Journal of Geography, Regional Planning and Development
Homepage : https://journal.antispublisher.id/index.php/JGRPD
Email : admin@antispublisher.com

e-ISSN : 3032-131X
JGRPD, Vol. 3, No. 8, August 2026
Page 1-29

The Impact of Human Activitieson Air Pollution in the Urban Environment of Samarra City

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DOI : https://doi.org/10.61796/jgrpd.v3i8.1910

Sections Info

Article history:
Submitted: Jun 23, 2026
Final Revised: Jun 11, 2026
Accepted: Aug 16, 2026
Published: Aug 25, 2026

Keywords:
air pollution
human activities
urban environment
Samarra City
transportation
spatial variation
atmospheric indicators
GIS

ABSTRACT

Objective: *Against this background, the present study examines the spatial relationship between human activities and air pollution within the urban environment of Samarra City.* ***Method:*** *The study adopted a geographical and descriptive-analytical approach supported by field surveys, environmental measurements, questionnaire data, and GIS-based spatial representation. Field measurements were conducted in cooperation with the Salah Al-Din Environment Directorate at five major intersections on 22 May 2026, during morning, midday, and evening peak periods. The monitored atmospheric indicators included sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), hydrocarbons (HC), and carbon dioxide (CO_2). The recorded values were analyzed as relative levels for comparative assessment among the selected monitoring sites.* ***Results:*** *The results revealed clear spatial variation in the relative levels of the monitored atmospheric indicators. Locations characterized by comparatively intensive traffic and commercial activity generally exhibited higher relative levels than locations with less intensive vehicular and commercial activity. Muraidi Market Intersection exhibited the highest overall relative pollution profile, recording CO_2 (80%), SO_2 (70%), NO_2 (50%), HC (30%), and CO (7%). Al-Alwa Intersection ranked second overall, recording CO_2 (75%), SO_2 (60%), NO_2 (53%), HC (25%), and CO (5%). Notably, Al-Alwa recorded a slightly higher relative NO_2 level than Muraidi Market, demonstrating that individual atmospheric indicators do not necessarily follow identical spatial patterns. The observed spatial pattern was associated with differences in traffic intensity, commercial activity, surrounding land use, and other human activities characterizing the monitoring locations.* ***Novelty:*** *However, because the study did not conduct quantitative source-apportionment analysis, these relationships are interpreted as spatial associations rather than evidence of the independent causal contribution of individual emission sources. The findings highlight the importance of expanding air-quality monitoring, improving urban traffic management, reducing uncontrolled waste burning, strengthening vehicle-emission inspection, promoting cleaner energy practices, and integrating air-quality considerations into urban planning. These measures may contribute to improving urban environmental quality and supporting sustainable development in Samarra City.*

INTRODUCTION

Air pollution has become an increasingly significant environmental concern in parallel with rapid urban growth and the intensification of human activities. Its consequences extend beyond atmospheric quality to human health, environmental conditions, economic activities, and the overall quality of urban life. Urban and industrial expansion, population growth, increasing energy demand, and the rising number of vehicles can increase atmospheric emissions, particularly in areas characterized by concentrated economic activities, intensive traffic, and frequent fuel-combustion processes. The spatial distribution of air pollution may vary considerably within urban areas according to differences in land use, transportation patterns, commercial activity, industrial functions, population concentration, and other anthropogenic pressures. Major transportation corridors and areas of intensive commercial or industrial activity may experience greater environmental pressure from vehicular emissions and fuel combustion than less congested locations. Such spatial differences make geographical analysis particularly relevant for examining urban air pollution, as it enables environmental observations to be interpreted in relation to the spatial distribution of human activities and the functional characteristics of individual urban locations.Samarra City has experienced continued urban development accompanied by the expansion of commercial and service activities and increased vehicular movement along major roads and intersections. These changes have created growing environmental pressures, particularly at locations characterized by intensive traffic, commercial concentration, and diverse urban functions. Understanding the spatial pattern of air pollution within the city therefore requires an integrated assessment of environmental measurements and the characteristics of human activities surrounding the selected monitoring sites.Accordingly, the present study examines the relationship between human activities and air pollution in the urban environment of Samarra City. It focuses on identifying potential anthropogenic emission sources and analyzing spatial variations in the relative levels of selected atmospheric indicators—SO_2, CO, NO_2, HC, and CO_2—across five monitoring sites. The study further interprets these spatial differences in relation to traffic intensity, commercial activity, surrounding land use, and other relevant urban activities. Field measurements, questionnaire data, and GIS-based spatial representation are integrated to provide a geographical assessment of the observed patterns and to support the development of practical recommendations for improving urban air-quality management and promoting sustainable urban environmental development in Samarra City. [1]

Research Problem

The research problem arises from the increasing environmental pressures associated with human activities in Samarra City, particularly transportation, commercial and service activities, industrial operations, electricity generation, and uncontrolled waste burning. These activities are unevenly distributed across the urban area and may therefore correspond with spatial differences in air-quality conditions among different locations. Despite the growing intensity of urban activities in Samarra, locally based evidence concerning the spatial distribution of atmospheric pollution and its relationship with patterns of human activity remains limited. Accordingly, the research problem focuses on examining the spatial relationship between human activities and the relative levels of selected atmospheric indicators across major urban locations in Samarra City. Particular attention is given to identifying spatial differences among the selected monitoring sites and interpreting these differences in relation to traffic intensity, commercial activity, surrounding land use, and other relevant anthropogenic pressures.

The main research question is:

How are human activities associated with the spatial pattern of air pollution in the urban environment of Samarra City?

The study addresses the following specific questions:

1. What are the major human activities potentially associated with air pollution in Samarra City?
2. What spatial variations exist in the relative levels of selected atmospheric indicators among the monitoring sites?
3. How do differences in traffic intensity, commercial activity, surrounding land use, and other urban activities correspond with the observed spatial pattern of air pollution?
4. Which monitoring sites exhibit the highest and lowest relative levels of the selected atmospheric indicators?
5. What practical measures may contribute to reducing anthropogenic emission pressures and improving urban air-quality management in Samarra City?

Working Hypotheses

The study is guided by the following working hypotheses:

1. The relative levels of selected atmospheric indicators vary spatially among the monitoring sites in Samarra City in association with differences in the intensity and distribution of human activities.
2. Monitoring sites characterized by intensive vehicular movement and commercial activity tend to exhibit higher relative levels of selected atmospheric indicators than locations characterized by less intensive traffic and commercial activity.
3. Individual atmospheric indicators exhibit different spatial patterns among the selected monitoring sites, reflecting variations in local traffic characteristics, surrounding land use, and other urban activities.
4. Transportation-related activities constitute an important anthropogenic pressure associated with the observed spatial pattern of air pollution in Samarra City, alongside other potential urban emission sources such as industrial activities, electricity generation, private generators, and uncontrolled waste burning.

Research Objectives

The primary objective of this study is to examine the spatial relationship between human activities and air pollution within the urban environment of Samarra City. To achieve this objective, the study seeks to:

1. Identify the major human activities that may represent potential sources of atmospheric emissions within Samarra City.
2. Analyze spatial variations in the relative levels of selected atmospheric indicators across the monitoring sites.

