رصد التغيرات في تلوث الهواء باستخدام بيانات القمر الصناعي Sentinel-5P في محافظة السليمانية، إقليم كردستان العراق(2019-2024)

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كيفية اقتباس البحث

عبدالله ، فرمێسك رشيد، سرياز صالح حسين، ئەژين إبراهيم سەمين ، پروين محمد مينا عمر ، رصد التغيرات في تلوث الهواء باستخدام بيانات القمر الصناعي Sentinel-5P في محافظة السليمانية، إقليم كردستان العراق(2019-2024) ،مجلة مركز بابل للدراسات الانسانية، آب 2026،المجلد:16 ،العدد:8.

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Monitoring air pollution changes using Sentinel-5P data in Sulaymaniyah Province, Kurdistan Region of Iraq(2019-2024)

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Keywords : Air Pollutants, Climate Parameters, Google Earth Engine, Remote Sensing, Sulaymaniyah.

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الملخص:

ي أصبح تغير المناخ، باعتباره أحد العناصر الرئيسية للبيئة، قضية رئيسية على المستويات الإقليمية والوطنية والعالمية في العقود القليلة الماضية. وتعد تلوث الهواء عاملاً حاسمًا يؤثر بشكل كبير على جودة البيئة والصحة العامة. تهدف هذه الدراسة إلى تحليل اتجاهات الملوثات الجوية الرئيسية، بما في ذلك ثاني أكسيد النيتروجين(NO_2) ، وثاني أكسيد الكبريت(SO_2) ، وأول أكسيد الكربون(CO) ، والأوزون(O_3) ، في محافظة السليمانية باستخدام بيانات Sentinel-5P ضمن منصة Google Earth Engine (GEE). بالإضافة إلى ذلك،

تقيّم الدراسة تأثير العوامل المناخية، وتحديدًا درجة حرارة سطح الأرض (LST) وكمية الهطول المطري، على هذه الملوثات خلال الفترة من 2019 إلى 2024. تشير النتائج إلى وجود زيادة سنوية مستمرة في تركيزات NO_2 و SO_2و CO و O_3في جميع أنحاء المحافظة، مما يبرز الحاجة الملحة إلى استراتيجيات للحد من هذا التلوث. ويحدد الرصد المكاني قضاء چمچمال ورانية وكلار باعتبارها الأقضية الأكثر تلوثًا. وعلى وجه التحديد، تتركز أعلى تركيزات NO_2 في مدينة السليمانية، بينما تُسجَّل أعلى نسب CO و SO_2في چمچمال، ويبلغ الأوزون (O_3) ذروته في رانية. كما يكشف التحليل الإحصائي عن وجود ارتباط إيجابي بين درجة حرارة سطح الأرض والهطول المطري من جهة، و NO_2من جهة أخرى، مقابل ارتباط سلبي مع SO_2. وتؤكد هذه النتائج على ضرورة اتخاذ تدابير شاملة، مثل الحد من الانبعاثات الحضرية، وتحسين جودة الوقود، وتعزيز وسائل النقل المستدامة، للتخفيف من تلوث الهواء في محافظة السليمانية.

Abstract:

Climate change, as one of the main elements of the environment, has become a major issue at regional, national and global levels in the past few decades، Air pollution is a critical factor significantly impacting environmental quality and public health. This study aims to analyze the trends of key air pollutants, including Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), Carbon Monoxide (CO), and Ozone (O_3), in Sulaymaniyah Province using Sentinel-5P data within the Google Earth Engine (GEE) framework. Additionally, the study assesses the influence of climatic parameters, specifically Land Surface Temperature (LST) and precipitation-on these pollutants from 2019 to 2024. The results indicate a consistent annual increase in the concentrations of NO_2, SO_2, CO, and O_3 across the province, highlighting the urgent need for mitigation strategies. Spatial monitoring identifies Chamchamal, Rania, and Kalar as the most polluted districts. Specifically, the highest NO_2 concentrations are centered in Sulaymaniyah city, while the highest shares of CO and SO_2 are found in Chamchamal, and O_3 peaks in Rania. Statistical analysis reveals that LST and precipitation correlate positively and negatively with NO_2 and SO_2, respectively. These findings emphasize the necessity of comprehensive measures, such as reducing urban emissions, improving fuel quality, and promoting sustainable transportation, to mitigate air pollution in Sulaymaniyah Governorate.

Introduction

Journal of Babylon Center for Humanities Studies: 2026, Volume: 16, Issue: 8

Climate change, as one of the main elements of the environment, has become a major issue at regional, national and global levels in the past few decades (Haque et al., 2022). Population growth, rapid economic development, industrialization and transportation contribute to the increase in air pollution (Juarez and Petersen, 2021). Air pollution is an impurity due to which the health of living organisms is affected (Meda et al., 2022). In addition, air pollution can affect vegetation, water resources and biodiversity (Uyar, 2024). The World Health Organization (WHO) has declared air pollution as one of the leading causes of premature death. About 4.2 million people worldwide die annually due to lung cancer, heart and respiratory diseases (Kafi et al., 2024). The greenhouse effect is a global phenomenon and is mainly caused by air pollution (Morad and Zeuss, 2024). This phenomenon, by blocking infrared radiation, is a major factor in changes in the Earth's energy balance, thereby increasing air temperature and global warming (Kweku et al., 2018). Key indicators of air pollution include nitrogen dioxide (NO2), sulfur dioxide (SO2), carbon monoxide (CO), and ozone (O3) (Saxena and Naik, 2019). Challenges arising from spatial and temporal variability of air pollutants, irregular ground surface sampling, and associated logistical costs highlight the limitations of achieving comprehensive air pollution data in different regions (Ghaderi et al., 2024). Among the various methods of air pollution monitoring, remote sensing approaches have gained considerable importance due to the continuous nature of data generation in space and time. One of the newest satellites for this purpose is Sentinel-5P, part of the Copernicus program of the European Space Agency (ESA). Since its launch in 2017, this satellite has provided reliable and efficient data for the study of air pollutants, including NO2, SO2, CO, and O3, providing a suitable platform for understanding the current air situation and future climate change on a global scale (Yousefi et al., 2022). Due to the growing concern about air pollution, several studies have been conducted to better understand and mitigate its impacts. (Yan et al.,2025) examined the trend of air pollutant changes in coastal areas of China. Sentinel-5P data were collected from 2019 to 2024 to monitor six air pollutants (SO2, NO2, HCHO, O3, CO, and CH4). Higher concentrations of NO2, SO2, HCHO, CO, and CH4 were observed in northern ports (Tianjin Xingang, Qinhuangdao, Tangshan, and Dalian), while southern ports in China (Shenzhen, Xiamen, and Haikou) showed lower pollution levels. (Kafi et al., 2024) studied air pollution using Sentinel-5P satellite images in Khorasan Razavi and South provinces. The average concentrations of CO, O3, NO2, and SO2 pollutants for the period 2019-2023 were obtained in the Google Earth Engine (GEE)

