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Research Paper

Spatiotemporal air quality variation between urban and agricultural areas: The influence of climatic factors and pollution dynamics

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ABSTRACT

Air pollution is a critical environmental and meteorological concern, significantly influenced by climatic conditions and atmospheric dynamics. Hence, the present study examines seasonal and daily variations in the concentrations of air pollutants, such as CO, SO_2, NO_x, and O_3, in Baghdad, based on the principle of meteorological influences during the wet and dry seasons. Data were collected at 23 transportation intersections in during morning and afternoon periods. The results indicated a robust relationship between the levels of pollutants addition to an agricultural area and meteorological conditions. Carbon monoxide showed an afternoon peak during the dry season owing to air stagnation (28.2–18.7 ppm). Ozone concentrations also heightened in this season due to increased temperature and photochemical reactions (0.515–0.35 ppm). Levels of ozone, sulfur dioxide and nitrogen oxides reflect over-national air quality standards, with maxima seen in the dry season and more so in the afternoons. The results of the Air Quality Index analysis show that the main factors causing a drastic decrease in quality during the dry season are higher temperatures, scanty rainfall, and increased levels of photochemical activity. This result emphasizes the need to integrate meteorology .into urban planning to mitigate pollution

Keywords: Air pollution, Air quality index, GIS analysis, Seasonal variation, Meteorology, Climate impact.

Air quality is one of the greatest environmental and health issues, being the one side on which air pollution directly affects human health, ecosystems, and climate. Whereas the World Health Organization attributed more than 7 million deaths annually due to air pollution directly or indirectly related, it remains one of the most serious environmental challenges (Bade *et al.,* 2024; WHO, 2023). Air quality is defined by the concentration levels of carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), nitrogen oxides (NOx), and ozone (O_3), also directly associated with severe health effects and substantial general environmental damage (Al-Qahtani *et al.,* 2024). Air pollution contributes to climate change by affecting greenhouse gas levels and acid rain formation, which impacts agricultural crops and infrastructure (Bertrand, 2021). Baghdad faces many environmental challenges, including air pollution from human, industrial, and transportation sources (Khaleel *et al.,* 2024; Al-Rikabi *et al.,* 2024; Talib *et al.,* 2021). Recently, environmental displacement has led to the expansion of urban centers, causing agricultural land to be converted into residential areas and vegetation cover to decrease, which has directly contributed to rising temperatures as a result of decreased natural cooling, increased absorption of solar radiation, and changing wind patterns (Hashim *et al.,* 2025; Ahmed and Al-Ramahi 2022). Excessive use of fossil fuels has increased dangerous atmospheric pollutants (Shah *et al.,* 2021). Research shows that pollutants such as NO_2 and SO_2 contribute to the aggravation of respiratory and heart diseases, while ground-level ozone is linked to increased incidence of chronic pulmonary diseases (Olstrup *et al.,* 2024).

The study aims to analyze the spatiotemporal distribution of gaseous pollutants (CO, SO_2, NO_x, O_3) in urban and agricultural areas in Baghdad. Comparison of air pollutant concentrations between wet and dry seasons to determine the impact of climatic conditions on air quality. Assess air quality using the AQI index and compare it with national and international standards. Understand the effects of climatic factors (temperature, humidity, and wind speed)

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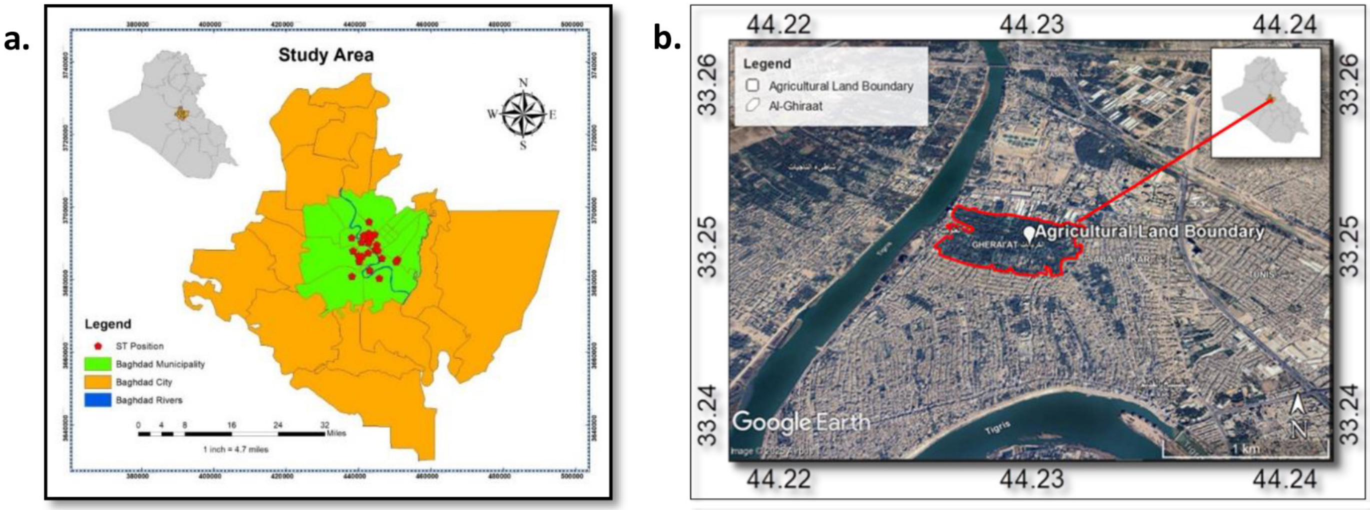

Fig. 1: Map of Baghdad showing **(a)** the locations of urban intersections, and **(b)** Al-Ghiraat agricultural boundary at the north of Baghdad

on pollutant accumulation. Provide environmental recommendations to improve air quality by integrating meteorological factors into sustainable urban planning.

