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Assessment of Air Pollution in Sulaymaniyah City Derived from the TROPOMI Sentinel-5P Using the Air Quality Index

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ABSTRACT

This research assessed the air pollution in Sulaymaniyah city, Iraq, using the air quality index (AQI) from 2019–2023. The data used in this research derived from the TROPOMI Sentinel-5P, including nitrogen oxide (NO2), Sulphur dioxide (SO2), carbon monoxide (CO), and ozone (O3). This research aimed to calculate the intensity of air pollution and illustrate the spatiotemporal variability of the AQI in Sulaymaniyah. The calculated AQI results illustrated that the highest aggregate AQI was 224.1 in 2020, the lowest was 199.1 in 2019, and the annual average was 213.8 (very unhealthy) from 2019 to 2023. The highest seasonal aggregate AQI was 249.8 (very unhealthy) in the winter, and the lowest was 177.7 (unhealthy) in the summer. During COVID-19, the aggregate AQI was 11.1% lower than the average aggregate AQI across the whole research period. Pollutants came from the combustion of fuels for transportation, electricity generation, home and building heating, cement production, oil industry and new construction. Daily inhalations by children aged 1 to 2 years were the highest. Older individuals and pregnant and breastfeeding women had ingested more toxins compared to younger groups. More research will continue to drive predictive analytics, and the findings can have a significant effect on how to act on air quality management.

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INTRODUCTION

As the world population continues to grow, air pollution is becoming a more serious issue. Air pollution is among the leading environmental challenges and public health concerns responsible for premature mortality in both developed and developing countries (Kaplan and Avdan, 2020; Al-Alola et al., 2022). Air pollutants consist of particulate matter (PM2.5 and PM10), nitrogen oxides and dioxides (NO, NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), and ozone (O_3) (Al-Alola et al., 2022). Urbanisation, energy consumption, transportation, motorisation, power generation, and burning waste in cities are among the major sources of air pollution (Kaplan and Avdan, 2020; WHO, 2021).

Overpopulation and rapid urbanisation have caused air pollution in urban areas, endangering the entire environment and individual well-being (Meena et al., 2024; Kumar et al., 2023). The most severe air pollution occurs in urban and industrial zones where pollutant sources emit hazardous substances (Morozova et al., 2022).

Calculating the air quality is vital, as it directly affects both human health and the environment.

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Calculating the air quality helps residents in advance to minimise health risks, mortalities, and property damage, thereby contributing to socio-economic development (Chen and Zheng, 2022). The air quality index (AQI) is a widely used tool to assess the intensity of air pollution. The AQI is an important instrument for communicating air quality data and determining the level of pollution, with higher AQI values illustrating higher health concerns. The AQI can also be used to develop policies related to managing air quality, pollution control, disaster mitigation, and urban planning (Anggraini et al., 2024).

While air quality has mostly been investigated on normal days, the relationship between air pollution and COVID-19 has also been considered; therefore, some research has attempted to determine AQI values during the pandemic using TROPOMI data. Kaloni et al. (2022) investigated air quality in the New Delhi metropolis under the COVID-19 lockdown. Bauwens et al. (2020) used TROPOMI data to assess NO_2 pollution during COVID-19. Shikwambana et al. (2020) used TROPOMI data to observe sulphur dioxide and nitrogen dioxide in South Africa. Also, Wang et al. (2020) observed NO_2 over China with comparison and validation of TROPOMI and OMI data. Furthermore, some studies have been conducted that used TROPOMI for air pollution mapping or used the same methodology (Onojeghuo et al., 2025; Wieczorek, 2023 and Ganbat et al., 2022). Some others worked on air pollution in the study area and other parts of the Kurdistan Region (Azeez et al., 2022; Hamadamin et al., 2022; Salih et al., 2024 and Abdulla and Souri, 2024).

Like many cities around the world, Sulaymaniyah is experiencing rapid urbanisation. This expansion led to the consumption of more fossil fuel for transportation, power generation, and industrial activities, subsequently worsening local air quality. Despite that, there is not a comprehensive and accurate study on Sulaymaniyah City's air quality and its impacts on the city's residents' health. Accordingly, this work attempts to fill this gap despite lacking ground-level data, using satellite data as an appropriate alternative.

The objectives of this research are to (i) calculate the intensity of air pollution (CO, O_3, NO_2, and SO_2) and illustrate the spatiotemporal variability of the AQI in Sulaymaniyah, Iraq, from 1 January 2019 to 31 December 2023, (ii) evaluate temporal fluctuations in air quality, including the COVID-19 period, and identify key sources of pollution and (iii) calculate inhalation exposure for different exposure groups and related health impacts. This research calculates the air quality index and pollutant rates for Sulaymaniyah based on offline TROPOMI Sentinel-5P satellite data. More research will continue to drive predictive analytics and have implications for public health in the future, as these measures inform policy decisions. This approach can have a significant effect on land use and pollution factors by providing insights into how to act on air quality management.