platform. The results showed that the spatial distribution of the concentrations of these pollutants in the mentioned provinces increased, and the highest values were observed in the north, northeast, and center of Khorasan Razavi province. (Pazoki et al.,2023) trended the three main air pollutants (aerosol, CO, and O3) in Tehran city using Sentinel-5P data over the period 2019-2023. Total aerosol changes were increasing, especially in the summer months. However, O3 concentrations were higher in the winter months than in the summer. CO concentration changes were quite stable but somewhat higher in late autumn and early winter. Air pollution levels in the Kurdistan Region of Iraq exceed WHO guidelines, leading to higher rates of premature mortality and cancer due to air pollutants (Abbas and Abbas, 2021). Iraq was ranked the second most polluted country in the world in 2022, according to the Air Quality Index (AQI). Air quality in Sulaymaniyah Governorate is poor due to smoke from industrial activities, generators, vehicles, and dust (Ali et al., 2023). Given the lack of ground stations in Sulaymaniyah Province, Sentinel-5P data with the ability to identify air pollutants can provide accurate, up-to-date, and spatially extensive information for air pollution monitoring. The specific objectives of the present study are as follows: 1) Analyze the trend of changes in air pollutants (NO2, SO2, CO, and O3) in Sulaymaniyah Province using Sentinel-5P data in the GEE framework. 2) Determine the impact of climate parameters (Land Surface Temperature (LST) and precipitation) on these pollutants between 2019 and 2024.

Materials and Methods

Study Area

Sulaymaniyah Province, located at approximately **35°55' N latitude and 45°43' E longitude**, is one of the primary provinces in the Kurdistan Region of Iraq. Excluding the recently separated Halabja Province, the study area covers 20,235 square kilometers. The topography is largely mountainous, with an average elevation of 853 meters above sea level, surrounded by ranges such as Izmir, Goyjeh, and Goleh Zard. The province has a population of **2,401,724** people, with a high density in the capital city. Significant industrial activities are concentrated in the western and central districts, including major cement plants and oil refineries in the Bazian and Chamchamal areas, which serve as the primary sources of emissions. The climate is Mediterranean, characterized by cold, rainy winters and hot, dry summers (**Abbaszadeh** et al., 2025).

Journal of Babylon Center for Humanities Studies: 2026, Volume: 16, Issue: 8

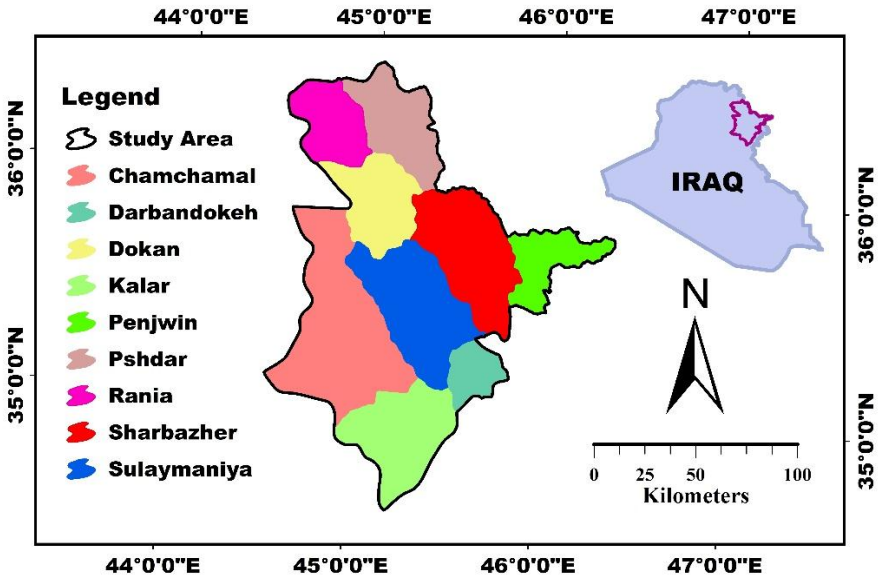

Figure 1. Location map of the study area

Data collection

The GEE platform and JavaScript programming language were utilized to monitor air pollutants and climatic parameters. Annual maps and seasonal averages were extracted for the period 2019–2024. GEE provides a powerful cloud-based environment for the rapid analysis of large-scale satellite imagery (Amani et al., 2020).

Analysis of geographic data and satellite imagery effectively paved the way for researchers to quickly extract meaningful information from remote sensing datasets (Amani et al., 2020). Figure 2 shows the workflow diagram. Sentinel-5P is a satellite launched into orbit by the European Space Agency (ESA) on October 13, 2017. It is the first satellite of the Copernicus mission dedicated to weather monitoring. Sentinel-5P is equipped with the Tropospheric Monitoring Instrument (TROPOMI), a multispectral imaging spectrometer. The instrument has high spatial resolution and covers the ultraviolet (UV) to shortwave infrared (SWIR) spectrum (Khedri Gharibvand et al., 2023). The products used in this study to extract air pollutants in moles per square meter are presented in Table 1. Climatic parameters (LST and mean precipitation) were obtained from the GEE platform in CSV format. Temperature data for Sulaymaniyah province were collected from the MOD11A2 version 6.1 product. These data were constructed as a level three pre-processed dataset on MOD11A1 daily images. LST values, which are presented in degrees Kelvin, were converted to degrees Celsius. In order to extract rainfall values, CHIRPS (a Combined Precipitation Set that integrates

satellite data with infrared information from ground stations around the world) was used. CHIRPS provides average rainfall for each region in millimeters.