MATERIALS AND METHODS

Study area

Baghdad Governorate is situated in central Iraq; the coordinates of Baghdad are (33.452°-184°N and longitude 44.189°-576°E) as shown in (Fig. 1a) Diyala borders it to the east, Wasit and Babil to the south, Anbar to the west, and Salah al-Din to the north. Baghdad has a desert climate characterized by extremely hot summers, with temperatures often exceeding fifty degrees Celsius. The air is typically dry, and the city frequently experiences severe dust storms. Scientists attribute these dust storms to various factors, including global warming, Iraq's desert environment, rising carbon levels in the atmosphere, and the phenomenon of desertification (ASGIS 2023).

Spatial limit

The study embraced 23 sites chosen within the city of Baghdad, at major streets and intersections heavily crowded with all manner of light and heavy vehicles, on both Karkh and Rusafa sides, 13 sites on the Rusafa side (comprising 12 intersections and one Expressway) and 10 sites on the Karkh side (comprising nine intersections and one Expressway) during morning and afternoon peak hours (Fig. 1a). Besides agricultural land, Al-Ghiraat is an area located north of Baghdad, on the Al-Rusafa side, along the eastern bank of the Tigris River, surrounded by water on three sides (Fig. 1b).; it has historically been a fertile agricultural area. This area was selected for control measurements, where the area's boundaries were manually traced based on recent satellite imagery using Google Earth Pro. The total area of agricultural land was approximately 57.3 hectares, with an outer perimeter of approximately 4.50 kilometers. This method approximates land areas, especially when precise official data is unavailable. These sites represent strategic points to study the variation in the concentration of pollutants in different environments and the impact of weather factors on them across the seasons. They included commercial intersections, public intersections, and intersections near universities, in addition to some highways and adjacent agricultural areas.

Temporal limit

Gaseous measurements were conducted during the wet season in February, March, and April of 2023, as well as during the dry season in June and October of 2023. Measurements were taken over two peak traffic congestion periods. The morning peak time is from 7:30 to 9:30 A.M. The noon peak time extends from 12:30 to 4:00 P.M. at both traffic intersections and Al-Ghiraat (the agricultural area) in Baghdad.

Samples collection

Air pollutant samples of 4 gases, CO, O_3, SO_2, and NOx, were collected at 24 locations and measured two times during the day (morning and afternoon) for a period of 5 months, including 2 wet seasons and 2 dry seasons. For each gas, 600 samples were collected in the morning, and 600 samples were collected in the afternoon, bringing the total number of samples to 1200 for each gas. Thus, the total number of samples for all gases combined during the study period was 4800, distributed equally between the two periods (morning and afternoon) corresponding to peak street traffic with vehicles for both intersections sites and an agricultural site (Al-Ghiraat). Official holidays were excluded; sample collection was confined to the official working hours of government institutions, including the ministries and the private sector. Residential, industrial, and commercial areas were excluded to ensure that measurements were carried away from private generators, government electrical stations, factories, etc. The Multi-Gas Detector (S318) model, Henan Zhongan Electronic Detection Technology Co., LTD., measured the samples for gaseous air pollutants CO, O_3, SO_2, and NO_X in study sites. Its error for CO is ±10% of full scale, equating to ±100 ppm over the (0–1000) ppm range and ±2% of full scale for O_3 (±0.2 ppm) over the (0–10) ppm range. For SO_2, it is ±5% of full scale, which corresponds to ±1.0 ppm over the (0–20) ppm range, and for NOx, it is ±3% of full scale (±0.6 ppm) over the (0–20) ppm range. Multi-Functional Environmental Meter (MS6300) model,

Table 1: Breakpoints concentration of AQI defined by USEPA [EPA 2024]

Category	AQI	Breakpoints		
		CO (ppm) 8-hour	O_3 (ppm) 1-hour	SO_2 (ppm) 1-hour
Good	0-50	0.0-4.4	-	0.0-0.035
Moderate	51-100	4.5-9.4	-	0.036-0.075
Unhealthy for sensitive groups	101-150	9.5-12.4	0.125-0.164	0.076-0.185
Unhealthy	151-200	12.5-15.4	0.165-0.204	0.186-0.304
Very unhealthy	201-300	15.5-30.4	0.205-0.404	0.305-0.604
Hazardous	301-400	30.5-40.4	0.405-0.504	0.605-0.804
Hazardous	401-500	40.5-50.4	0.505-0.604	0.805-1.004

MASTECH Company- for physical climatic factors temperature, humidity (RH), and wind speed (WS). Samples were collected upwind, under sun conditions, at an elevation of about 1.5 meters above the surface for 40 minutes at each location. Five readings (replicates) were taken for each gas, and the average was calculated

Air quality index

The US Environmental Protection Agency (USEPA) equation calculates the air quality index at traffic intersections [EPA,2024].

$$I_P = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}} (C_P - BP_{Lo}) + I_{Lo}$$

Where: I_p = The index for pollutant p, C_p = The truncated concentration of pollutant p, BP_{Hi} = The concentration breakpoint that is greater than or equal to C_p , BP_{Lo} = The concentration breakpoint that is less than or equal to C_p, I_{Hi} = The AQI value corresponding to BP_{Hi} , I_{Lo} = The AQI value corresponding to BP_{Lo} . Units of the breakpoint values for SO_2 in the AQI report have been converted from ppb to ppm by multiplying (ppb value *0.001) to match the units of pollutant concentrations measured in ppm, as shown in Table 1.

