Region to the east, the Republic of Kazakhstan to the north and northwest, and the Syrdarya Region to the southwest. The total area is 15.3 thousand km², excluding the territory of Tashkent city. Over 3 million people live there as of 2023.

2.2 Data Acquisition

Utilizing the 'COPERNICUS/S5P/NRTI/L3_SO2' Image Collection available in GEE, data for the year 2019 is retrieved, filtered based on the defined study area and time range ('2019-01-01' to '2019-12-31') and ('2023-01-01' to '2023-12-31'). The 'SO_2_column_number_density' band is selected for further analysis. A time series chart is generated using the 'ui.Chart.image.series' function, depicting the variation in SO_2 concentration over time. The chart is customized with axis titles and a title reflecting the parameter being visualized.

Table 1. Sentinel-5P/TROPOMI measurement bands and resolutions summary [21]

Band Name	Description	Spatial Resolution
UV Aerosol Index	Measure of UV aerosol absorption	~7x7 km
AAI (Absorbing Aerosol Index)	Quantifies absorbing aerosols in the atmosphere	~3.5x7 km
Cloud Fraction	Fraction of sky covered by clouds	~3.5x7 km
Ozone (O_3)	Total column ozone concentration	~3.5x7 km
Nitrogen Dioxide (NO_2)	Total column nitrogen dioxide concentration	~3.5x7 km
Sulphur Dioxide (SO_2)	Total column sulfur dioxide concentration	~3.5x7 km
Carbon Monoxide (CO)	Total column carbon monoxide concentration	~3.5x7 km
Methane (CH_4)	Total column methane concentration	~7x7 km
Formaldehyde (HCHO)	Total column formaldehyde concentration	~7x7 km
Tropospheric Ozone (O_3)	Tropospheric ozone concentration	~3.5x7 km
Aerosol Layer Height	Height of aerosol layer above ground level	~3.5x7 km
Cloud Top Pressure	Pressure at the top of cloud layer	~3.5x7 km
Cloud Top Height	Height of cloud top above sea level	~3.5x7 km
Cloud Optical Thickness	Thickness of clouds	~3.5x7 km
Cloud Albedo	Reflectivity of clouds	~3.5x7 km

The time series chart and spatial visualization of SO_2 concentration facilitate the identification of temporal trends and spatial patterns in air pollution levels within the Tashkent region. The analysis sheds light on the seasonal variability and potential sources of SO_2 emissions, providing valuable insights for environmental monitoring and policymaking. Leveraging Sentinel-5P satellite data and GEE analytics offers several advantages, including the ability to conduct large-scale spatial analyses and temporal assessments with high accuracy and efficiency. This methodology enables comprehensive monitoring of air quality parameters, facilitating timely decision-making and environmental management. The methodology presented herein holds significant implications for environmental monitoring and management in Central Asian countries. By leveraging remote sensing technology, countries like Uzbekistan can enhance their capacity for air quality monitoring, contributing to regional efforts aimed at addressing shared environmental challenges.

3. Results and Discussion

The analysis of sulfur dioxide (SO_2) concentrations in the Tashkent region, conducted using Sentinel-5P/TROPOMI data and Google Earth Engine (GEE) analytics, revealed noteworthy spatial and temporal patterns indicative of air pollution dynamics within the study area (Figure 2). The examination spanned the critical years of 2019 and 2023, providing a comprehensive understanding of SO_2 column density patterns over time. The investigation uncovered pronounced spatial heterogeneity in SO_2 emissions across the Tashkent region, with the southern expanse emerging as a focal point of heightened concentration. This phenomenon was prominently linked to the extensive presence of industrial complexes and manufacturing facilities in the region. Notably, a distinct circular pattern of elevated SO_2 concentrations concentrically encircled the capital city, Tashkent, indicating a localized source of pollution. Anthropogenic activities, including the combustion of fossil fuels within greenhouse infrastructures and escalating vehicular emissions stemming from the increasing urban populace, were identified as key contributors to the observed spatial anomalies in SO_2 concentrations. The findings underscore the intricate interplay between human activities and air quality dynamics in the Tashkent region, highlighting the need for targeted interventions to mitigate the adverse effects of air pollution. Overall, the results of the analysis provide valuable insights into the spatial and temporal trends of SO_2 pollution in the Tashkent region (Figure 3), facilitating informed decision-making and policy formulation aimed at improving air quality and safeguarding public health.

3.1 Spatial Distribution of SO_2 Concentrations

Spatial visualization of mean SO_2 concentrations depicted distinct patterns across the Tashkent region. Particularly, elevated SO_2 levels were observed in the southern part of the region, coinciding with the presence of industrial zones and manufacturing plants. This spatial clustering of SO_2 emissions underscores the significant contribution of anthropogenic activities to air pollution burdens in industrialized areas.

Figure 2 illustrates the spatial distribution of sulfur dioxide (SO_2) concentration across the Tashkent region for the respective years. In 2023, there is observable expansion and a moderate increase in SO_2 concentration compared to 2019. This suggests a potential escalation in air pollution levels over the study period, possibly influenced by factors such as industrial activities, vehicular emissions, and changing socio-economic dynamics. The spatial analysis provides valuable insights into the temporal trends of SO_2 pollution, aiding in the assessment of air quality dynamics and the formulation of targeted mitigation strategies to address environmental concerns in the region.