Table 1. Air pollutant data

Air Pollutant	Image Name	Brand Name	Dataset providers
NO_2	Sentinel-5P OFFL: NO_2	NO_2 Column Number Density	European Union/ ESA/Copernicus
SO_2	Sentinel-5P OFFL: SO_2	SO_2 Column Number Density	European Union/ ESA/Copernicus
CO	Sentinel-5P OFFL: CO	CO Column Number Density	European Union/ ESA/Copernicus
O_3	Sentinel-5P OFFL: O_3	O_3 Column Number Density	European Union/ ESA/Copernicus

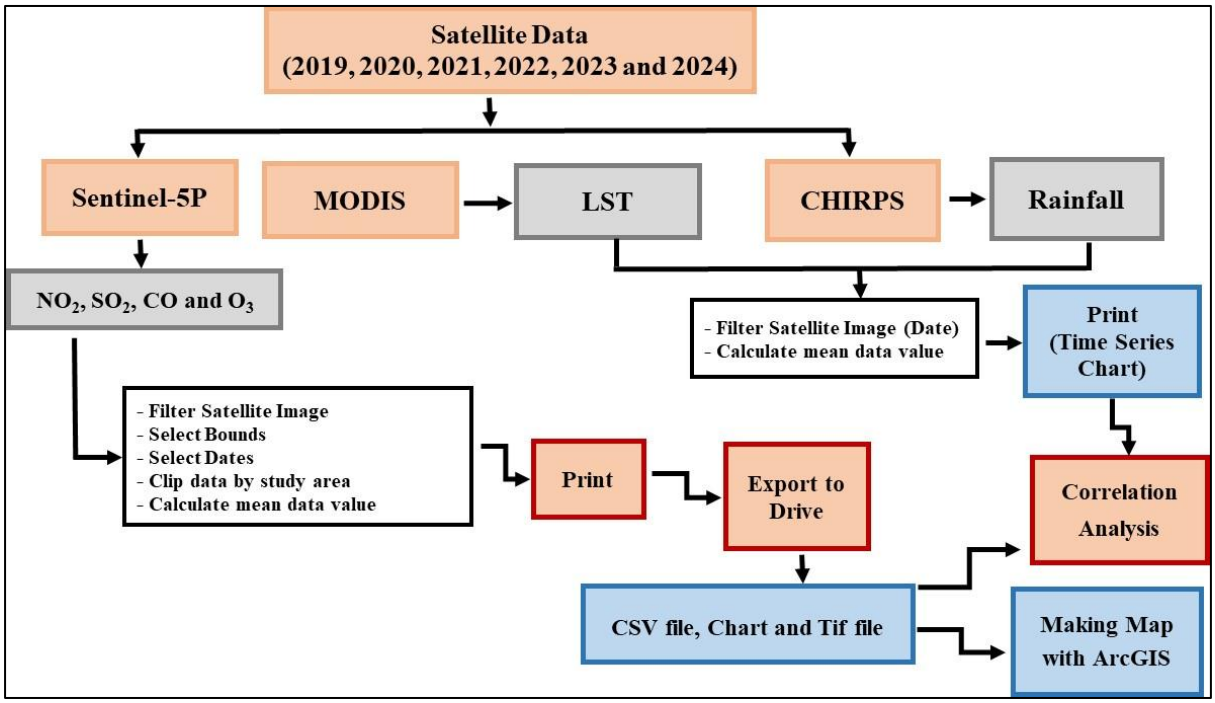

Figure 2. Workflow diagram

Analysis and Validation of Air Pollutants

Since temperature and precipitation have a direct impact on air pollutant concentrations, Pearson correlation test was used to determine the relationship between them. Setting up a ground monitoring station is costly for developing countries. In Sulaymaniyah province, validation of

Journal of Babylon Center for Humanities Studies: 2026, Volume: 16, Issue: 8

satellite data was not possible due to the lack of a ground monitoring station. However, the agreement of TROPOMI data with ground observations has been confirmed in various studies (Choo et al., 2024; Hadian and Moradizadeh, 2024).

Results

Trends of changes in air pollutants and climate parameters

After running the programming in the GEE environment, spatial distribution maps for NO_2, SO_2, CO and O_3 were generated based on the average concentration of each pollutant from 2019 to 2024. The NO2 concentration in 2019 was recorded at 0.00012 mol/m^2, and this value showed a significant increase by 2024, reaching 0.00016 mol/m^2 (Figure 3). Similarly, the SO_2 concentration in 2019 was 0.00038 mol/m^2, which increased to 0.00052 mol/m^2 by 2024 (Figure 4). The lowest NO2 (0.00011 mol/m^2) and SO_2 (0.00040 mol/m^2) were observed in 2020 and 2022, respectively. As can be seen in Figure 5, the CO concentration in 2019 was 0.032 mol/m^2 and increased slightly to 0.034 mol/m^2 in 2024. In addition, the O_3 concentration increased from 0.137 mol/m^2 in 2019 to 0.144 mol/m^2 in 2024 (Figure 6). CO (0.031 mol/m^2) in 2022 and O_3 (0.135 mol/m^2) in 2020 and 2021 reached their lowest values. From a seasonal perspective, NO_2 and CO concentrations reached their highest values in spring and summer, while their lowest values were observed in autumn and winter (Figures 7 and 9). As can be seen in Figure 8, the average SO_2 values were significantly higher in autumn and winter than in spring and summer. The O_3 concentration reached its highest value in spring and winter and its lowest value was observed in summer and autumn (Figure 10). The trend of temperature and precipitation changes is shown in Figures 11 and 12, respectively. The maximum and minimum temperatures in Sulaymaniyah province were recorded in summer and winter, respectively. While the opposite was true for precipitation.