MATERIAL AND METHODS

Sulaymaniyah is situated in the eastern part of the Kurdistan Region of northeast Iraq, covering an area of 180.64 km². Geographically, it lies between latitudes 35° 28′ 22″ N and 35° 37′ 49″ N and longitudes 45° 16′ 40″ E and 45° 30′ 08″ E. Its elevation ranged from 639 m in the south and southwest to about 1700 m above sea level in the north and northeast (Fig. 1). The city has a Mediterranean climate characterized by rainy, cold winters and dry, hot summers. The average maximum temperature is 33.4°C in July, and the average minimum temperature is 7°C in January, while the maximum temperature reaches 45°C and the minimum temperature drops to below zero in both July and January, respectively. The annual precipitation is approximately 718mm. Wind speed ranged from 1 m/s in January to 1.8 m/s in July. Relative humidity ranged from 71.1% in January to 25.3% in July, while evaporation ranged from 50.1 mm in January to

362 mm in July (KRG, 2020). As of 2024, the population of Sulaymaniyah city was 1,056,067 (Commission of statistics and GIS, 2024).

In this research, offline TROPOMI Sentinel-5P satellite data was used to assess the air quality index and pollutant levels for Sulaymaniyah from 1 January 2019 to 31 December 2023. The EPA has established National Ambient Air Quality Standards (NAAQS) for each of these contaminants in order to protect against potential health risks (U.S. EPA, 2001). The single AQI is calculated using the linear interpolation equation (Equation 1), pollutant concentration data, and a reference concentration (U.S. EPA, 2018). The EPA set breakpoint concentrations based on NAAQS (Table 1).

$$I_P = \left(I_{H_i} - I_{L_0}\right) / \left(BP_{H_i} - BP_{L_0}\right) * \left(Cp - BP_{L_0}\right) + I_{L_0} \quad (1)$$

Where Ip = The index for pollutant p (sub index calculation), Cp = Recorded pollutant concentration

BP_{Hi} = Concentration breakpoint that is ≥ Cp, BP_{Lo} = Concentration breakpoint that is ≤ Cp

I_{Hi} = The AQI value corresponding to BP_{Hi}, I_{Lo} = The AQI value corresponding to BP_{Lo}

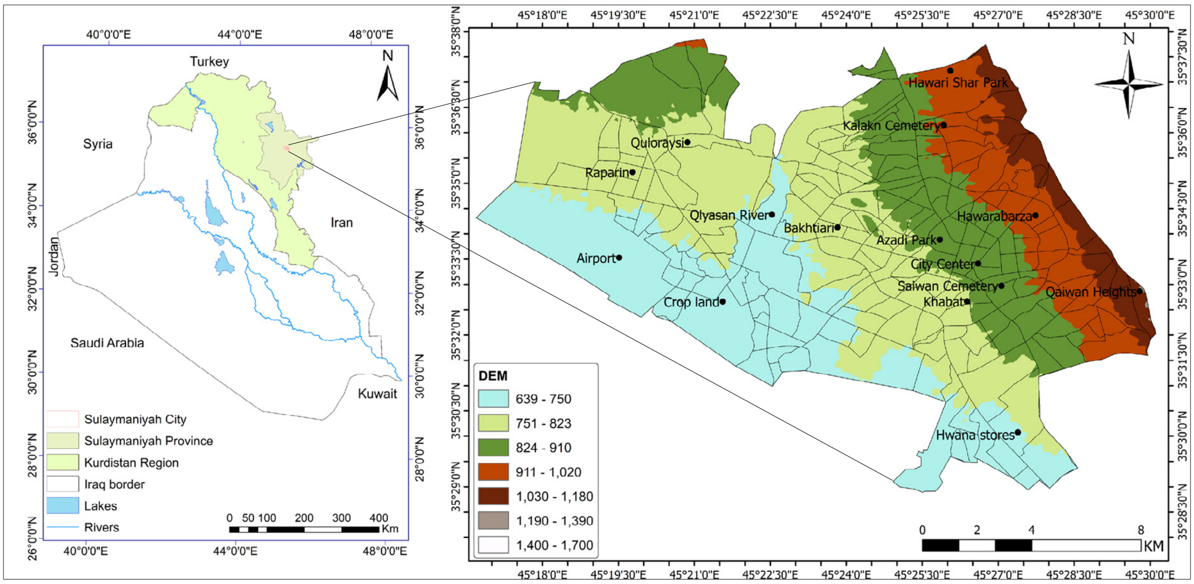

Fig. 1. Study area and selected locations for calculating AQI

Table 1. Modified EPA breakpoints and categories of the AQI (U.S. EPA, 2018).

O_3 (ppm) 8-hour	O_3 (ppm) 1-hour	CO (ppm) 8-hour	SO_2 (ppb) 1-hour	NO_2 (ppb) 1-hour	AQI	category
0.000 - 0.054	-	0.0 - 4.4	0 - 35	0 - 53	0 - 50	Good
0.055 - 0.070	-	4.5 - 9.4	36 - 75	54 - 100	51 - 100	Moderate
0.071 - 0.085	0.125 - 0.164	9.5 - 12.4	76 - 185	101 - 360	101 - 150	Unhealthy for Sensitive Groups
0.086 - 0.105	0.165 - 0.204	12.5 - 15.4	186 - 304	361 - 649	151 - 200	Unhealthy
0.106 - 0.200	0.205 - 0.404	15.5 - 30.4	305 - 604	650 - 1249	201 - 300	Very unhealthy
-	0.405 - 0.604	30.5 - 50.4	605 - 1004	1250 - 2049	301 - 500	Hazardous
-	0.605 - 0.804	50.5 - 60.4	1005 - 5004	2050 - 3049	501 - 600	*Very hazardous

* This category was added due to high SO_2 levels in several cases throughout the research period (the original categories included two hazardous categories, which we combined "Modified").