3. Examine how traffic intensity, commercial activity, surrounding land use, and other urban activities correspond with differences in the observed relative atmospheric indicator levels.
4. Identify the monitoring sites exhibiting the highest and lowest relative levels of the selected atmospheric indicators and interpret their geographical and functional characteristics.
5. Employ GIS-based spatial representation to illustrate differences in relative atmospheric indicator levels among the selected monitoring sites.
6. Propose practical measures that may contribute to reducing anthropogenic emission pressures and improving urban air-quality management in Samarra City.

METHODOLOGY

The study adopted a geographical and descriptive-analytical approach to investigate spatial variations in air pollution and their relationship with human activities in Samarra City. The geographical approach was used to examine the spatial distribution of urban activities and differences in the relative levels of selected atmospheric indicators across the monitoring sites. The descriptive-analytical approach was employed to characterize potential anthropogenic emission sources and interpret the observed spatial patterns in relation to traffic conditions, commercial activity, surrounding land use, and other urban characteristics.

Fieldwork constituted a central component of the study. Environmental measurements were conducted in cooperation with the Salah Al-Din Environment Directorate at five selected monitoring sites in Samarra City: Muraidi Market, Al-Alwa, Al-Razzaq, Al-Qadisiyah, and Al-Istishariyah. The selected sites represent different urban and functional characteristics, including variations in vehicular movement, commercial activity, surrounding land use, and other forms of human activity.

The field-measurement component focused on five atmospheric indicators: sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), hydrocarbons (HC), and carbon dioxide (CO_2). CO_2 was included as a supplementary combustion-related atmospheric indicator and was not treated as a conventional health-based ambient air pollutant.

Field measurements were conducted on 22 May 2026 during morning, midday, and evening peak periods. The measurements obtained during these periods were organized and compared across the five monitoring sites to examine spatial differences in the recorded atmospheric conditions. The resulting values are presented in the study as relative percentage levels derived from the field-measurement dataset for comparative purposes among the selected sites. They should not be interpreted as absolute atmospheric concentrations, annual averages, or percentages of international air-quality guideline limits.

A field questionnaire was also employed as a complementary source of information concerning residents' perceptions of human activities and environmental pressures in Samarra City. A total of 200 questionnaires were distributed, 190 were returned, and 180 valid questionnaires were included in the final statistical analysis. The questionnaire consisted of 21 items distributed across four analytical dimensions. Descriptive statistical techniques, including frequencies, percentages, means, standard deviations, and relative weights, were used to summarize and interpret the questionnaire responses. Internal consistency reliability was assessed using Cronbach's alpha, with an overall coefficient of 0.932.

Geographic Information Systems (GIS) were used to represent the field data spatially and illustrate differences among the selected monitoring sites. ArcGIS 10.8 was employed to prepare the spatial outputs and maps and to support the geographical interpretation of the observed distribution of relative atmospheric indicator levels across the study area.

The study integrates field measurements, questionnaire findings, field observations, and GIS-based spatial representation to provide a descriptive and spatially comparative assessment of urban air pollution in Samarra City. Because the field measurements were obtained on a single date and the study did not include continuous monitoring or quantitative source-apportionment analysis, the findings are interpreted as evidence of spatial association rather than proof of the independent causal contribution of individual emission sources.

Questionnaire Sample and Participant Selection

A total of **200 questionnaires** were distributed among residents of selected neighborhoods in Samarra City representing different residential, commercial, and mixed-use settings. Of these, **190 questionnaires were returned (95%)**, and **180 valid questionnaires (90% of the distributed forms)** were retained for the final statistical analysis. The questionnaire collected information on residents' perceptions of pollution sources, environmental manifestations and effects, and proposed pollution-control measures.

Validity and Reliability of the Questionnaire

The questionnaire consisted of **21 items** distributed across four dimensions: sources of air pollution, manifestations of environmental pollution, effects on residents and the urban environment, and pollution-control measures. The items were developed in accordance with the objectives and research questions of the study and were reviewed for clarity, relevance, and consistency with the environmental context of Samarra City.

Internal consistency was assessed using **Cronbach's alpha** based on the **180 valid responses**. The coefficients were **0.807** for Sources of Air Pollution, **0.778** for Manifestations of Pollution, **0.728** for Effects on Residents and the Urban Environment, and **0.782** for Pollution-Control Measures. The overall coefficient for the 21-item questionnaire was **0.932**, indicating high internal consistency for the instrument as a whole.

Table 1. Reliability Analysis of the Questionnaire Dimensions.

Dimension	No. of Items	Mean Score	Cronbach's Alpha
Sources of Air Pollution	**6**	**2.459**	**0.807**
Manifestations of Pollution	**5**	**2.444**	**0.778**
Effects on Residents and the Urban Environment	**4**	**2.493**	**0.728**
Pollution-Control Measures	**6**	**2.640**	**0.782**
Overall Questionnaire	**21**	**2.514**	**0.932**

The reliability results indicate that all questionnaire dimensions achieved acceptable internal consistency, while the overall instrument demonstrated a high reliability coefficient.

Temporal Scope of Field Measurements

The field measurements provide a spatial assessment of air-pollution conditions at the selected monitoring sites during the survey conducted on 22 May 2026. Accordingly, the recorded values are interpreted as observations of the conditions prevailing during the measurement periods rather than as annual average concentrations for Samarra City. This temporal scope was considered when interpreting spatial differences among the monitoring sites, as pollutant levels may vary over time in response to changes in traffic intensity, local activities, and prevailing environmental conditions.