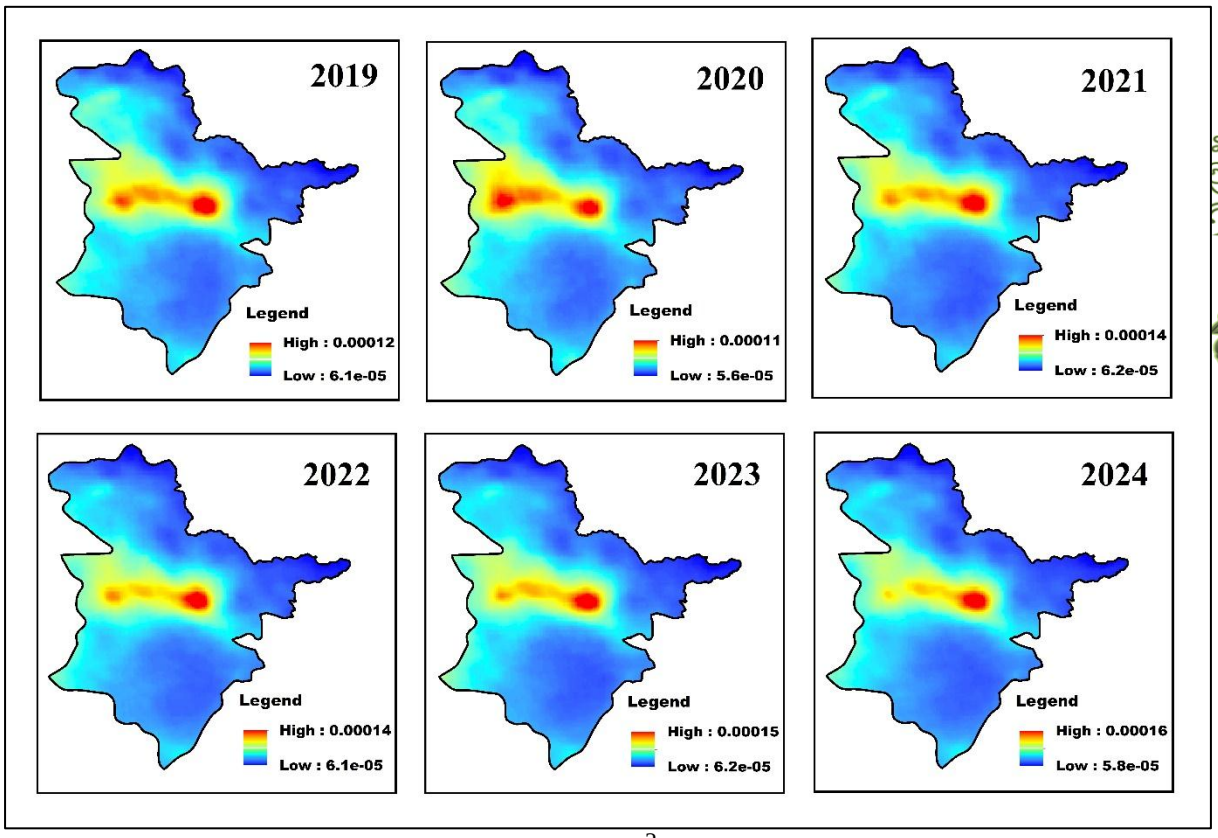

Figure 3. Annual average NO_2 (mol/m^2) in Sulaymaniyah Province (2019-2024)

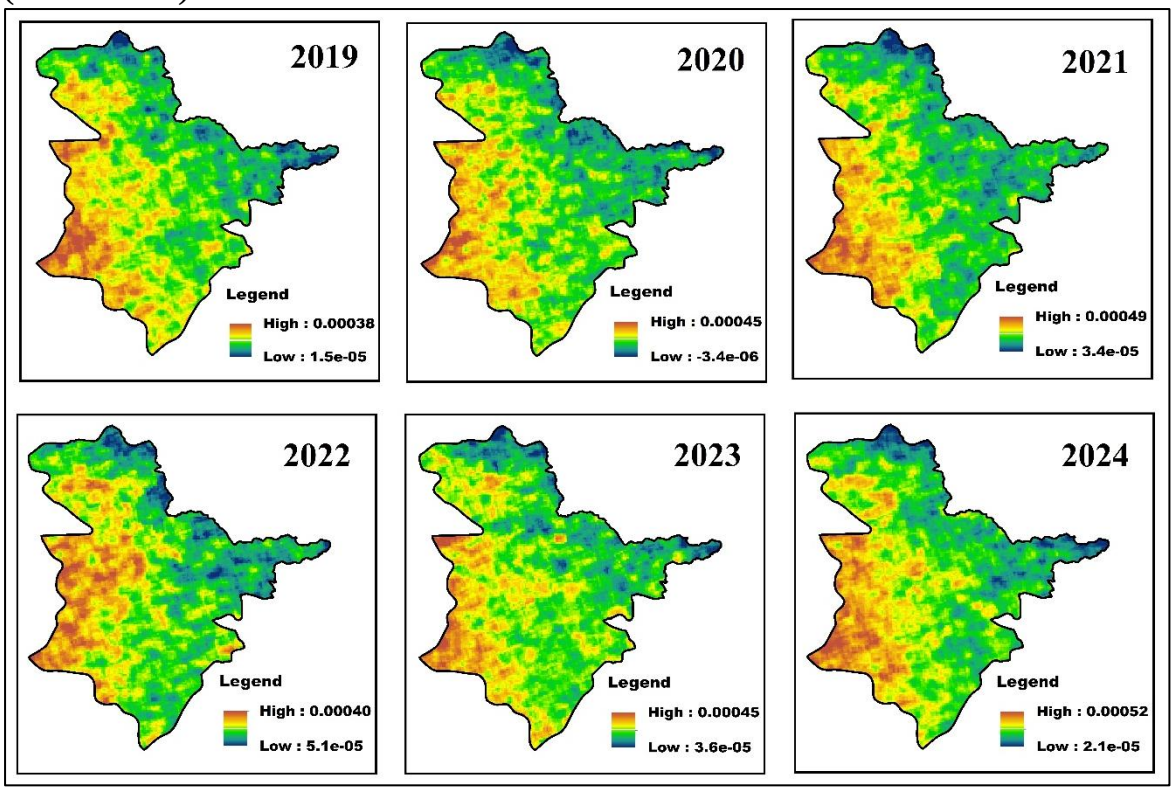

Figure 4. Annual average SO_2 (mol/m^2) in Sulaymaniyah Province (2019-2024)