Air quality standards for gaseous pollutants

Air quality standards are one of the fundamental pillars of preserving human health and the environment, as national and international organizations determine the permissible limits for the concentration of pollutants in the air. In Iraq, national air quality standards have been adopted based on the maximum allowable values for the concentration of pollutants in the air, such as CO, SO_2, O_3, and NO_2 (Table 2). These standards are similar in some cases to those set by the World Health Organization (WHO) and the US Environmental Protection Agency (EPA). Still, there are subtle differences that reflect the local environmental challenges and needs of each region.

No uniform global standard exists for NO_x because most standards focus on NO_2 due to its most harmful health effect. NO_x is a combination of nitrogen oxides NO_x = (NO + NO_2); 90% of NO_x results from vehicle exhaust are NO, and only 10% are NO_2. However, NO is gradually oxidized in the atmosphere to NO_2 after being emitted. Assuming NO_2 makes up the largest proportion of NO_x in the urban environment, often 70%-90 % in contaminated areas. Considering the Iraqi standard limiter NO_2 is 0.1 ppm, we can assume that NO_x will be higher because it also includes NO. An approximate determinant of NO_x considering the ratio of NO_2 to NO_x is about 80% (a common average ratio in urban areas):

limited standard $NOx = \frac{\text{Limited standard } NO_2}{\text{Ratio}} = \frac{0.1}{0.8} = 0.125$ ppm, meaning the local NO_x limiter may be approximately≈ 0.125 ppm as a rough reference.

Statistical analysis

Descriptive statistics was done using box and whisker plots to show gaseous pollutants along with climatic factors at two site types urban intersections and an agricultural site for wet and dry seasons using OriginPro 2025. Spatial data was mapped and analyzed using ArcMap 10.8, a Geographic Information Systems (GIS) software package. The software was used to perform accurate geolocation and to create illustrative maps showing how the concentration of pollutants changed between two times of the day (morning and noon) and two seasons (wet and dry). The Air Quality Index (AQI) was calculated using Microsoft Excel.

RESULTS AND DISCUSSION

Seasonal analysis changes in concentrations of polluting gases in Baghdad

In Baghdad, concentrations of polluting gases were affected by traffic congestion and weather conditions throughout the seasons. As shown in (Fig. 2) CO recorded its highest levels during the morning in the wet season in Al-Bayaa, Mohammed Al-Qasim, Al-Shaab, Al-Nahda Garage, and Al-Alawi Garage (19.8 - 13.55 ppm) due to congestion and high humidity, while high concentrations were recorded in the afternoon in Adan, Al-Nahdha Garage, Al-Shaab, Baghdad Al-Jadidah, and Al-Bayaa (17.8 - 13.4 ppm) due to improved ventilation and high temperatures. In the dry season, concentrations peaked in the morning in Al-Khalani, Bab Al-Muadham, Al-Mawal, Baghdad Al-Jadidah, and Adan Sq. (24.4 - 15.8 ppm) due to the absence of humidity and gas accumulation due to the morning coolness, while the highest values were recorded in the afternoon in Baghdad Al-Jadidah, Al-Khalani, Al-Nidaa, Bab Al-Muadham, and Al-Liqaa Sq. (28.2 – 18.7 ppm).

Table 2: Comparison of air quality determinants of pollutants between Iraqi national standards, WHO, and EPA standards (in ppm)

Pollutant	Iraqi determinant (ppm)	WHO determinant (ppm)	EPA determinant (ppm)
CO	35/ 1 hour	35/ 1 hour	35/ 1 hour
SO_2	0.15/ 1 hour	0.175/1 hour	0.075/ 1 hour
O_3	0.1/1 hour	0.1/1 hour	0.070 /8 hour
NO_2	0.1/1 hour	0.2/ 1 hour	0.1/1 hour