Location of the Study Area

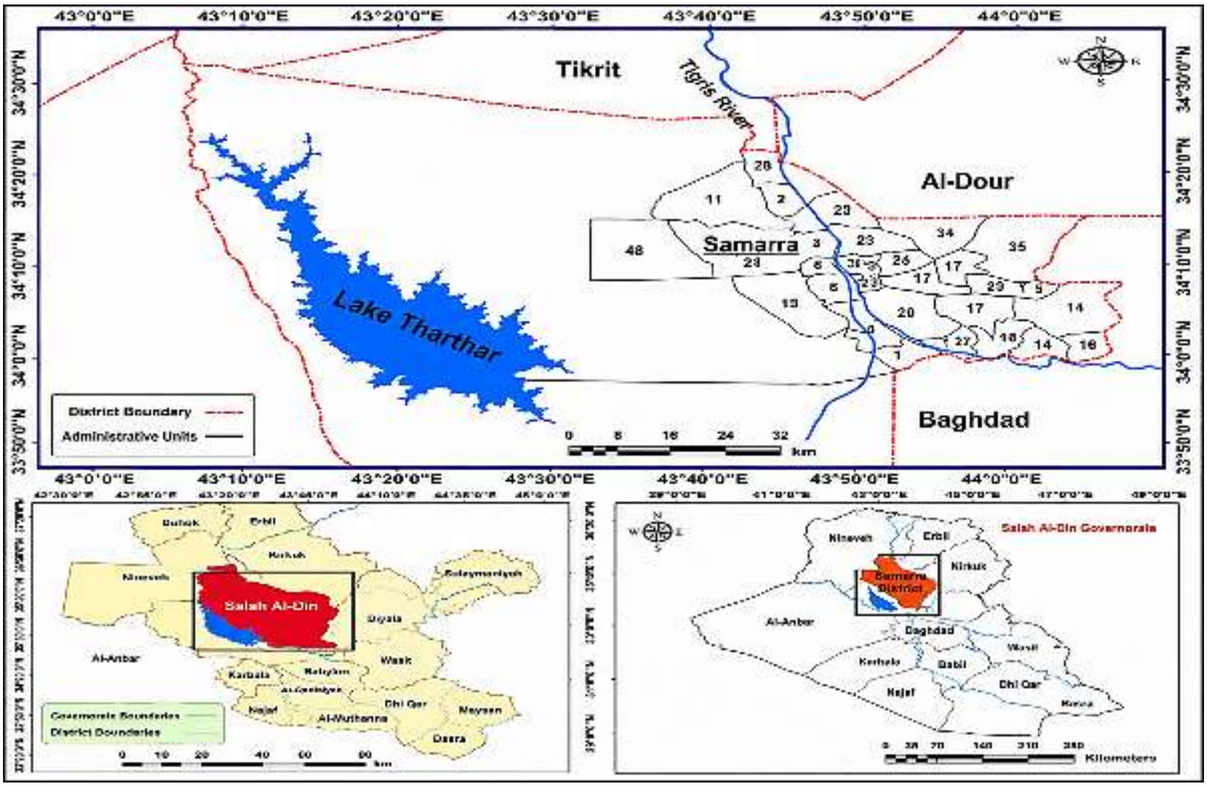
1. Astronomical Location

Samarra City is located between latitudes **34°10′–34°13′ N** and longitudes **43°52′–43°57′ E**, as shown in Map (1). Its astronomical location influences its climatic characteristics, which are generally marked by high temperatures during summer and lower temperatures in winter, together with low rainfall and high evaporation rates.

2. Geographical Location

Samarra City is situated in the southern part of **Salah Al-Din Governorate** and serves as the administrative center of Samarra District, which includes the subdistricts of **Al-Markaz, Al-Mu'tasim, and Dijla**. The city covers an area of approximately **46 km²** and comprises **27 residential neighborhoods**, while Samarra District has a total area of approximately **4,504 km²**.Samarra District is bordered by **Tikrit** to the north, **Balad** to the south, and **Al-Dour** to the northeast. The city is also strategically located along the **Tigris River** and is connected to surrounding areas through an extensive road network. This geographical setting has strengthened its administrative, commercial, and service functions and has contributed to increased population mobility, vehicular traffic, and the intensity of human activities within the city.[2]

Map 1. Location of the Study Area.



Source: Prepared by the researcher based on the Administrative Map of Iraq, the Administrative Map of Salah Al-Din Governorate, the base map of Samarra City, and satellite imagery, using ArcGIS 10.8.

Impact of Human Activities on Urban Environmental Pollution

Human activities are a major driver of the changes occurring in urban environments. The concentration of population, economic activities, and services within cities increases the demand for energy, transportation, housing, and public services. This, in turn, leads to greater fuel consumption, increased vehicular movement, and the expansion of various facilities, resulting in higher volumes of emissions released into the urban environment.Air pollution is among the most prominent environmental problems associated with these activities, particularly in areas characterized by heavy traffic or concentrations of industrial and commercial activities. Fuel combustion in vehicles, generators, and industrial facilities releases a range of gaseous pollutants and particulate matter. Pollutant levels tend to increase at locations where vehicles frequently stop, traffic congestion is persistent, and traffic flow is restricted.The effects of urban growth are not limited to increasing emission sources. They also involve changes in land-use patterns, the decline of some open and green spaces, and increasing building and population densities. Consequently, the degree of exposure to air pollution varies across different parts of the city according to the type and intensity of prevailing activities, traffic volume, and the urban characteristics of each area.In Samarra City, this relationship is particularly evident in areas where commercial and service activities are concentrated alongside intensive vehicular movement. Areas characterized by greater traffic and commercial activity are therefore expected to record higher pollutant levels than less active areas. This relationship can be assessed by comparing the results of field measurements obtained from the selected monitoring sites. Geographical analysis provides an effective means of interpreting these spatial variations by examining the relationships among **location, land use, human activity, and pollution levels**, rather than considering pollutant concentrations in isolation. This approach makes it possible to identify pollution hotspots and explain the factors responsible for higher or lower pollutant levels across different parts of the study area.[3]

Theme One

Conceptual Framework of Air Pollution

The Concept of the Environment

The environment represents the setting in which humans and other living organisms exist and carry out their various activities. It consists of a range of natural and human elements that interact through complex and reciprocal relationships. These elements include air, water, soil, and living organisms, as well as population, economic activities, and patterns of urban development.

The urban environment is characterized by continuous interaction between natural and human components. Changes in population size, land-use patterns, transportation activity, and economic functions can influence environmental conditions within cities. Therefore, studying the urban environment requires an examination of the relationship between people and place, together with an assessment of the environmental consequences associated with human activities.[4]

The Concept of Air Pollution

Air pollution refers to the presence of pollutants in the atmosphere at levels capable of adversely affecting human health, other living organisms, and environmental systems. The magnitude of these effects depends on several factors, including the type and concentration of pollutants, the duration of exposure, and meteorological conditions that influence their dispersion and accumulation (World Health Organization [WHO], 2021).

Sources of air pollution can generally be classified into natural and anthropogenic sources. Natural sources include phenomena such as dust storms, whereas anthropogenic sources include transportation, industrial activities, power generation, fuel combustion, and waste burning. These human-related sources are particularly important in urban environments because population, transportation, commercial activities, and energy consumption are spatially concentrated within cities (United Nations Environment Programme [UNEP], 2021).

Table 2. Approximate Atmospheric Composition of Dry Air.

Component	Symbol	Approximate Concentration (%)
Nitrogen	N_2	78.08
Oxygen	O_2	20.95
Argon	Ar	0.93
Carbon Dioxide	CO_2	≈ 0.04
Other Trace Gases	–	< 0.01

Note: The values represent the approximate composition of dry atmospheric air. Carbon dioxide concentration may vary over time and location, while several other atmospheric gases occur only in trace amounts.

Air pollution occurs when substances are introduced into the atmosphere, or when naturally occurring atmospheric constituents reach levels capable of adversely affecting human health, living organisms, or environmental quality. According to the World Health Organization (WHO, 2021), major air pollutants of public-health concern include particulate matter, carbon monoxide, ozone, nitrogen dioxide, and sulfur dioxide. In urban environments, these pollutants are commonly associated with anthropogenic activities such as transportation, fuel combustion, power generation, industrial activities, and waste burning.

The principal atmospheric pollutants and related indicators relevant to the present study include:

- Sulfur oxides (SO_x).
- Nitrogen oxides (NO_x).
- Carbon monoxide (CO).
- Carbon dioxide (CO_2).
- Hydrocarbons (HC).
- Suspended particulate matter (TSP and PM).
- Ground-level ozone (O_3).