The aggregated AQI is calculated using equation 2 (Shikwambana et al., 2024);

$$AQI = \left(I_{p1} + I_{p2} + \cdots I_{P_n}\right) / n \quad (2)$$

where I_p is the sub-index of the pollutant concentration, and n is the number of pollutants.

Correspondingly, Equation 3 can be used to convert pollutant concentration from TROPOMI to near-ground values (Shikwambana et al., 2024).

$$C = \frac{C_{Col}}{H} \cdot M \cdot A \quad (3)$$

where Ccol is the pollutant column content in (mol/m^2) for CO and O_3 and in (mmol/m^2) for NO_2 and SO_2; M is the molar mass in (g/mol) for all parameters; A is a constant value for conversion from g/m³ to mg/m³, which is equal to 1000; and H is the height of pollutants in the troposphere expressed in meters. Depending on the literature, in this research, a value of H = 11000 m was chosen for CO and O_3 (Li et al., 2001; Abdulfattah et al., 2020), 4000 m for NO_2 (Chan et al., 2020), and 5000 m for SO_2 (Al-Khuwaylidee et al., 2023). The AQI results were calculated by Microsoft Excel 2019 and illustrated in maps using ArcGIS 10.8 with the inverse distance weighted (IDW) interpolation technique.

Moreover, the inhalation rate was calculated. The average daily dose (ADD) is a calculation of the dose rate over a given exposure time and is expressed as a daily dosage per unit of body weight. The ADD can be calculated with the following equation (US EPA, 1997).

$$ADD = \left(Cair * InhR * ET * EF * ED\right) / \left(AT * BW\right)$$

ADD = Average daily dose in mg/kg-day, Cair = contaminant concentration in air in mg/m³, InhR = Inhalation rate in m³/hour, ET = Exposure time in hours/day, EF = Exposure frequency in days/year, ED = Exposure duration in years, AT = Averaging time in days and BW = Body weight in kg.

RESULTS AND DISCUSSION

The Pearson correlation test was used to determine the correlations between parameters (using Origin Pro 2025). The interaction of variables can provide critical information about the origins of pollutants. Pearson's correlation coefficients (r) for the parameters were utilised to create the correlation matrix, which described the relationship between the parameter sources. The results of the selected parameters revealed some positive correlations in all seasons with parameter modifications (Fig. 2). Nonetheless, these favourable relationships are non-significant. This signifies that the parameters came from various sources.

The main sources for these pollutants in the study area's air may be burning fuels from transportation, power generation, the heating of homes and buildings, and cement production. In 2022, the study area had 721,551 cars and 1,731 power generators, and more than 14 million tonnes of cement were produced in the Bazian and Tasluja areas located southeast of Sulaymaniyah (Central Statistical Organisation of Iraq, 2021; Kurdistan Region Statistics Office, 2024). CO showed a low positive correlation with the number of generators and average temperature, as well as a very low positive correlation with wind speed and precipitation (Fig. 3). This weak positive correlation between CO and precipitation may occur due to the subsequent weakening in fuel combustion efficiency and escalating traffic congestion (Zalakeviciute et al., 2018). O_3 had a high positive correlation with the number of generators, precipitation, and