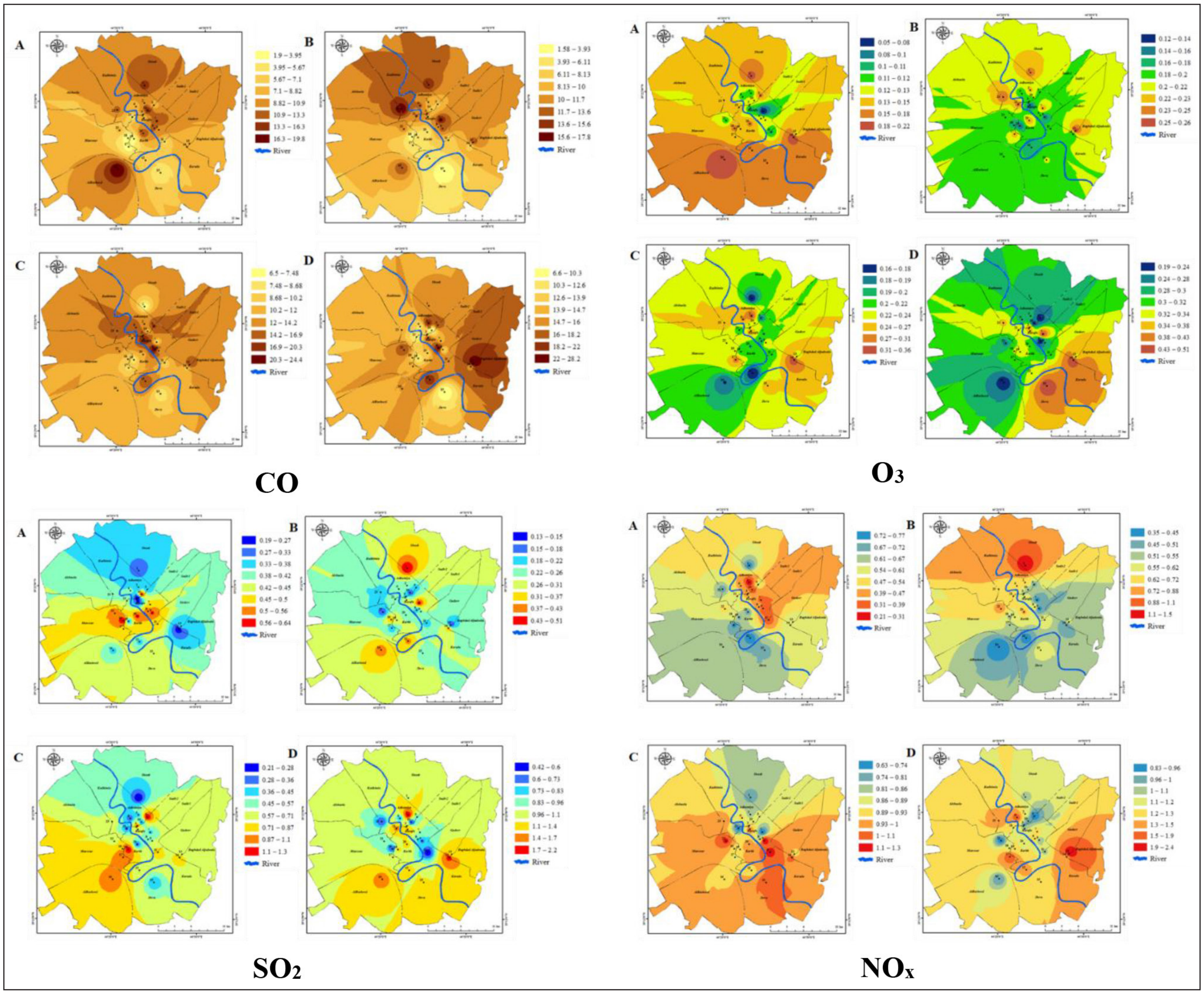

Fig. 2: Temporal and spatial distribution of CO, O_3, SO_2, NO_x concentrations (ppm) in Baghdad intersections: (**A**) wet season morning, (**B**) wet season noon, (**C**) dry season morning, (**D**) dry season noon.

As for O_3, its concentrations in the morning during the wet season were higher in Al-Bayaa, Al-Dora Expressway, Al-Shaab, Al-Jadriya, and Al-Masafi Street (0.215 - 0.17 ppm) due to the lack of sunlight, and increased at noon in Baghdad Al-Jadidah, Adan Square, Al-Shaab, Al-Alawi Garage, and Al-Nahdha Garage (0.265 - 0.235 ppm) with increased photochemical reactions. In the dry season, morning concentrations were high in Al-Dora Expressway, Al-Nidaa, Al-Nisour, Bab Al-Muadham, and Antar bin Shaddad (0.36 - 0.275 ppm), while the highest levels were recorded in the afternoon at Al-Dora Expressway, Al-Masafi Street, Al-Nahdha Garage, Al-Waziriya, and Bab Al-Muadham+Adan (0.515 - 0.35 ppm) due to intense solar radiation. SO_2 recorded its highest concentrations during the wet morning in Al-Ruwad Street, Mohammed Al-Qasim, Al-Alawi Garage, Al-Tayaran, and Al-Khalani+ Al-Liqaa (0.64 - 0.54 ppm) due to high humidity and decreased at noon in Al-Shaab Street, Al-Nahdha Garage, Al-

Table 3: Seasonal variations in air pollutants by season and period compared to agricultural area

Time period	Sites	Gaseous pollutants			
		CO (ppm)	O_3 (ppm)	SO_2 (ppm)	NOx (ppm)
Wet Morning	Urban intersections	8.73	0.14	0.42	0.54
	Agri.area	0.0	0.13	0.15	0.34
Wet Afternoon	Urban intersections	9.28	0.20	0.26	0.61
	Agri. area	0.0	0.11	0.20	0.39
Dry Morning	Urban intersections	12.80	0.23	0.65	0.93
	Agri. area	0.0	0.17	0.34	0.41
Dry Afternoon	Urban intersections	15.08	0.32	1.09	1.24
	Agri. area	0.0	0.22	0.59	0.63