The environmental and health significance of these atmospheric constituents varies according to their concentrations, chemical characteristics, duration of exposure, and prevailing meteorological conditions. Elevated levels of conventional air pollutants may adversely affect human health and contribute to the deterioration of urban environmental quality. Atmospheric pollutants and their precursors are also associated with broader environmental processes, including acid deposition, photochemical smog formation, and damage to vegetation, while greenhouse gases such as carbon dioxide are primarily associated with climate change (WHO, 2021; UNEP, 2021).

Air Pollutants

Air pollutants include gaseous substances and particulate matter that may adversely affect human health and environmental quality when present in the atmosphere at elevated levels. Transportation represents an important anthropogenic source of urban air pollution because fuel combustion in vehicle engines releases pollutants such as carbon monoxide, nitrogen oxides, hydrocarbons, particulate matter, and, depending on fuel composition, sulfur oxides.

The quantity and composition of vehicle emissions are influenced by several factors, including traffic volume, fuel type, vehicle age, engine efficiency, maintenance condition, and driving patterns. Traffic congestion and repeated acceleration, deceleration, and idling can increase fuel consumption and may contribute to elevated emissions at heavily congested urban locations.

Meteorological conditions, particularly wind speed and direction, temperature, and atmospheric stability, also influence the transport, dispersion, and accumulation of air pollutants. Consequently, pollution levels may vary considerably among monitoring locations within the same urban area (UNEP, 2021).

Among the gaseous pollutants and related atmospheric indicators considered in the present study are carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), hydrocarbons (HC), and carbon dioxide (CO_2).

Carbon Monoxide (CO): Carbon monoxide is a colorless and odorless gas produced primarily through the incomplete combustion of carbon-containing fuels. In urban environments, important anthropogenic sources include motor vehicles, electricity generators, and other fuel-burning equipment. When inhaled at elevated levels, CO binds to hemoglobin and reduces the blood's capacity to transport oxygen, potentially causing adverse health effects depending on the concentration and duration of exposure. Consequently, CO is considered an important indicator of combustion-related urban air pollution, particularly in areas characterized by heavy traffic and intensive fuel use. The World Health Organization identifies carbon monoxide as one of the major air pollutants of public-health concern and provides health-based air-quality guideline levels for its assessment (WHO, 2021).

Sulfur Dioxide (SO_2): Sulfur dioxide is a gaseous air pollutant produced mainly through the combustion of sulfur-containing fuels. In urban environments, its anthropogenic sources may include power generation, industrial activities, fuel-burning equipment, and certain transportation activities using sulfur-containing fuels. Exposure to elevated concentrations of SO_2 can adversely affect the respiratory system and may aggravate respiratory symptoms, particularly among sensitive population groups. In the atmosphere, sulfur dioxide can also participate in chemical reactions that contribute to the formation of secondary particulate matter and acid deposition. The World Health Organization identifies SO_2 as one of the major air pollutants of public-health concern and provides health-based air-quality guideline levels for its assessment (WHO, 2021).

Nitrogen Dioxide (NO_2): Nitrogen dioxide is an important gaseous air pollutant associated primarily with high-temperature combustion processes. In urban environments, major anthropogenic sources include motor-vehicle engines, power-generation systems, and other fuel-combustion activities. NO_2 is one component of nitrogen oxides (NO_x) and is commonly used as an indicator of combustion-related urban air pollution. Exposure to elevated concentrations of NO_2 can adversely affect the respiratory system, particularly among sensitive population groups. Nitrogen dioxide also participates in atmospheric chemical reactions that contribute to the formation of ground-level ozone and secondary particulate matter. The World Health Organization identifies NO_2 as one of the major air pollutants of public-health concern and provides both short-term and long-term air-quality guideline levels for its assessment (WHO, 2021).

Hydrocarbons (HC): Hydrocarbons comprise a broad and chemically diverse group of organic compounds that may be released into urban air through incomplete fuel combustion, fuel evaporation, storage and distribution processes, vehicle-related activities, and other anthropogenic sources. Their environmental and health significance varies according to the chemical composition, concentration, and duration of exposure; therefore, the potential health effects of HC should not be generalized to all hydrocarbon compounds without identifying the specific substances involved. Certain volatile hydrocarbons can also participate in photochemical reactions with nitrogen oxides (NO_x) in the presence of sunlight, contributing to the formation of ground-level ozone and photochemical smog. In the present study, HC is treated as a general field-measurement indicator rather than as a measure of individual hydrocarbon compounds.

Carbon Dioxide (CO_2): Carbon dioxide is a naturally occurring atmospheric gas and an essential component of the global carbon cycle. It is produced naturally through processes such as respiration and decomposition, while anthropogenic activities, particularly the combustion of fossil fuels, contribute additional CO_2 to the atmosphere. In urban environments, transportation, electricity generation, industrial activities, and other fuel-combustion processes can contribute to local CO_2 emissions. Unlike carbon monoxide (CO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2), carbon dioxide is not treated by the World Health Organization's global ambient air-quality guidelines as a conventional outdoor air pollutant with a health-based guideline value. Its broader environmental significance is primarily associated with its role as a greenhouse gas and its contribution to climate change (UNEP, 2021). In the present study, CO_2 is therefore treated as a supplementary indicator associated with combustion-related human activities rather than as a conventional criteria air pollutant. The relative CO_2 values obtained from the selected monitoring sites are used for spatial comparison within Samarra City and should not be interpreted as absolute atmospheric concentrations or as exceedances of international health-based air-quality standards.[5]

Table 3. Reported Exhaust Emission Values by Vehicle Weight.

Vehicle Weight (kg)	CO (g)	HC (g)	NO_x (g)
Up to 750	60	4.7	9.6
850–1020	70	5.2	10.5
1020–1250	80	6.1	11.4
More than 1250	132	8.3	17.4

Source: Naas, H. H. (2008). Air Pollution Caused by Automobiles and Traffic Movement in Damascus City, Faculty of Arts, Damascus University, p. 605.

Note: The values presented in the table are reproduced from the cited source and are included for comparative and contextual purposes. They do not represent direct measurements from vehicles operating in Samarra City and should not be interpreted as current regulatory emission limits.

The data reported in Table 3 show an increasing pattern in the listed exhaust-emission values across the vehicle-weight categories presented in the original source. CO increases from **60 g** for vehicles weighing up to **750 kg** to **132 g** for vehicles weighing more than **1,250 kg**. Similarly, HC increases from **4.7 g** to **8.3 g**, while NO_x increases from **9.6 g** to **17.4 g**.

These reference values provide contextual support for considering vehicle characteristics when examining transportation-related air pollution. However, they should not be used to establish a direct quantitative relationship between vehicle weight and the relative pollutant levels measured in Samarra City, because the table originates from a different study context and the present field investigation did not measure emissions from individual vehicles according to weight categories. In the current study, the potential influence of heavy-duty vehicle movement is therefore interpreted together with traffic intensity, congestion, surrounding land use, and the spatial pattern observed at the selected monitoring sites.truck movement.

The main dimensions and their corresponding indicators are presented in Table 4.