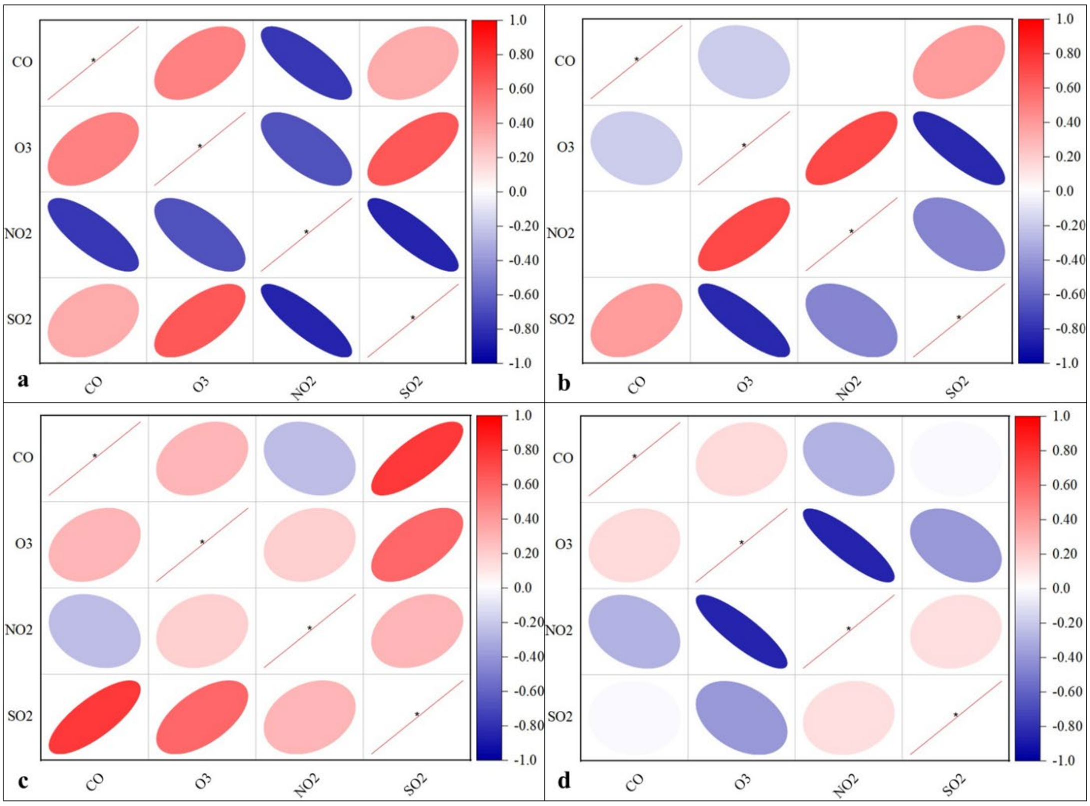

Fig. 2. Pearson correlation between seasonal concentrations of parameters in mg/m³ from 2019 to 2023: a. spring, b. summer, c. autumn, and d. winter (* p<=0.05).

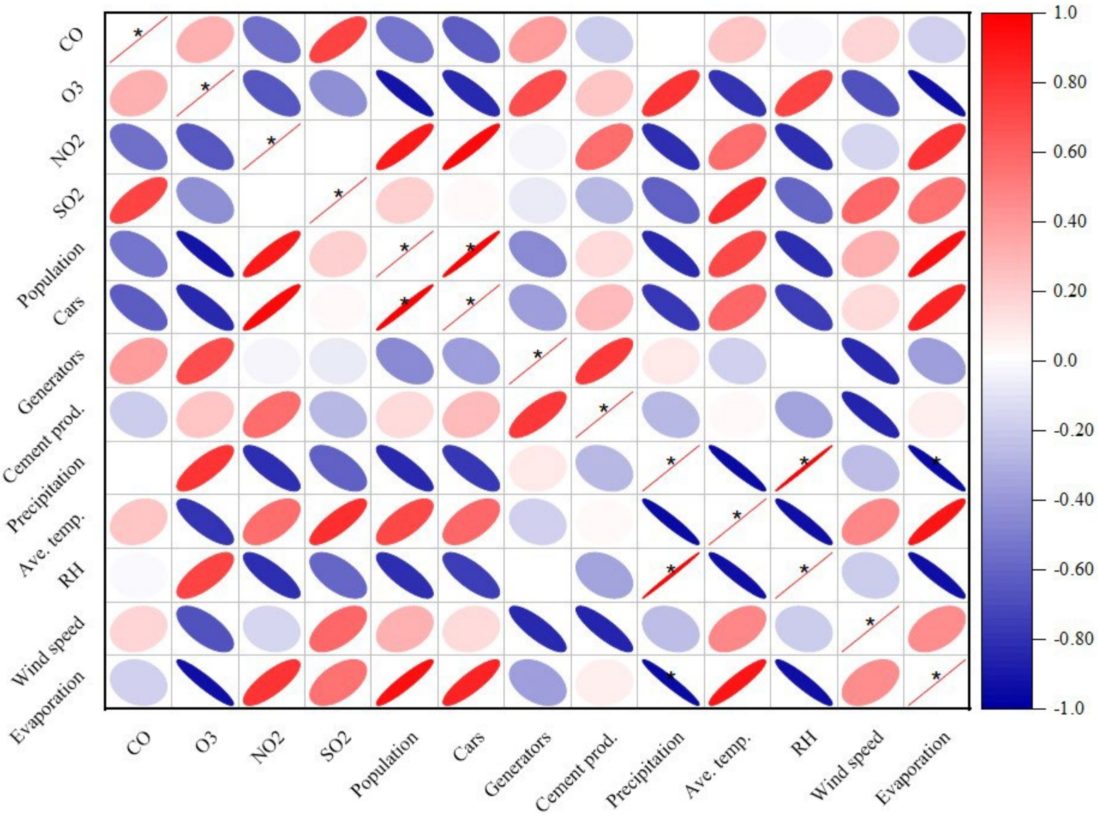

Fig. 3. Pearson correlation between parameters and air pollution factors (* p<=0.05).

humidity and a weak positive correlation with cement production. NO_2 had a very high positive correlation with the number of cars and population, a high positive correlation with evaporation, and a moderate positive correlation with average temperature and cement production. SO_2 had a very high positive correlation with average temperature, a medium positive correlation with evaporation and wind speed (KRG, 2024), and a very low positive correlation with the number of cars and population.

The O_3 AQI shows slight seasonal variation. The maximum value of 256.5 occurred during the spring, while the lowest value of 237.6 occurred in the autumn, both of which were within the very unhealthy category (Fig 4a). The greatest values were primarily recorded in the city's south and southwest in the summer and winter; the eastern half in the spring; and the middle, south, and northwest in the autumn. The lowest values occurred in the eastern part of the city in all seasons except spring, when they occurred in the western section of the city. These results were obtained because of the lower altitude in the south, heavy traffic and the higher level of industrial activities, including cement production in Bazian. The CO AQI showed no notable seasonal variations: in all seasons, the results were less than 1 (good) in the study area (Fig 4a).