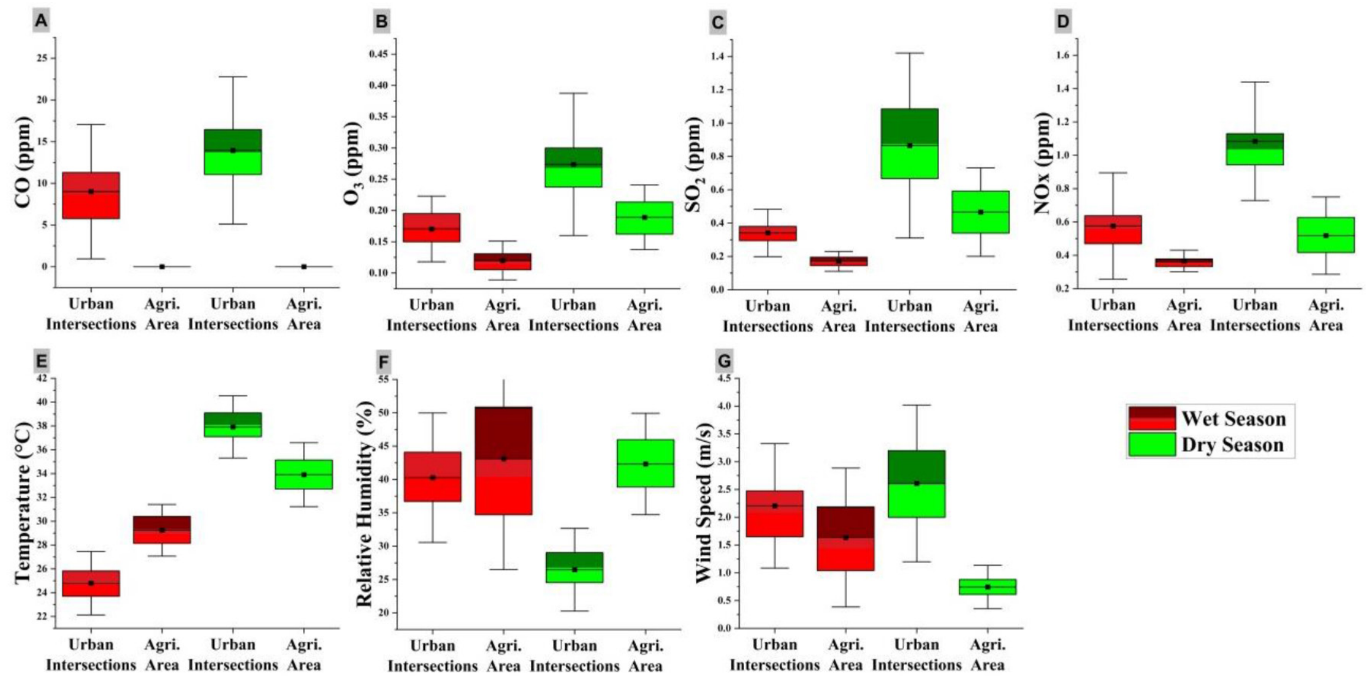

Fig. 3: Box plot of pollutants and weather parameters by site and season

Bayaa, Al-Jadriyah, and Al-Ruwad Street (0.51 - 0.37 ppm) due to high temperature. In the dry season, morning concentrations peaked in Al-Mawal, Al-Faris Al-Arabi, Al-Nisour, Al-Waziryia, and Al-Bayaa (1.31 - 0.97 ppm) due to fossil fuel emissions and increased at noon in Al-Nidaa, Al-Dora Expressway, Bab Al-Muadham, Al-Bayaa, and Burathaa (2.18 - 1.52 ppm).

NOx increased in the morning during the wet season in Al-Jadriya, Al-Shaab, Al-Alawi Garage, Adan, and Al-Masafi Street + Al-Faris Al-Arabi (0.765 - 0.685 ppm) due to traffic density, while the highest values were recorded at noon in Al-Shaab, Al-Liqa Square, Al-Alawi

In the dry season, morning concentrations increased in Al-Tayaran, Kahramana, Al-Liqaa, Al-Masafi St., and Dora Expressway (1.27 - 1.04 ppm) and reached the highest values at noon in Baghdad AL-Jadidah, Al-Nisour, Antar Ibn Shaddad, Adan, and Al-Khalani (2.38 - 1.345 ppm). The results show that traffic congestion and high humidity during the wet season enhanced the accumulation of some gases, such as SO_2 and CO, while high temperatures in the dry season increased O_3 and NO_x.

Urban–agricultural contrast in air pollution

In the wet season, the gaseous pollutants in the urban intersections were higher than those at the control site (Fig. 3). The recorded concentrations of pollutants of CO, O_3, SO_2, and NO_x amounted 9.005 ppm, 0.17 ppm, 0.34 ppm, and 0.575 ppm, respectively, accompanied by a temperature of 24.8°C, RH of 40.27%, and WS of 2.21 m/s. In contrast, the control site during this season reached markedly lower pollutant levels, with undetectable CO, O_3 at 0.12 ppm, SO_2 at 0.21 ppm, and NO_x at 0.365 ppm. The climatic factors were more stable in the control site; there was slightly more humidity (43.02%), less wind speed (1.6 m/s), and a higher temperature (29.6 °C) compared to the urban area. Such high values can be attributed to heavy traffic emissions within the city bounds, which are fossil fuel-powered and ensure dense clouds of CO and NO_x are generated. On the other hand, the agricultural control site recorded very low levels of pollutants since it is away from the main roads and does not have intensive vehicular movement; hence,