The field questionnaire was organized into four main analytical dimensions designed to address the objectives of the study and examine residents' perceptions of environmental pollution associated with human activities in Samarra City. These dimensions covered the principal sources of air pollution, manifestations of environmental pollution, effects on residents and the urban environment, and measures proposed to reduce pollution. The main dimensions and their corresponding indicators are presented in Table

Table 4. Main Dimensions and Indicators of the Field Questionnaire.

No.	Main Dimension	Main Indicators
1	Sources of air pollution	Traffic, congestion, heavy vehicles, generators, industrial and commercial activities, and waste burning
2	Manifestations of pollution	Smoke and exhaust emissions, dust, unpleasant odors, noise, and visual pollution
3	Effects on residents and the urban environment	Reduced daily comfort, deterioration of the residential environment, sleep disturbance, and reduced urban environmental quality

No.	Main Dimension	Main Indicators
4	Pollution-control measures	Traffic regulation, prevention of waste burning, expansion of green spaces, emission monitoring, vehicle inspection, and promotion of cleaner energy

Source: Prepared by the researcher based on the field questionnaire conducted in Samarra City, 2026.

Questionnaire Statistical Results

Descriptive statistical analysis was conducted for the 21 questionnaire items using frequencies, percentages, arithmetic means, standard deviations, and rank order. Responses were coded on a three-point scale, where a higher mean score indicates a greater perceived importance or intensity of the corresponding item.

Table 5. Overall Statistical Results of the Questionnaire Dimensions.

Dimension	No. of Items	Mean Score	Rank
Pollution-Control Measures	6	**2.640**	1
Effects on Residents and the Urban Environment	4	**2.493**	2
Sources of Air Pollution	6	**2.459**	3
Manifestations of Pollution	5	**2.444**	4
Overall Questionnaire	**21**	**2.514**	—

The results indicate an overall mean score of **2.514 out of 3**, reflecting a relatively high level of agreement among respondents regarding the environmental pressures associated with human activities in Samarra City. Pollution-control measures recorded the highest dimension mean (**2.640**), followed by effects on residents and the urban environment (**2.493**), sources of air pollution (**2.459**), and manifestations of pollution (**2.444**).

Results of the Sources of Air Pollution Dimension

Table 6. Respondents' Assessment of the Main Sources of Air Pollution (n = 180).

Rank	Source	High n (%)	Moderate n (%)	Low n (%)	Mean	SD
1	Heavy vehicular traffic	121 (67.2%)	50 (27.8%)	9 (5.0%)	2.622	0.580
2	Traffic congestion and frequent vehicle stops	120 (66.7%)	45 (25.0%)	15 (8.3%)	2.583	0.642
3	Movement of trucks and heavy-duty vehicles	110 (61.1%)	52 (28.9%)	18 (10.0%)	2.511	0.673
4	Private electric generators	94 (52.2%)	60 (33.3%)	26 (14.4%)	2.378	0.726

Rank	Source	High n (%)	Moderate n (%)	Low n (%)	Mean	SD
5	Industrial and commercial activities	87 (48.3%)	71 (39.4%)	22 (12.2%)	2.361	0.691
6	Waste burning	91 (50.6%)	52 (28.9%)	37 (20.6%)	2.300	0.790

Overall Dimension Mean = 2.459

The results show that transportation-related activities occupied the leading positions among the perceived sources of air pollution. Heavy vehicular traffic ranked first with a mean score of **2.622**, followed by traffic congestion and frequent vehicle stops (**2.583**) and the movement of trucks and heavy-duty vehicles (**2.511**). Private generators, industrial and commercial activities, and waste burning followed with mean scores of **2.378, 2.361, and 2.300**, respectively. These results indicate the prominent position of transportation-related pressures in respondents' perceptions of urban air pollution in Samarra City.[6]

Results of the Manifestations of Environmental Pollution Dimension

Table 7. Respondents' Assessment of the Manifestations of Environmental Pollution (n = 180).

Rank	Manifestation	High n (%)	Moderate n (%)	Low n (%)	Mean	SD
1	Dust and airborne particles	110 (61.1%)	58 (32.2%)	12 (6.7%)	2.544	0.619
2	Smoke and exhaust emissions	106 (58.9%)	63 (35.0%)	11 (6.1%)	2.528	0.611
3	Noise pollution	111 (61.7%)	52 (28.9%)	17 (9.4%)	2.522	0.664
4	Visual pollution and deterioration of the urban landscape	80 (44.4%)	77 (42.8%)	23 (12.8%)	2.317	0.689
5	Unpleasant odors	81 (45.0%)	74 (41.1%)	25 (13.9%)	2.311	0.703

Overall Dimension Mean = 2.444

Dust and airborne particles ranked first among the perceived manifestations of environmental pollution, with a mean score of **2.544**, followed closely by smoke and exhaust emissions (**2.528**) and noise pollution (**2.522**). These results indicate that respondents most frequently associated environmental deterioration in Samarra City with visible airborne particles, combustion-related emissions, and noise-related disturbance.Visual pollution and deterioration of the urban landscape ranked fourth, with a mean score of **2.317**, while unpleasant odors ranked fifth, with a mean score of **2.311**. Although these two manifestations received comparatively lower mean scores, their values still indicate a noticeable presence in respondents' perceptions of the urban environment.The overall dimension mean of **2.444** indicates a generally elevated perception of environmental pollution manifestations among the surveyed respondents. However, these findings represent questionnaire-based assessments and should not be interpreted as direct measurements of atmospheric pollutant concentrations, particulate-matter levels, noise intensity, or other physical environmental parameters. Rather, they provide complementary evidence regarding how residents perceive environmental pressures within the study area.

Results of the Effects on Residents and the Urban Environment Dimension

Table 8. Respondents' Assessment of the Effects of Environmental Pollution (n = 180).

Rank	Effect	High n (%)	Moderate n (%)	Low n (%)	Mean	SD
1	Smoke and dust negatively affect the residential environment	119 (66.1%)	46 (25.6%)	15 (8.3%)	2.578	0.643
2	Air pollution affects residents' daily comfort	110 (61.1%)	55 (30.6%)	15 (8.3%)	2.528	0.647
3	Traffic congestion reduces the quality of the urban environment	106 (58.9%)	57 (31.7%)	17 (9.4%)	2.494	0.664
4	Noise affects comfort and sleep	88 (48.9%)	71 (39.4%)	21 (11.7%)	2.372	0.685

Overall Dimension Mean = 2.493

The results show that the negative effect of smoke and dust on the residential environment ranked first, with a mean score of **2.578**, followed by the effect of air pollution on residents' daily comfort (**2.528**). The effect of traffic congestion on urban environmental quality ranked third (**2.494**), while the effect of noise on comfort and sleep ranked fourth (**2.372**). The overall mean of **2.493** indicates that respondents perceived environmental pollution as an important pressure affecting both residential conditions and the quality of everyday urban life.[7]

Results of the Pollution-Control Measures Dimension

Table 9. Respondents' Assessment of Proposed Pollution-Control Measures (n = 180).