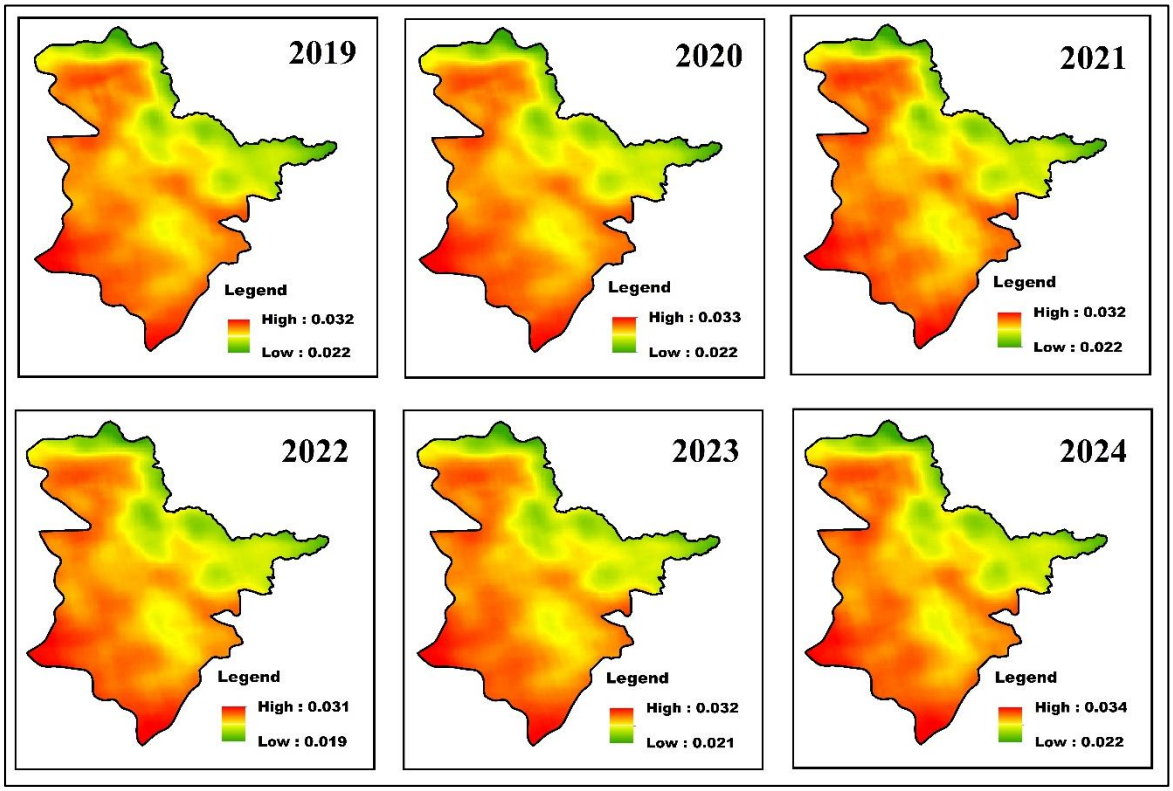

Figure 5. Annual average CO (mol/m^2) in Sulaymaniyah Province (2019-2024)

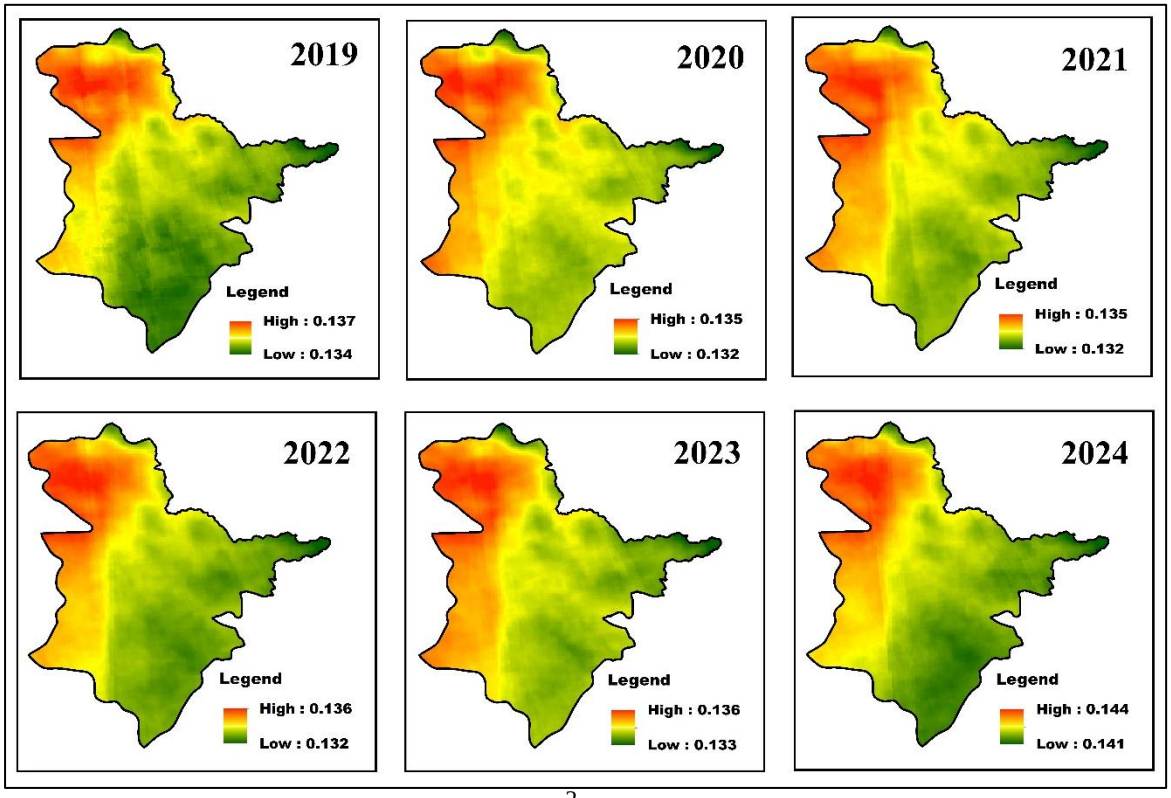

Figure 6. Annual average O_3 (mol/m^2) in Sulaymaniyah Province (2019-2024)