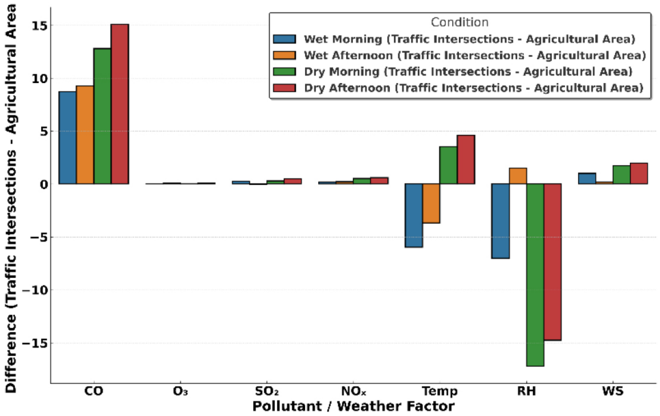

Fig. 4: Differences between pollutants and weather factors at traffic intersections and agricultural area

its emission profile is low. The fairly high humidity, and frequent rains during the wet season might have helped in the spreading and deposition of pollutants; thus, generally, lower levels are seen compared to the dry season.

In the dry season, pollutant levels at the urban intersections increased further. CO rose to 13.94 ppm, O_3 to 0.275 ppm, SO_2 to 0.87 ppm, and NO_x to 1.085 ppm also temperature increased to 37.9 °C, humidity dropped to 26.47%, while WS has risen slightly to 2.61 m/s. On the other hand, the control site in the dry season kept pollution levels relatively low: CO remained at 0 ppm, O_3 reached only 0.195 ppm, SO_2 was 0.465 ppm, and NO_x was 0.52 ppm. The climatic variables showed typical dry season shifts with temperature having risen to 33 .85 °C, humidity has fallen slightly to 42 .45%, and WS is down to 0 .75 m/s. The dry season further accentuated the disparities. While pollutant concentrations in the urban intersecting points increased substantially, those in the control site remained low. Such differences can be attributed to the levels of intensity urban transportation and traffic congestions usually show during dry periods when there is better road weather. The absence of rain and stronger solar radiation has compounded the accumulation of pollutants and photochemical reactions due to existing high-density populations. The control site, which is proximate to green-featuring plants and open space, has derived a lot from natural air purification mechanisms such as plant uptake and increased dispersion, which have added to its constantly cleaner air profile. Findings are consistent with the study on the effects of weather factors on greenhouse gas emissions at traffic intersections in Baghdad. High temperatures and low rainfall in the dry season further enhance the accumulation of air pollutants. This demonstrates how climate factors together affect the air quality of the urban area (Abdulateef, *et al.,* 2025).

Role of weather factors in pollution levels between traffic intersections and agricultural area

Fig. 4 compares pollution levels at traffic intersections and the agricultural area during the wet and dry seasons, in the morning and afternoon, based on the concentration recorded at both locations. The horizontal axis represents the types of gases and atmospheric factors (CO, O_3, SO_2, NO_x, Temp, RH, and WS). The vertical axis represents the difference between intersections and agricultural areas pollution. Positive bars indicate higher pollution at intersections, while negative bars are the opposite. Positive bars mean pollution is higher in the intersections and vice versa for negative bars. Gaseous pollutants (CO, O_3, SO_2, and NO_x) were approximately an order of magnitude higher at the traffic intersections compared to the agricultural area, particularly in the dry season, which indicates the level of influence of heavy traffic-related emissions. The comparatively lower concentrations of pollutants in the agricultural area are basically because of the ability of plants to absorb harmful gases, dissolving some of the pollutants because of humidity, very little direct emissions, and also clean air being spread by wind; thus, it has relatively cleaner air quality compared to any other traffic intersection in the area.

Higher WS traffic intersections might help disperse pollutants; however, lower concentrations are observed in agricultural areas due to vegetation, which absorbs SO_2 and NO_x during photosynthesis, and organic-rich soil that can trap some gaseous pollutants. Higher water vapor also increases gaseous pollutants in the atmosphere due to reactions between gases and humidity. In WS traffic intersections, there are direct emissions like CO and NO_x, but there are no significant sources in WS agricultural areas, hence having cleaner air.

Findings from this study show that the concentrations of air pollutants are higher during the dry season than the wet season, which is also similar to a study conducted by (Al-Rikabi *et al.,* 2024), where they noted that high temperatures enhance the process of NO_2 and CO accumulation. Results of the analysis of (Ali *et al*., 2024) support these results since their study reports that air quality drops appreciably in industrial areas over the summer months due to augmented photochemical activity. On the other hand, (Nasser *et al*., 2024) show that the effect of high humidity in the wet season helps reduce some pollutant concentrations through absorption and deposition processes, which may explain the low values observed in the data of this study during the wet season.