Rank	Proposed Measure	Mean	SD
1	Periodic inspection of vehicle exhaust emissions	**2.706**	0.504
2	Prevention of uncontrolled waste burning	**2.689**	0.572
3	Traffic regulation and reduction of congestion	**2.672**	0.537
4	Monitoring emissions from industrial activities and private generators	**2.611**	0.583

Rank	Proposed Measure	Mean	SD
5	Promotion of cleaner fuels and clean-energy alternatives	**2.589**	0.623
6	Expansion and maintenance of urban green spaces	**2.572**	0.608

Overall Dimension Mean = 2.640

The pollution-control measures dimension recorded the highest overall mean among the four questionnaire dimensions (**2.640**). Periodic inspection of vehicle exhaust emissions ranked first with a mean of **2.706**, followed by preventing uncontrolled waste burning (**2.689**) and regulating traffic and reducing congestion (**2.672**). Monitoring industrial and generator emissions, promoting cleaner fuels and energy alternatives, and expanding urban green spaces also received relatively high mean scores.

The results demonstrate that respondents placed particular emphasis on practical measures directed toward transportation emissions, waste burning, and other fuel-combustion sources. These priorities are broadly consistent with the principal anthropogenic pressures identified elsewhere in the study.

Overall Interpretation of the Questionnaire Results

Overall, the questionnaire findings reveal a coherent pattern in respondents' perceptions of environmental pollution in Samarra City. Transportation-related activities, particularly heavy vehicular traffic, congestion, and heavy-duty vehicle movement, occupied the leading positions among perceived pollution sources. Dust, airborne particles, smoke, exhaust emissions, and noise were among the most prominent manifestations, while deterioration of the residential environment and reduced daily comfort represented important perceived effects.At the same time, respondents expressed strong support for practical pollution-control measures, particularly periodic vehicle-emission inspections, prevention of uncontrolled waste burning, and improved traffic management. The overall questionnaire mean of **2.514 out of 3** indicates a relatively high level of perceived importance across the investigated environmental issues. When considered alongside the environmental measurements, the questionnaire findings provide complementary evidence regarding the relationship between intensive human activities and environmental pressures within Samarra City. However, questionnaire responses represent residents' perceptions and should therefore be interpreted separately from the direct measurements of atmospheric pollutants.[8]

Theme Two

Human Activities and Their Impact on Urban Air Pollution in Samarra City

Human Activities Contributing to Air Pollution

Human activities contributing to air pollution in Samarra City vary according to the city's functions and land-use patterns. Road transportation is one of the major sources of emissions due to the high volume of vehicular traffic along several major routes and intersections. Other important sources include industrial activities, power-generation facilities, generators, service-related activities, and waste burning.The intensity of these impacts varies spatially across the city. Environmental pressure tends to be greater in locations where several urban functions, such as transportation, commerce, and services, are concentrated, whereas it is relatively lower in areas characterized by less traffic and limited economic activity. Therefore, identifying the sources of air pollution depends not only on the presence of a particular activity but also on its intensity, location, continuity, and relationship with surrounding land-use patterns.

Pollutants Emitted from Transportation

Road transportation represents an important anthropogenic source of urban air pollution in Samarra City because motor vehicles depend predominantly on fuel combustion. Vehicle-related emissions commonly include carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), particulate matter (PM), and, depending on fuel composition and operating conditions, sulfur oxides (SO_x).

The quantity and composition of these emissions vary according to several factors, including fuel type, vehicle age, engine condition, maintenance efficiency, traffic volume, congestion, and driving conditions. Repeated stopping, acceleration, deceleration, and idling in congested areas may increase fuel consumption and exhaust emissions. In addition, the movement of trucks and heavy-duty vehicles may contribute to transportation-related environmental pressure, while vehicle movement on unpaved or dusty roads can contribute to the resuspension of road dust and particulate matter.

In the present study, the relationship between transportation activity and urban air pollution was examined primarily through field measurements at selected monitoring sites and was complemented by questionnaire results concerning residents' perceptions of major pollution sources. Accordingly, transportation is evaluated as an important component of the broader pattern of human activities associated with spatial variations in air pollution across Samarra City.[9]

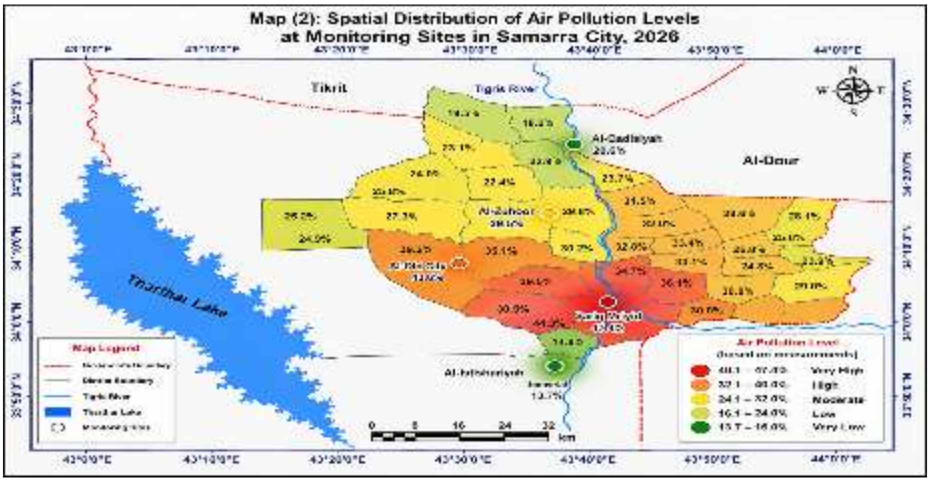
The Effect of Traffic Density on Pollutant Levels

Traffic intensity is an important factor when examining spatial variations in transportation-related air pollution. Locations characterized by large numbers of vehicles, recurrent congestion, prolonged idling, and repeated stopping and acceleration may experience greater emission pressure than locations with less intensive traffic movement. Nevertheless, pollutant levels at a particular location may also be influenced by vehicle composition, surrounding land use, nearby emission sources, and prevailing meteorological conditions.In Samarra City, the selected monitoring sites differed in their traffic characteristics and surrounding urban functions. Field measurements from five major intersections were therefore compared to examine whether locations characterized by more intensive traffic and commercial activity also exhibited comparatively higher relative pollutant levels. This comparison is interpreted as a spatial association rather than as a direct quantitative measurement of the independent effect of traffic density, because the present study did not conduct continuous vehicle counts or source-apportionment analysis at each monitoring site.

Spatial Analysis of Relative Air-Pollution Levels at Major Intersections in Samarra City

Major urban intersections provide important locations for examining traffic-related air pollution because they are characterized by varying levels of vehicle movement, stopping and acceleration, engine idling, and surrounding commercial and service activities. These characteristics may contribute to differences in atmospheric pollutant levels among urban locations.The present study relied on field measurements conducted in cooperation with the Salah Al-Din Environment Directorate at five major intersections in Samarra City. Measurements were obtained on **22 May 2026** during morning, midday, and evening peak periods. The monitored atmospheric indicators included sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), hydrocarbons (HC), and carbon dioxide (CO_2).The recorded values were organized as relative levels and compared across the five monitoring sites to identify spatial differences within the study area. These values are used for comparative spatial analysis and should not be interpreted as annual average concentrations or as percentages of international air-quality guideline limits. The observed spatial patterns are subsequently interpreted in relation to traffic intensity, commercial activity, surrounding land use, and other human activities characterizing each monitoring location.[10]

Map 2. Spatial Distribution of Air Pollution Levels at Monitoring Sites in Samarra City, 2026.