The NO_2 and SO_2 AQI values showed significant seasonal fluctuation. The maximum values of NO_2 and SO_2 were recorded in the winter at 216.6 (very unhealthy) and 531.9 (very hazardous), respectively. In contrast, spring had the lowest level of NO_2 at 148.3 (unhealthy for sensitive individuals) and summer had the lowest level of SO_2 at 298.8 (very unhealthy) (Fig 4a). The locations of the highest values of SO_2 were recorded to vary in the city depending on the seasons. The highest values occurred in the city's centre and its surroundings in the summer, while the majority of the study areas had high SO_2 AQI values in the autumn. In the spring and winter, the highest values were scattered unevenly around the study area (Fig. 5).

As with O_3 and CO, previous studies also primarily illustrated similar results for NO_2 and SO_2. The highest values of NO_2 occurred in the autumn and winter, while the lowest values occurred in the spring and summer (Al-Lami et al., 2021; Van Geffen et al., 2022). In the winter, higher levels of NO_2 and SO_2 may be related to temperature inversion resulting in smog events (Cichowicz et al., 2017).

Seasonal aggregate AQI was determined using AQI results for pollutants. Summer, spring, autumn, and winter had an aggregate AQI of 177.7 (unhealthy), 193.1 (unhealthy), 234.7 (very unhealthy), and 249.8 (very unhealthy). The annual average aggregate AQI was 213.8, which falls into the very unhealthy category. The highest was 224.1 in 2020, while the lowest was 199.1 in 2019 (Fig. 4b).

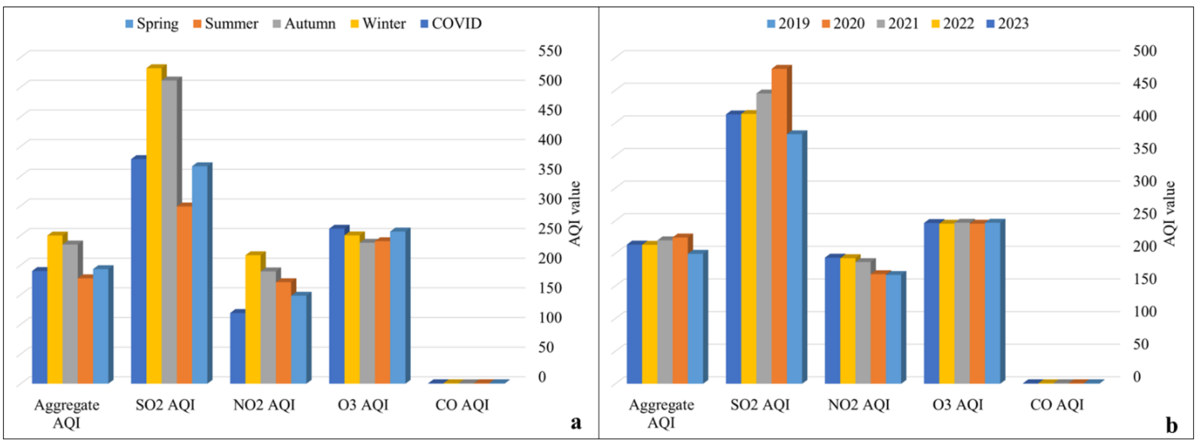

Fig. 4. Seasonal and annual AQI, a. seasonal, COVID-19 and seasonal aggregate AQI, and b. annual and annual aggregate AQI