Seasonal air quality analysis of average air pollutant concentrations

The measurements recorded at urban intersections during both wet and dry seasons demonstrated consistently elevated concentrations of gaseous pollutants (Table 3), clearly reflecting the influence of intensive vehicular emissions and urban activities. In the wet season, CO levels between 8.73 and 9.28 ppm are far below the Iraqi threshold of 35 ppm (Table 2), but show active traffic. O_3 concentrations also stand at 0.14–0.20 ppm, well above the permissible limit of 0.1ppm (Table 2). The concentrations of SO_2 and NO_x (0.26–0.42 ppm and 0.54–0.61 ppm respectively), are greater than the levels of national standards (SO_2 0.15ppm, NOx 0.125 ppm) (Table 2). Despite rainfall and higher humidity typically aiding in pollutant dispersion, the presence of these elevated values during the wet season highlights the persistent load of traffic-related emissions. In the dry season pollutant concentrations increased greatly. CO did reach 15.08 ppm, O_3 was 0.32 ppm, SO_2 and NO_x levels were 1.09 and 1.24 ppm respectively far above Iraqi, WHO. and EPA standards (Table 2). Increases are due to reduced atmospheric cleansing (no rain), higher temperatures, and stronger solar radiation which serves to both concentrate pollutants as well

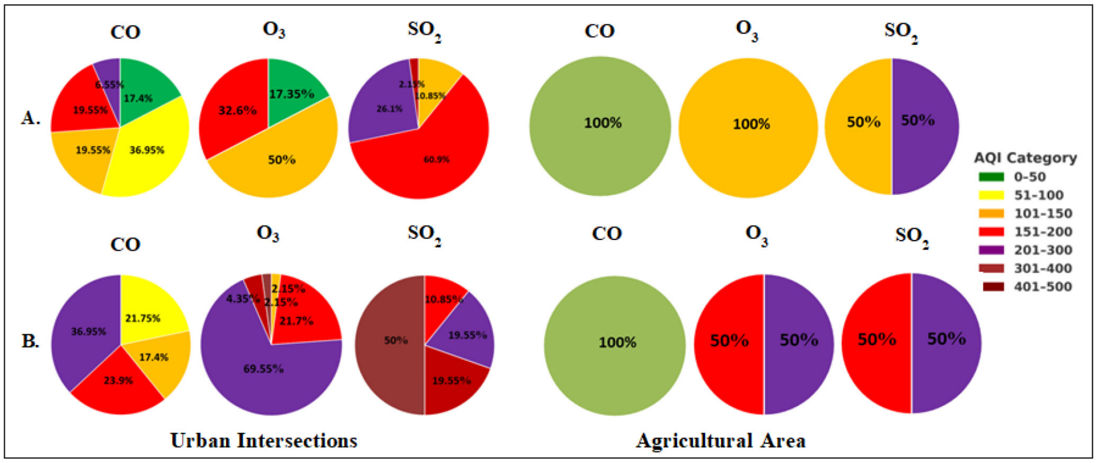

Fig. 5 : Total diurnal average percentage of study sites air quality **(A)** wet season **(B)** dry season

as enhance photochemical reactions leading to ozone The very high levels of pollutants observed in both seasons places urban intersections as key hotspots for air pollution largely driven by sources from transportation.

The concentrations of gaseous pollutants measured at the agricultural control site during wet and dry seasons showed low pollution levels on the whole, with some variation. CO was never detected (0.0 ppm) in any of the time periods, wet or dry season included. Such total nonexistence of CO proves there is little combustion of fossil fuels and vehicle emmissions in the agriculture area; it also falls much below Iraqi, WHO, and EPA air quality standards which permit 35 ppm for 1 hour. O_3 levels at the control site were between 0.11 and 0.13 ppm in the wet season; latter rising to 0.17-0.22 ppm in the dry season. These values have always surpassed the Iraqi standard of 0.1 ppm for 1 hour, indicating possible ozone formation as a result of photochemical reactions driven by increased temperatures and solar radiation in dry conditions, even within low-emission environments. The concentration of SO_2 was between 0.15 to 0.20 ppm in the wet season and got to 0.34-0.59 ppm in dry months. These amounts surpass the Iraqi limit of 0.15 ppm in a lot of cases, especially in the dry afternoons; Although agricultural areas are not major sources of SO_2, these elevated values may reflect industrial activity. NO_x were also found to be high, having values of 0.34-0.39 ppm during the wet season and rising to 0.41-0.63 ppm in dry months. All these values were many times greater than standard of 0.125 ppm. Although traffic is a prime source of NO_x in towns, its high levels seen at the agricultural control site may also come partially from agricultural practices, like using nitrogen-based fertilizers which can cause microbial actions in the soil that release NO and N_2O gases. This local contribution along with possible regional movement might give reasons for the excess of NO_x levels even in a place with low traffic. Agricultural area showed a clean CO profile; it was not detected at any of the sampling periods. However, the regular exceedance of threshold values for O_3 and SO_2, and particularly NO_x, emphasizes that aspects like seasonal atmospheric influences and local agricultural practices should be considered as contributors to air pollution levels, even in places where traffic or industrial activities are less pronounced. These findings concur with previous investigations in Baghdad. Jasim *et al*., (2018) documented higher concentrations of SO_2 and NO_2 in urban areas, particularly during hot months, attributed to traffic and climatic factors. Similarly, Muter *et al*., (2025) reported a decrease in rainfall in central and southern Iraq; this supports our findings of increased pollution during the dry season because of the reduced cleaning of the atmosphere and increased solar radiation. It is worth noting that by referring to the error percentage for each measured gas, the measured values might be higher than the actual concentrations; that is, in reality, these gases' concentrations in ambient air should be less than what the measuring devices indicate, especially in relatively low pollution areas like agricultural areas with a considerable distance from direct emission sources.