Source: Prepared by the researcher based on the results of the field study and environmental measurements conducted in cooperation with the Salah Al-Din Environment Directorate on 22 May 2026, using ArcGIS 10.8.

Table 11. Relative Levels of Selected Atmospheric Indicators at Major Intersections in Samarra City, 2026

Monitoring Site	SO_2 (%)	CO (%)	NO_2 (%)	HC (%)	CO_2 (%)
Muraidi Market	70	7	50	30	80
Al-Alwa	60	5	53	25	75
Al-Razzaq	50	4	20	10	65
Al-Qadisiyah	20	2	18	8	55

Monitoring Site	SO_2 (%)	CO (%)	NO_2 (%)	HC (%)	CO_2 (%)
Al-Istishariyah	5	1.5	10	7	45

Source: Prepared by the researcher based on field measurements conducted in cooperation with the Salah Al-Din Environment Directorate on 22 May 2026 during morning, midday, and evening peak periods.

Note: Values are expressed as relative percentage levels derived from the field-measurement dataset and are intended for comparison among the selected monitoring sites. They should not be interpreted as absolute atmospheric concentrations or as percentages of international air-quality guideline limits. CO_2 is included as a supplementary combustion-related atmospheric indicator rather than as a conventional health-based ambient air pollutant.

Muraidi Market Intersection

Muraidi Market Intersection exhibited the highest overall relative pollution profile among the five monitoring sites. The recorded relative levels were **80% for CO_2, 70% for SO_2, 50% for NO_2, 30% for HC, and 7% for CO**.

The site is characterized by intensive traffic movement, substantial commercial activity, and frequent vehicle stopping and acceleration. These characteristics provide a plausible contextual explanation for the comparatively elevated relative levels observed at this location. However, because the study did not separately quantify the contribution of each emission source, the observed pattern should be interpreted as an association with the intensity of surrounding human activities rather than as evidence of a single direct causal source.Compared with the other monitoring sites, Muraidi Market recorded the highest relative levels of CO_2, SO_2, HC, and CO. It did not, however, record the highest NO_2 value, which was observed at Al-Alwa Intersection. Muraidi Market can therefore be described as having the highest **overall relative pollution profile**, rather than the highest value for every individual indicator.

Al-Alwa Intersection

Al-Alwa Intersection also exhibited relatively elevated pollution levels. The recorded relative levels were **75% for CO_2, 60% for SO_2, 53% for NO_2, 25% for HC, and 5% for CO**.The site is characterized by substantial commercial activity, vehicular movement, and frequent loading and unloading operations. These characteristics are consistent with the relatively elevated pollution profile observed at this location.Notably, **NO_2 reached 53% at Al-Alwa compared with 50% at Muraidi Market**, making Al-Alwa the site with the highest relative NO_2 level among the five monitoring locations. For the other four indicators, however, Muraidi Market recorded higher relative values.

Al-Razzaq Intersection

Al-Razzaq Intersection displayed an intermediate pollution profile, with relative levels of **65% for CO_2, 50% for SO_2, 20% for NO_2, 10% for HC, and 4% for CO**.These values were lower than those recorded at Muraidi Market and Al-Alwa but generally higher than those observed at Al-Qadisiyah and Al-Istishariyah. Differences in traffic intensity, surrounding land use, and the concentration of commercial activities may contribute to this intermediate spatial pattern.

Al-Qadisiyah Intersection

Al-Qadisiyah Intersection exhibited comparatively lower relative levels, with **55% for CO_2, 20% for SO_2, 18% for NO_2, 8% for HC, and 2% for CO**.

The surrounding area is characterized by less intensive commercial activity and lower levels of heavy-vehicle movement compared with Muraidi Market and Al-Alwa. These differences in local activity patterns may help explain the comparatively lower pollution profile observed at this monitoring site.

Al-Istishariyah Intersection

Al-Istishariyah Intersection recorded the lowest overall relative pollution profile among the five monitoring sites, with **45% for CO_2, 10% for NO_2, 7% for HC, 5% for SO_2, and 1.5% for CO**. This comparatively low profile is consistent with the site's predominantly administrative and healthcare functions and its lower intensity of commercial activity and heavy-vehicle movement.

Overall, the five monitoring sites showed clear spatial variation in relative pollution levels. Muraidi Market exhibited the highest overall profile, followed generally by Al-Alwa and Al-Razzaq, whereas Al-Qadisiyah and Al-Istishariyah recorded lower levels. This pattern broadly corresponds with differences in traffic intensity, commercial activity, and surrounding urban functions. However, because measurements were conducted on a single field date and individual emission sources were not quantified separately, these relationships are interpreted as spatial associations rather than definitive causal relationships.

Supplementary Urban Environmental Indicators

In addition to atmospheric pollution, the questionnaire examined **noise-related disturbance and visual environmental degradation** as supplementary indicators of urban environmental quality. These indicators

reflect residents' perceptions and are analyzed separately from the direct atmospheric measurements.[11]

Supplementary Indicator 1: Perceived Noise Pollution

Noise-related disturbance was assessed through questionnaire responses rather than direct acoustic measurements. Respondents' perceptions varied across the surveyed neighborhoods, potentially reflecting differences in transportation activity, land use, population concentration, commercial and service functions, and characteristics of the built environment. The principal reported causes are presented in **Table 12**. Because no direct sound-level measurements were conducted, the reported percentages represent **perceived noise-related environmental pressure rather than measured acoustic intensity**.

Table 12. Relative Distribution of the Reported Causes of Noise-Related Disturbance across the Surveyed Neighborhoods of Samarra City, 2026

No.	Reported Cause of Noise-Related Disturbance	Percentage (%)	Rank
1	Children playing in alleys and streets	**39.8**	First
2	Functional overlap among urban land uses	**27.9**	Second
3	Vehicular and pedestrian movement	**23.2**	Third
4	Traditional urban form	**5.8**	Fourth
	Recorded Total	**96.7**	–

Note: The four reported categories collectively account for **96.7%** of the questionnaire results. The remaining **3.3%** was not assigned to a separate category in the available field dataset. Therefore, the original percentages were retained without adjustment or normalization.

Source: Prepared by the researcher based on field-study data and the results of the questionnaire conducted in Samarra City, 2026.

The questionnaire results reveal differences in the relative importance of the reported causes of noise-related disturbance across the surveyed neighborhoods. Children playing in alleys and streets ranked first, accounting for **39.8%** of the recorded responses, followed by functional overlap among urban land uses at **27.9%**. Vehicular and pedestrian movement ranked third at **23.2%**, whereas traditional urban form recorded the lowest percentage at **5.8%**. Collectively, these findings indicate that respondents associated noise-related disturbance with a combination of social activities, land-use characteristics, transportation movement, and features of the built environment. Because these percentages are derived from questionnaire responses rather than direct sound-level measurements, they represent residents' perceptions of the relative importance of the reported causes and should not be interpreted as measured contributions to total environmental noise.