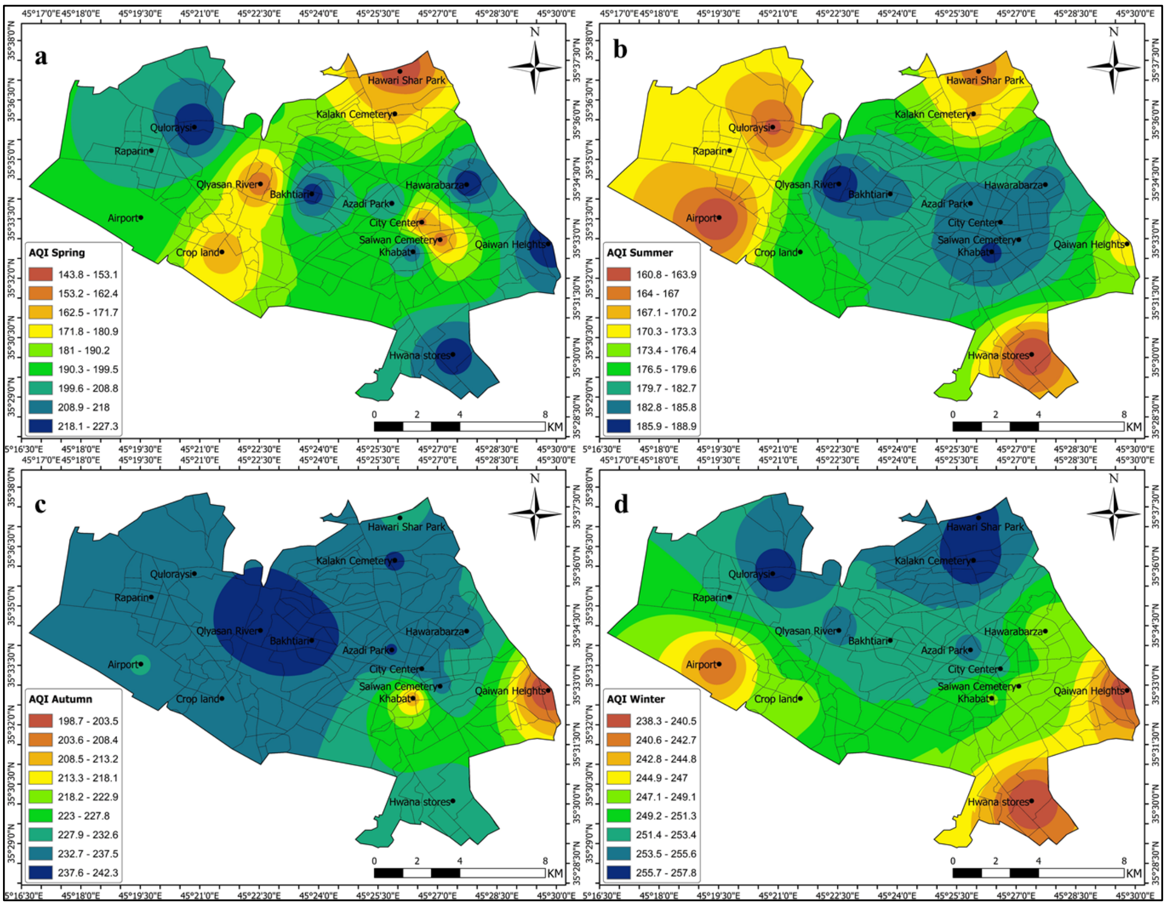

Fig. 5. Seasonal aggregate AQI (a. spring, b. summer, c. autumn, d. winter)

The pollutant share ratios based on aggregate AQI were 49.9% for SO_2, 28.8% for O_3, 21.2% for NO_2, and 0.1% for CO. However, the pollutant share ratios in aggregate AQI varied in different years (Fig. 4b). The amount of pollutants contributed by aggregate AQI is proportional to the level of pollutants in the research area's air and their respective EPA breakpoints. SO_2 had a high concentration with moderate breakpoints, while CO had a low concentration and high breakpoints. These results make the research area's air quality nearly as poor as Delhi's, which was 256 (very unhealthy) in October 2024 (Singh et al., 2023).

The spatiotemporal variability in AQI levels in the study area is influenced by the number of the city's residents; their daily activities and requirements; industrial production, especially cement production in Bazian, oil industry, Altitude above sea level; and unregulated construction activities in Sulaymaniyah, particularly in the northern part. Furthermore, meteorological parameters such as temperature, precipitation, humidity, evaporation, and wind speed contributed to the variation in outcomes between seasons.

The impact of cement production on air pollution was obvious in the Bazian District, located southwest of Sulaymaniyah. The AQI in Bazian was 216.8 (very unhealthy), 4.1 higher than in Sulaymaniyah. Moreover, in Kalar District, which is situated southeast of Sulaymaniya, the AQI was 199.8 (unhealthy). Although Bazian has more precipitation and just over 38,000 inhabitants (nearly 4.6% of Sulaymaniyah's population), Kalar has approximately half the precipitation and more than 145,000 people.

During COVID-19, the Kurdistan Regional Government, like countries around the world, ordered a lockdown to control the spread of the virus from 14 March 2020 to 21 May 2020.

Even though, on some days, the lockdown was only partially implemented, it partially improved the air quality compared to the days before and after. Like on normal days, the O_3 AQI showed insignificant variation. The highest value was 261.7, and the lowest was 260.7, both of which fall into the very unhealthy category (Fig. 4a). The CO AQI was less than 1, in the good category. NO_2, like O_3 and CO, showed no significant variance. The highest value was 123.7 at Azadi Park, and the lowest was 107.8 at Hwana stores, both falling into the unhealthy for sensitive groups category. Unlike other parameters, SO_2 exhibited significant fluctuation. The highest AQI was 533.6 in Hawarabarza, indicating a very hazardous situation. In contrast, the lowest was near zero at Hawari Shar Park because the SO_2 was very low.

The aggregate AQI during COVID-19 was 190, which was 11.1% lower than the aggregate AQI from 2019 to 2023. NO_2 and SO_2 AQI levels decreased by 34.3% and 11.3%, respectively. The O_3 AQI increased by 6.2%, whereas the CO AQI remained steady. Al-Lami et al. (2021) mainly obtained similar results; they stated that the CO concentrations were reduced by about 6%–9% and NO_2 by nearly 3%–46% due to the eradication of traffic and manufacturing processes. However, O_3 increased by about 2%–8% as a result of local burning activities. Furthermore, NOx regulates the photochemical production of O_3 by converting NO_2 to O_3 in atmospheric chemistry (Brancher, 2021; Lama et al., 2023).