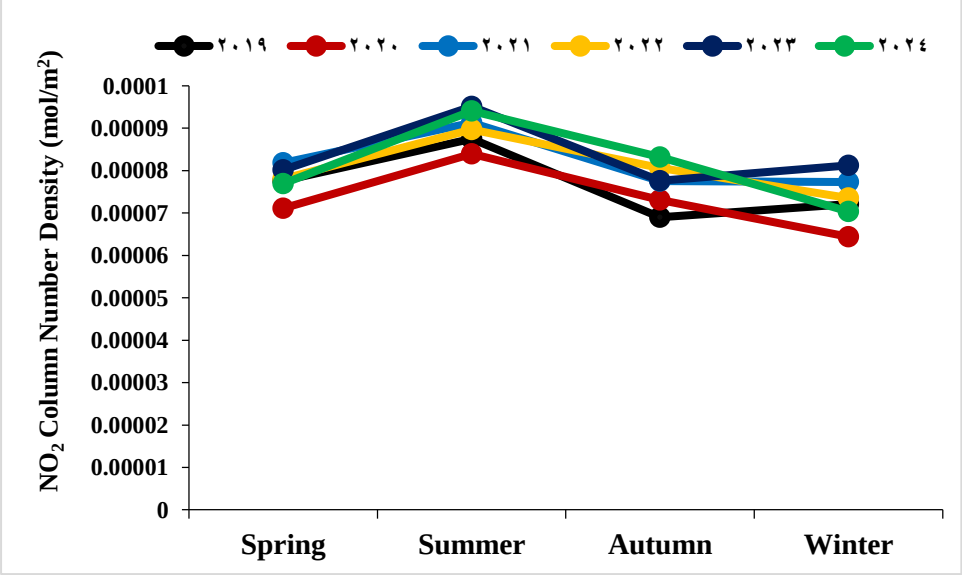

Figure 7. Seasonal average NO_2 in Sulaymaniyah Province (2019-2024)

Journal of Babylon Center for Humanities Studies: 2026, Volume: 16, Issue: 8

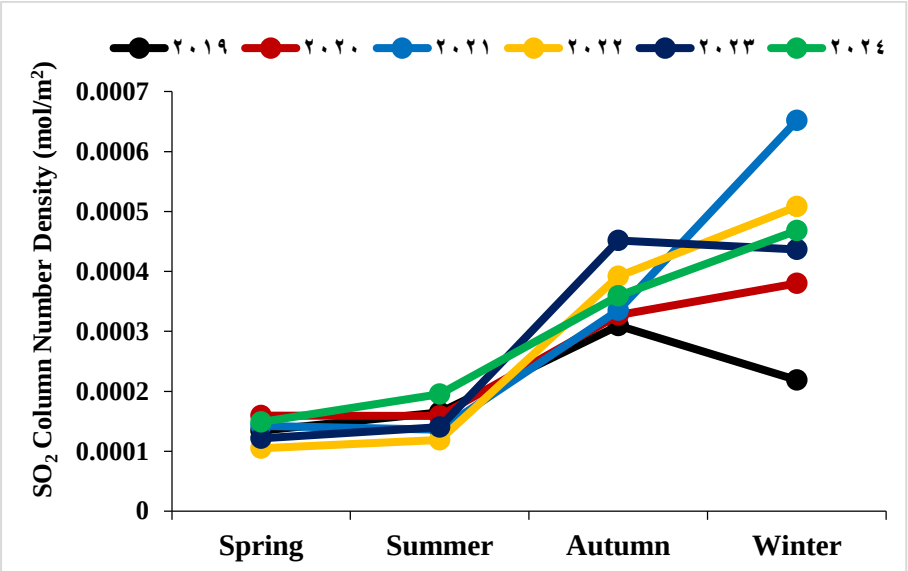

Figure 8. Seasonal average SO_2 in Sulaymaniyah Province (2019-2024)

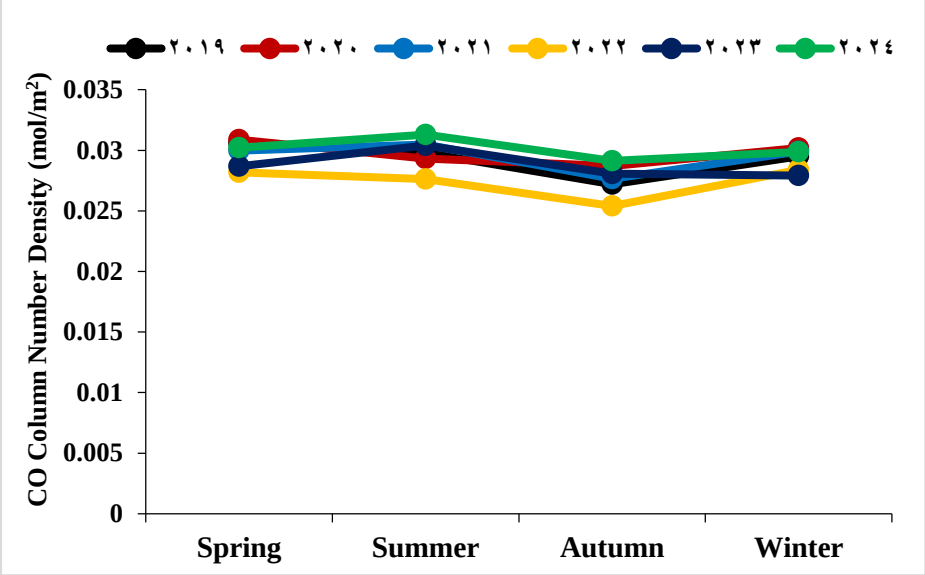

Figure 9. Seasonal average CO in Sulaymaniyah Province (2019-2024)