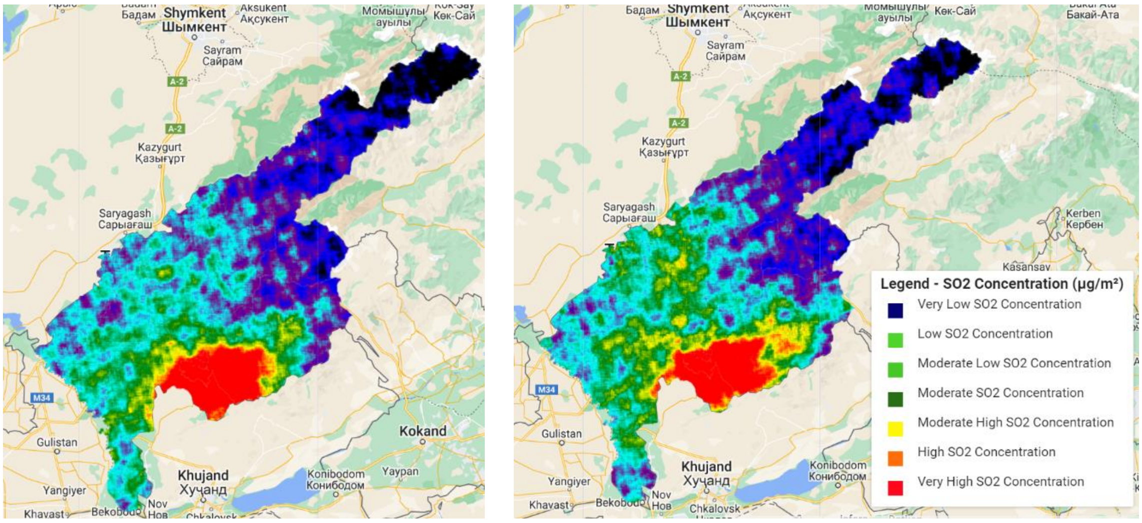

Fig. 2. Temporal comparison of annual mean SO_2 concentration: 2019 (left) and 2023 (right)

Moreover, a circular pattern of heightened SO_2 concentrations surrounding Tashkent city was identified, indicative of localized pollution sources. The circular shape suggests the influence of vehicular emissions and fossil fuel combustion, attributed to urbanization and population growth in the capital city.

3.1Temporal Trends in SO_2 Concentrations

The time series analysis revealed temporal variability in SO_2 concentrations over the study period. Monthly fluctuations in SO_2 levels exhibited seasonal trends, with peak concentrations observed during certain months. This temporal variability reflects seasonal variations in meteorological conditions, industrial activities, and vehicular emissions, highlighting the dynamic nature of air pollution in the region.

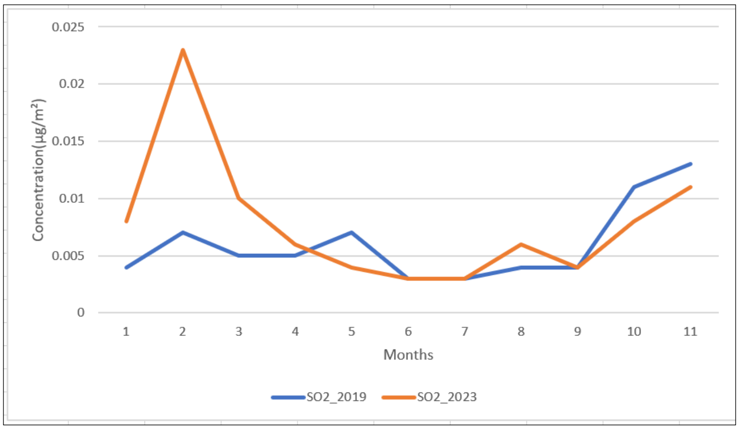

Fig. 3. Emporal variation of sulfur dioxide (SO_2) concentration depicted as a line graph, comparing data from 2019 to 2023

Figure 3 illustrates the annual mean SO_2 concentrations over the specified period, offering insights into the dynamic trends of air quality within the Tashkent region. From the plotted data, discernible fluctuations in SO_2 levels can be observed, with notable shifts occurring between the years under scrutiny.
The results of this investigation are consistent with other studies that have documented how urbanization and industry have affected the quality of the air in Central Asian nations. The current research on the origins and distribution of air pollutants in similar locations is corroborated by the geographical clustering of SO_2 emissions around industrial sites and urban centres. The Tashkent region's environmental management and policies are significantly impacted by the observed temporal and geographical patterns of SO_2 concentrations. Finding emission hotspots and seasonal patterns provide important information for focused efforts meant to reduce air pollution and enhance public health. The results

also highlight how crucial it is to include geospatial analytic software and remote sensing technologies into environmental monitoring frameworks in order to support evidence-based decision-making and sustainable development programmes. It is important to recognize certain inherent limits of the analysis, such as possible inaccuracies related to atmospheric modelling and satellite data processing. Subsequent investigations might aim to overcome these constraints by integrating observations from the ground and verifying the outcomes of remote sensing. In addition, broadening the scope of the study to encompass other air pollutants and investigating the interrelationships among environmental elements might augment our comprehension of the dynamics of air quality and provide guidance for all-encompassing approaches to mitigate air pollution and promote environmental sustainability.

4. Conclusions

In summary, the study's findings add to the expanding corpus of information on Central Asian nations' air quality monitoring programs and offer important new understandings of the spatiotemporal trends in SO_2 concentrations in the Tashkent region. This research establishes the foundation for evidence-based environmental management policies targeted at tackling air pollution concerns and promoting sustainable development in the region by utilizing remote sensing technologies and GIS analytic methodologies.

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