Toxic chemicals may be present in both ambient and indoor air at various levels. The contaminated air can affect people while engaging in their daily lives in various environments. The toxic substances may be inhaled by adults and children in different sources from both outdoor and indoor air (US EPA, 2011). The inhalation of chemicals varied with the exposure group in the study area (Table 2). In terms of daily inhalation, children aged 1 to 2 years had the highest exposure to all chemicals. The inhalations were approximately 55.5, 17, 1.18, and 5.32 mg/kg/day for SO_2, NO_2, CO, and O_3, respectively. However, older individuals (≥81 years) had the highest lifetime exposure to all pollutants. Inhalations were nearly 31.7, 9.8, 0.67, and 3 kg for SO_2, NO_2, CO, and O_3, respectively. Furthermore, older groups ingested more toxins than younger groups across their lifetimes due to their lifespan. Pregnant and breastfeeding women were also heavily exposed to toxins due to the research area's high pollution levels.

Air pollution can cause some diseases in city residents, such as cancer. During the research period, 728 instances of bronchus and lung cancer were reported, 548 of which were male and 180 were female (Republic of Iraq, Ministry of Health and Environment, Iraqi Cancer Board, 2019–2022). Pollutants and the AQI results showed some positive correlation with the number of bronchus and lung cancer cases in the study area. CO concentration showed a very low positive correlation with the number of bronchus and lung cancer cases in the female group. However, the CO AQI result showed a low negative correlation with the number of bronchus and lung cancer cases in the female group. NO_2 concentration and NO_2 AQI results had a very high positive correlation with the number of bronchus and lung cancer cases in males and the whole population and a high positive correlation with the female group (Fig. 6).

SO_2 concentration had a low positive correlation, and SO_2 AQI results had a medium positive correlation with the number of cancer cases in the male group. SO_2 concentration had a high positive correlation, and SO_2 AQI results had a very high positive correlation with the number of cancer cases in the female group. Also, SO_2 concentration had a medium positive correlation, and SO_2 AQI results had a high positive correlation with the number of cancer cases in both gender groups. Males are disproportionately affected compared to females due to their increased time spent outdoors.

Relevant outcomes have been found in the literature. India is the world's fifth most polluted country, and its poor air quality is the leading cause of lung cancer among citizens (Singh et al., 2023). Long-term exposure to NO_2, SO_2, and O_3 has been found to have the biggest and most

Table 2. Daily average exposure and age group inhalation of toxic substances in Sulaymaniyah City during 2019-2023 (depending on ATSDR, 2020)

Exposure group	ED = Exposure duration (years)	AT = Averaging time (days)	Long term default inhalation rate (m3/day)	Body weight (kg)	O_3			CO			NO_2			SO_2		
					Inhalation by Age (kg)	Inhalation by Exposure group (kg)	ADD (mg/kg-day)	Inhalation by Age (kg)	Inhalation by Exposure group (kg)	ADD (mg/kg-day)	Inhalation by Age (kg)	Inhalation by Exposure group (kg)	ADD (mg/kg-day)	Inhalation by Age (kg)	Inhalation by Exposure group (kg)	ADD (mg/kg-day)
Birth to <1 year	1	365	5.4	7.8	0.015	0.015	5.250	0.003	0.003	1.163	0.048	0.048	16.848	0.156	0.156	54.714
1 to <2 years	2	730	8	11.4	0.059	0.044	5.322	0.013	0.010	1.179	0.190	0.142	17.078	0.617	0.462	55.461
2 to <3 years	3	1095	8.9	13.8	0.133	0.074	4.891	0.029	0.016	1.083	0.427	0.237	15.695	1.388	0.770	50.970
3 to <6 years	5	1825	10.1	18.6	0.273	0.140	4.118	0.060	0.031	0.912	0.876	0.449	13.215	2.844	1.457	42.915
6 to <11 years	10	3650	12	31.8	0.605	0.332	2.862	0.134	0.074	0.634	1.942	1.066	9.183	6.306	3.462	29.823
11 to <16 years	15	5475	15.2	56.8	1.236	0.631	2.030	0.274	0.140	0.450	3.967	2.025	6.512	12.883	6.577	21.149
16 to <21 years	20	7300	16.3	71.6	2.139	0.902	1.727	0.474	0.200	0.382	6.863	2.896	5.540	22.287	9.404	17.992
21 to <31 years	30	10950	15.7	80	3.442	1.304	1.488	0.763	0.289	0.330	11.046	4.184	4.776	35.874	13.587	15.510
31 to <41 years	40	14600	16	80	5.214	1.772	1.517	1.155	0.392	0.336	16.731	5.685	4.867	54.336	18.462	15.806
41 to <51 years	50	18250	16	80	7.429	2.215	1.517	1.646	0.491	0.336	23.837	7.106	4.867	77.413	23.077	15.806
51 to <61 years	60	21900	15.7	80	10.036	2.608	1.488	2.223	0.578	0.330	32.205	8.367	4.776	104.587	27.174	15.510
61 to <71 years	70	25550	14.2	80	12.788	2.752	1.346	2.833	0.610	0.298	41.034	8.829	4.320	133.260	28.674	14.028
71 to <81 years	80	29200	12.9	80	15.645	2.857	1.223	3.466	0.633	0.271	50.201	9.167	3.924	163.030	29.770	12.744
≥81 years	90	32850	12.2	80	18.684	3.039	1.157	4.139	0.673	0.256	59.954	9.753	3.711	194.704	31.674	12.052
Pregnant Women	0.76713	280.00245	21.1	73	0.045	0.045	2.192	0.010	0.010	0.486	0.144	0.144	7.034	0.467	0.467	22.843
Lactating Women	2	730	22.8	73	0.126	0.126	2.369	0.028	0.028	0.525	0.405	0.405	7.601	1.315	1.315	24.684