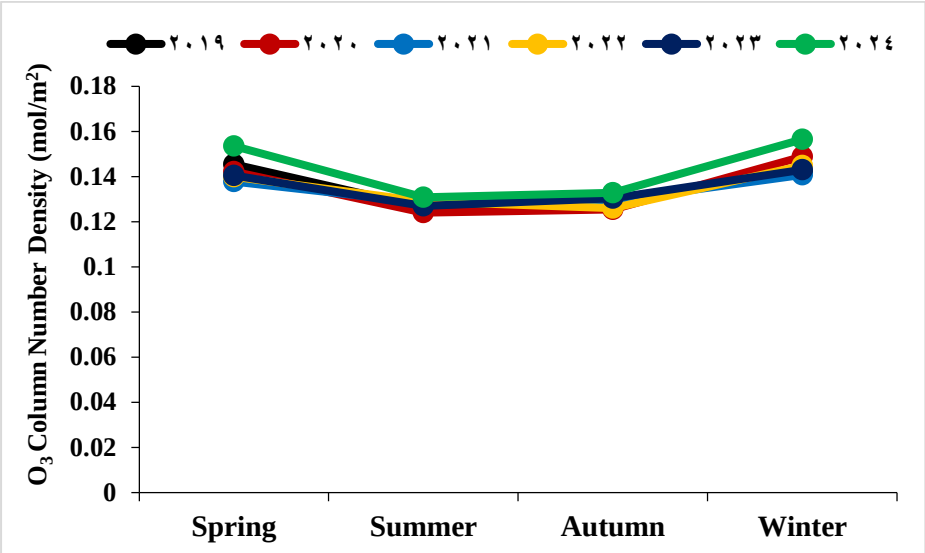

Figure 10. Seasonal average O_3 in Sulaymaniyah Province (2019-2024)

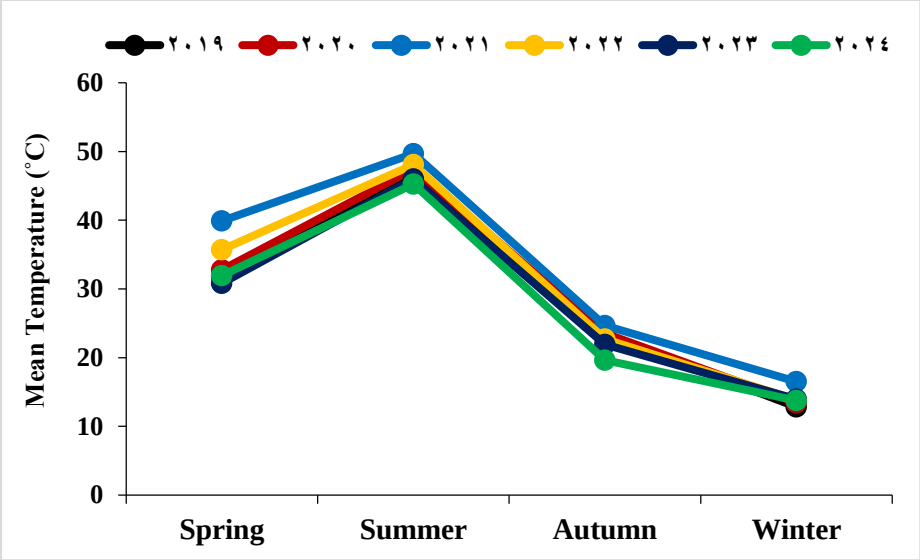

Figure 11. Seasonal average temperature in Sulaymaniyah Province (2019-2024)

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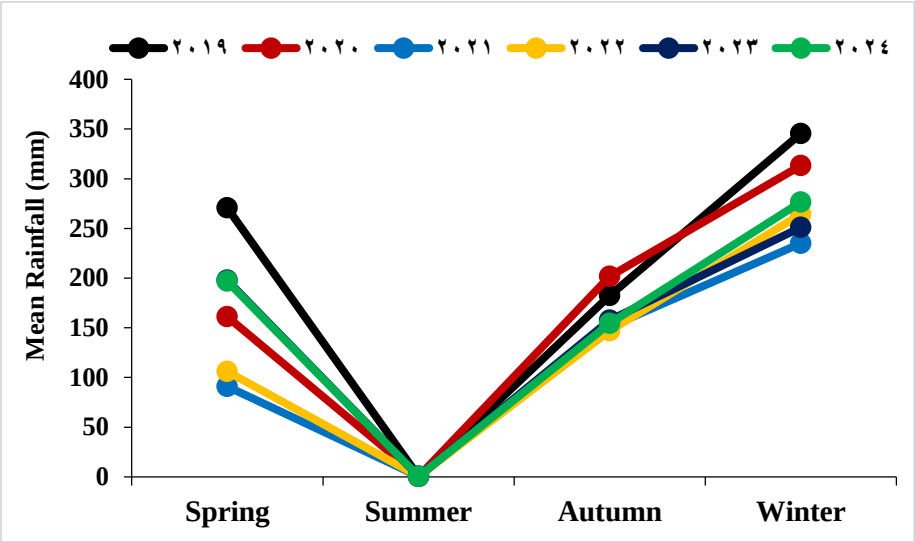

Figure 12. Seasonal average rainfall in Sulaymaniyah Province (2019-2024)

Investigating the relationship between air pollutants and climatic parameters

Table 2 presents the correlation coefficients between air pollutants and climatic parameters (temperature and rainfall) in Sulaymaniyah province. Based on the results of the Pearson test, a negative correlation was observed between NO_2 and SO_2 pollutants and rainfall. However, only the correlation between SO_2 and rainfall was significant ($p<0.05$). The correlation between temperature and NO_2 and SO2 pollutants was positive, but only the correlation between NO_2 and temperature was significant ($p<0.05$). No significant correlation was observed between air pollutants during the study period. However, SO_2 showed a positive and high correlation with NO_2.