Air quality index (AQI)

Based on the breakpoints concentration of AQI as given in Table 1, it is clear that the air quality in Baghdad intersections is greatly affected by the climatic seasons, being better during the wet season, while pollution levels rise significantly during the dry season. AQI results during the wet season showed a clear difference between urban and agricultural areas (Fig. 5A). For CO, pollution levels varied across urban areas 36.95% of measurements fell into the "moderate" (51-100) category, 19.55% fell into the "unhealthy" category, 6.55% fell into the "very high" (201-300) category, and only 17.4% fell into the "good" (0-50) category. In agricultural areas, however, 100% of the measurements fell into the "good" (0-50) category. For O_3, 50% of urban measurements fell into the "unhealthy for sensitive groups" (101-150) category, and 32.6% fell into the "unhealthy" (151-200) category, indicating an increase in photochemical reactions. In agricultural areas, 100% of the values fell into the "unhealthy for sensitive groups" (101-150) category, indicating that sunlight is beginning to affect the formation of ground-level ozone. For SO_2, 60.9% of urban measurements fell into the "unhealthy" (151-200) category, 26.1% fell into the "very unhealthy" (201-300) category, and 2.15% fell into the "hazardous" (301-400) category. At the same time, agricultural readings were evenly split between the "unhealthy for sensitive groups" (101-150) category and "very unhealthy" (201-300). These results reflect the impact of transportation and industrial emissions in urban areas, while industrial activities may contribute to emissions of some pollutants , such as SO_2, that wind brings.

Pollution levels increased significantly during the dry season, especially in urban areas. Urban CO levels show a significant rise in pollution levels (Fig. 5B). 36.95% of the values are in the “very unhealthy” category (201-300) and 23.9% in the “unhealthy” (151-200) category. This reflects the continued strong impact of traffic emissions, as well as the increasing impact of industrial activities, whose emissions increase with the rising temperatures at this time of year. In contrast, 100% of CO levels in agricultural areas remained in the “good” range. O_3 accounted for 69.55% of urban values in the “very unhealthy” category (201-300). This high proportion may be due to photochemical interactions between the main pollutants from vehicles, especially due to increased solar radiation during the dry season. In agricultural areas, the values are evenly distributed between “unhealthy” and “very unhealthy,” which may be partly attributed to agricultural activities. However, diffuse pollution from nearby industrial areas may have contributed to the higher values. As for SO_2, 50% of urban levels were in the “very hazardous” category (401-500), and 19.55% were in both the “very unhealthy” (201-300) category and “hazardous” (301-400) category, which could be due to vehicles and industrial emissions such as refineries, asphalt, brick, or cement factories. In agricultural areas, values ranged from “unhealthy” to “very unhealthy,” indicating the presence of non-transport sources of pollution, including air pollution in industrial areas or emissions from the use of fertilizers and pesticides. Overall, these results reflect air quality is affected by a complex mix of emissions, weather conditions, and industrial sources as well as transportation-related emissions (Sokhi *et al*., 2021), the significant impact of industrial activities on the deterioration of air quality in both seasons which becomes more pronounced in the dry season due to low rainfall, increased evaporation, and decreased wind speed (Shelton et al., 2022). As well as high temperatures, which contribute to increased accumulation of pollutants and lower rates of natural dilution.

These results confirm that the wet season improves air quality compared with the dry season, which worsens pollution, especially in the afternoon when O_3 and SO_2 concentrations increase to dangerous levels that exceed safe limits according to AQI standards, which may threaten public health. It is worth noting that the air quality index for NOx was not calculated in this study, even though it was measured in the study sites, because the EPA equation includes calculating air quality exclusively for NO_2 values, which represents a portion of NOx in combination with NO. Therefore, it wasn’t easy to estimate the percentage of NO_2 emitted from mobile vehicles due to the variety of cars, sizes, models, and types of fuel burned.

CONCLUSION

The spatiotemporal distribution of gaseous pollutants (CO, SO_2, NO_x, O_3) in urban and agricultural areas of Baghdad was analyzed, focusing on the influence of climatic factors such as temperature, humidity, and wind speed. The results indicate that during the dry season, more pollutants are accumulated due to high temperatures and low humidity, which then enhance photochemical reactions. Thus, the more heavily polluted conditions were in the afternoon due to the heavy traffic and increased solar activity. Overall, low levels of pollutants were recorded at the agricultural site, particularly for CO, which was not detected at all. This underscores the role that vegetation coverage and distance from direct emission sources play in air quality improvement. High concentrations of some pollutants were noted at the agricultural site SO_2 and NO_x distant industrial impacts or agricultural practice (fertilizer use) could be indicated here, plus wind transport of the pollutants.The results prove that seasonal changes and temporal and spatial variations in air quality are very heavily based on climatic conditions and human activities. In these results, the strong need to integrate climatic factors into the strategies of managing quality air, more so in the urban areas, will receive support. The recommendation here is to adopt green infrastructures such as trees and green spaces to improve air quality. Another recommendation would be efficient traffic management and control measures of vehicle emissions, particularly in the afternoon and dry season when concentrations are the highest. Consequently, the study further contributes to understanding how air pollution dynamics occur in an arid urban setting to facilitate the decision-maker’s formulation of sustainable environmental policies. Further studies can be done to permit assessments of the impacts of long-term climatic variations on air quality in Baghdad regarding the health and economic effects of air pollution.

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