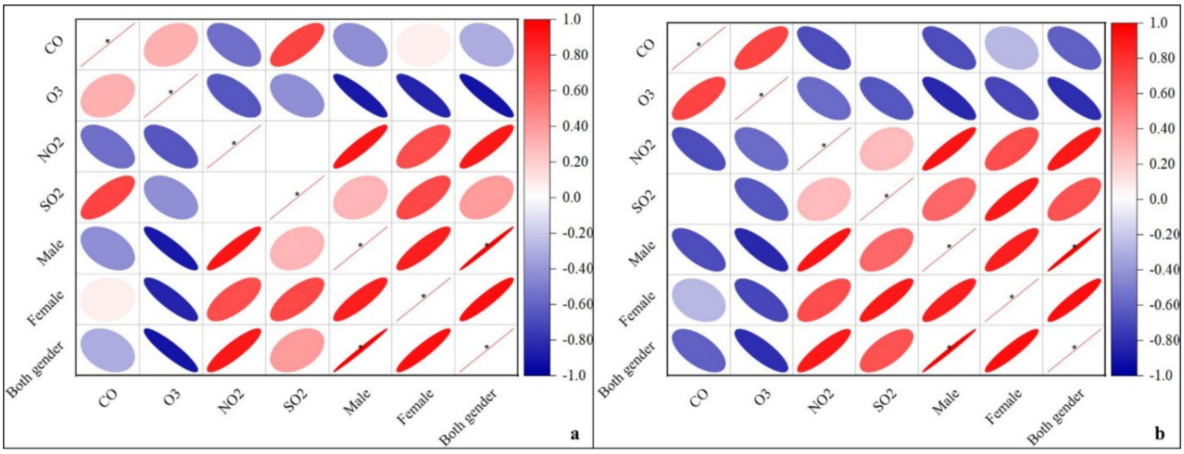

Fig. 6. Pearson correlation between a. parameters' concentrations in mg/m3 and bronchus and lung cancer (2019-2022). b. AQI results and bronchus and lung cancer (2019-2022) (* p<=0.05).

consistent impact on respiratory illness and lung cancer incidence (Liu et al., 2023; Wang et al., 2022; Kazemiparkouhi et al., 2020; Tseng et al., 2012).

CONCLUSION

This research, which assessed the intensity of pollutants and illustrated the spatial distribution of the AQI in Sulaymaniyah, concluded with the following outcomes:

- Based on the concentrations of pollutants, the AQI of O_3 ranged from 237.6 in the autumn to 256.5, which occurred in the spring. The CO AQI results were less than 1, indicating a good category in all seasons. In the winter, the maximum AQI values for NO_2 and SO_2 were 216.6 and 531.9. In contrast, spring saw the lowest levels, with NO_2 at 148.3 and summer saw the lowest levels, with SO_2 at 298.8. Winter had the highest aggregate AQI of 249.8, which is very unhealthy, and summer had the lowest at 177.7, which is unhealthy.
- The annual aggregate AQI was 213.8 from 2019 to 2023; the highest was 224.1 in 2020, while the lowest was 199.1 in 2019.
- The pollutant share ratios from aggregate AQI were 49.9%, 28.8%, 21.2%, and 0.1% for SO_2, O_3, NO_2, and CO, respectively. During COVID, the aggregate AQI was 11.1% lower than the average across 2019–2023. NO_2 and SO_2 AQI levels decreased, and O_3 rose, whereas CO remained steady.
- The pollutants came from the combustion of fuels for transportation, electricity generation, home and building heating, cement production, and new home construction. Also, the rate of pollutants was affected by meteorological factors in different seasons at various levels.
- Daily inhalation by children aged 1 to 2 years was the highest: around 55.5, 17, 1.18, and 5.32 mg/kg/day for SO_2, NO_2, CO, and O_3, respectively. Cumulative inhalation by individuals older than 81 years was approximately 31.7, 9.8, 0.67, and 3 kg for SO_2, NO_2, CO, and O_3, correspondingly. Older groups and pregnant and breastfeeding women had ingested more toxins than younger groups.
- NO_2 and SO_2 concentrations and NO_2 and SO_2 AQI results had positive correlations at different levels with the number of bronchus and lung cancer cases in males, females, and the whole study population. Males were disproportionately affected by bronchus and lung cancer compared to females due to their increased time spent outdoors.
- This research effectively provides a detailed baseline of air pollution in Sulaymaniyah City

and solves the rarity of accurate research and unavailability of ground-based data. Scholars may conduct more research in this field by creating robust ground-based data or using next-generation satellite sensors with better imagery.

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The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

LIMITATION

There is no ground-based station data in the study area to calibrate the TROPOMI data with, and there are no previous studies on air pollution with valuable results.

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