Table 2. Pearson correlation between air pollutants and climate parameters

	NO_2	SO_2	CO	O_3	LST	Rainfall
NO_2	1					
SO_2	0.689	1				
CO	-0.270	-0.017	1			
O_3	0.134	0.091	0.487	1		
LST	0.508*	0.425	-0.168	-0.611	1	
Rainfall	-0.619	-0.907*	0.356	0.203	-0.649	1

*Correlation is significant at the 0.05 level

Discussion

The levels of air pollutants (NO_2, SO_2, CO, and O_3) in Sulaymaniyah province showed an increasing trend during the years 2019–2024. The results of the study by Hossin et al. (2025) in the Dhaka region showed a significant increase in the concentrations of NO_2, SO_2, and CO in the years 2021 and 2022 compared to 2020, indicating a worrying upward trend. The most important sources of NO_2 emissions are vehicle exhaust, industrial boilers, waste incinerators, and domestic heaters (Khedri Gharibvand et al., 2023).

The spatial distribution of pollutants reveals distinct patterns based on the source of emissions. The highest NO_2 levels were recorded in Sulaymaniyah city during the six-year period. The peak NO_2 levels observed in this central region are directly linked to high vehicular density and urban activities in the capital. In contrast, the highest contribution of SO_2 and CO is from Chamchamal City and the western districts. The elevated concentrations of SO_2 and CO in Chamchamal and Bazian are attributed to the heavy industrial presence, including oil refineries and cement manufacturing plants that rely on fossil fuel combustion.

Ozone (O_3) is a pollutant found near the surface of the Earth. Unlike the protective layer of O_3 in the stratosphere, O_3 at the ground surface is a threat to human health (Lingxia et al., 2023). The study showed that O_3 levels increased from Chamchamal to Rania City, with the highest levels observed in the north and northwest. O_3 exhibits a more uniform regional distribution across the province, which is characteristic of secondary pollutants formed through photochemical reactions rather than staying localized at the point of emission.

Due to its relatively short lifetime, CO does not mix well in the atmosphere. However, CO emissions can affect the lifetime of O_3 and CO_2 (Kafi et al., 2024). The main source of these pollutants is the increase in population, which has reached 2,401,724 in the province, alongside human and industrial activities (Shami et al., 2021). Analysis of NO_2 and CO changes shows high concentrations during spring and summer. In the study by Kafi et al. (2024) in the Khorasan Razavi and South Khorasan provinces of Iran, an increase in pollutants was similarly observed. Also, Pazoki et al. (2023) noted that O_3 levels in Tehran, Iran, decreased from 2019 to 2023.

Climatic parameters such as Land Surface Temperature (LST) and precipitation have a significant impact on the dynamics of air pollutants (Oji and Adamu, 2020). The present study highlights a clear negative

association between SO_2 and rainfall. Rain acts as a natural cleaner and reduces pollution due to decomposition and dilution (Abbaszadeh Tehrani et al., 2021). The relationship between NO_2 and LST was positive in Sulaymaniyah. Results in the Nile Delta also showed a positive relationship between LST and air pollutant particles (Elgammal et al., 2012).

While this study focuses on gaseous pollutants, it is important to acknowledge that aerosols significantly contribute to regional air pollution, especially given Iraq's susceptibility to frequent dust storms. However, aerosols were excluded from this specific scope to maintain a focused analysis on anthropogenic gaseous emissions. Additionally, while meteorological parameters such as wind speed and humidity influence pollutant dispersion, this research prioritized LST and precipitation as the primary climatic drivers available with high spatial consistency in the GEE framework for the 2019–2024 period. Future research should integrate aerosol optical depth (AOD) and wind dynamics to provide a more holistic model. Remote sensing plays an important role in monitoring air pollution (Geddes et al., 2016). Given the increasing trend of air pollutants in Sulaymaniyah province, the present study emphasizes the need to implement stricter regulations to reduce pollution.

Conclusion

This study analyzed the trend of air pollution changes from 2019 to 2024 using advanced approaches such as GEE and Sentinel-5P satellite data. The results show an annual increase in air pollutants (NO_2, SO_2, CO and O_3) in Sulaymaniyah Province. Therefore, it is crucial to emphasize fundamental measures to reduce the sources of these pollutants. Pollution monitoring showed that Chamchamal, Rania, and Kalar are the most polluted cities in the study area. In addition, regional analysis of the cities' contribution to air pollutants showed that the highest share of NO_2 belongs to Sulaymaniya city. The highest share of CO and SO_2 was observed in Chamchamal City and the highest share of O_3 was observed in Rania City. Climatic parameters affected the pattern of air pollutants, such that temperature and precipitation showed positive and negative correlations with NO_2 and SO_2, respectively. These results emphasize the urgent need for comprehensive measures, including reducing greenhouse gas emissions from urban sources, improving fuel quality, and promoting sustainable transportation to reduce air pollution in Sulaymaniyah Governorate.

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Author Contributions

Frmesk Rashid Abdollah: Contributed to conceptualization, data collection and processing, spatial analysis using Google Earth Engine, result interpretation, and manuscript writing.
Saryaz Salih Hussein: Contributed to study design, methodology development, supervision of the research process, statistical analysis, manuscript writing, and revision.
Azhin Ibrahim Samin: Contributed to data processing, validation, visualization of results, preparation of figures and maps, and manuscript review.
Parwin Mohammed Mina Omar: Contributed to data collection and manuscript review.
All authors have read and approved the final manuscript.

Declaration of Generative AI in scientific writing

During the preparation of this manuscript, the authors utilized generative artificial intelligence (AI) tools to enhance the language, grammar, and overall academic readability of the text. After using these tools, the authors carefully reviewed and edited the content to ensure scientific accuracy and take full responsibility for the final version of the publication.

Ethical Approval

All authors have read, understood, and complied as applicable with the statement on ethical responsibilities of authors.

Consent to Participate

Not applicable.

Consent to Publish

Not applicable.

Competing Interests

The authors declare no competing interests.

Data Availability

The datasets generated and analyzed during the current study are available from the public data repositories of the Google Earth Engine (GEE) and the European Space Agency (ESA) Copernicus program. Specific processed data are available from the corresponding author upon reasonable request.

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