Children Playing in Alleys and Streets

Children playing in alleys and streets ranked first among the reported causes of noise-related disturbance, accounting for **39.8%** of the recorded questionnaire responses. This finding indicates that respondents perceived children's outdoor activities as the most prominent cause among the categories included in Table 12. Field observations and the geographical characteristics of the surveyed neighborhoods suggest that the use of alleys and streets for recreational activities may be related to the availability and spatial distribution of dedicated recreational spaces, public parks, and playgrounds. In neighborhoods where such facilities are limited, streets and alleys may serve as alternative spaces for children's outdoor activities. However, this interpretation should be regarded as contextual rather than as a statistically established causal relationship.

According to the available field data, the neighborhoods of **Al-Ifraz, Al-Mu'tasim, Al-Bunaisan, Al-Khadraa, Al-Imam, Al-Muthanna, and Al-Ziraa** showed comparatively greater prominence of this reported indicator. Differences among neighborhoods may be associated with variations in population concentration, recreational-space availability, and characteristics of the urban fabric. These factors provide a geographical context for interpreting residents' perceptions but do not constitute direct acoustic evidence of higher sound levels.[12]

Functional Overlap among Urban Land Uses

Functional overlap among residential, commercial, and other urban land uses ranked second among the reported causes of noise-related disturbance, accounting for **27.9%** of questionnaire responses. The coexistence of commercial and service activities with residential uses may increase vehicular and pedestrian movement and loading and unloading activities, thereby contributing to residents' perceptions of noise-related disturbance. **Al-Armoushiyah neighborhood** showed the greatest prominence of this indicator among the surveyed neighborhoods. However, because no direct sound-level measurements were conducted, the relationship is interpreted as a perception-based association rather than a confirmed causal effect.

Vehicular and Pedestrian Movement

Vehicular and pedestrian movement ranked third, accounting for **23.2%** of the reported causes of noise-related disturbance. Respondents associated this factor particularly with areas characterized by intensive traffic, commercial activity, and overlapping urban functions. Vehicle acceleration, braking, engine operation, horn use, and pedestrian movement may contribute to perceived environmental disturbance. Since the study did not include direct acoustic measurements or continuous neighborhood-level traffic counts, this percentage represents residents' perceptions rather than a measured contribution to environmental noise.

Traditional Urban Form

Traditional urban form accounted for **5.8%**, the lowest percentage among the reported causes of noise-related disturbance. Narrow streets, compact building patterns, and the close proximity of residential units may influence residents' experience of urban noise. Nevertheless, these characteristics are interpreted as contextual factors because the study did not directly measure sound propagation in relation to street width, building density, or construction characteristics.

Supplementary Indicator 2: Visual Environmental Degradation

Visual environmental degradation was examined as a supplementary indicator of urban environmental quality rather than as a component of atmospheric pollution. According to Table 7, visual pollution and deterioration of the urban landscape recorded a mean score of **2.317**, ranking below dust and airborne particles, smoke and exhaust emissions, and noise. Potential manifestations include deterioration of the built environment, poorly maintained public spaces, irregular infrastructure, and inconsistencies among urban land uses. However, these features were not assessed through a separate quantitative inventory and are therefore interpreted as contextual observations.

Older Neighborhoods: Older parts of Samarra may exhibit aging buildings, narrow streets, compact urban form, and variations in infrastructure conditions that influence perceptions of visual environmental quality. Because the questionnaire did not provide separate quantitative measurements for individual neighborhoods, differences among these areas are interpreted descriptively rather than as statistically established variations.

Transitional and Modern Neighborhoods: More recently developed areas may also experience visual degradation associated with rapid urban expansion, differences in architectural styles and building heights, road conditions, vacant land, infrastructure development, and public-space maintenance. These remain qualitative observations. Improved infrastructure, organized land use, and better maintenance of public spaces may enhance visual environmental quality while preserving Samarra's historical and cultural character.[13]

Industrial and Other Anthropogenic Emission Sources

Industrial and workshop activities represent potential anthropogenic sources of urban air pollution because fuel combustion, material processing, and other energy-dependent operations may release gaseous pollutants and particulate matter. Their potential influence varies according to activity type and scale, fuel characteristics, operating conditions, emission-control practices, and location.

Within Samarra City and its surrounding urban environment, these activities should be considered alongside transportation, electricity generation, commercial activities, private generators, and waste burning. Because the study did not quantify emissions from individual industrial facilities, their contribution is interpreted as part of the broader pattern of potential anthropogenic environmental pressures rather than as an independently measured source.

Asphalt Production and Related Industrial Activities

Asphalt production represents a potential local emission source because heating, handling, and processing asphalt mixtures involve high-temperature operations and petroleum-derived materials. Depending on fuel type, production processes, operating conditions, and emission-control systems, these activities may release **particulate matter, combustion gases, hydrocarbons, and volatile organic compounds**.

Field observations documented asphalt-production activity within the study area. However, facility-specific emission rates were not measured and no source-apportionment analysis was conducted. Consequently, the independent contribution of asphalt-production facilities to the relative atmospheric indicator levels recorded at the monitoring sites cannot be quantified, and these facilities are treated as potential rather than confirmed quantitative contributors to the observed pollution pattern.

The photograph was taken on 23 May 2026.

The photograph provides qualitative documentation of visible emissions associated with asphalt-production activity at the observed site. While the image confirms the presence of an active emission source, it does not provide a quantitative measure of pollutant concentrations, emission rates, or the specific chemical composition of the released emissions. The potential influence of asphalt-production emissions on surrounding air quality depends on several factors, including the production process, type of fuel used, operating conditions, effectiveness of emission-control systems, distance from surrounding receptors, and prevailing meteorological conditions. Wind speed and direction may also influence the transport and dispersion of emitted pollutants. Accordingly, the photograph is used as supporting field documentation and should not be interpreted as direct evidence of the magnitude of the facility's contribution to the relative atmospheric indicator levels measured at the selected monitoring sites.[14]

Electric Power Generation Facilities

Electric power generation based on fossil-fuel combustion represents a potential anthropogenic source of atmospheric emissions. Depending on the fuel used, combustion technology, operating conditions, and emission-control systems, power-generation facilities may release nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon dioxide (CO_2), carbon monoxide (CO), particulate matter (PM), and other combustion-related compounds. Power-generation activities within Samarra and the broader regional setting of Salah Al-Din Governorate provide an important contextual factor when considering anthropogenic emission sources. However, the present study did not directly measure emissions from individual power-generation facilities or quantify their independent contribution to the atmospheric indicators recorded at the five monitoring sites. Their potential influence should therefore be considered together with transportation, industrial activities, commercial activities, private generators, waste burning, and other local emission sources. The dispersion and potential environmental influence of emissions from power-generation facilities may vary according to operating duration, fuel characteristics, emission-control efficiency, distance from the source, wind speed and direction, and atmospheric stability. Consequently, their contribution to air quality cannot be determined solely from their presence within the wider geographical area and would require source-specific emission measurements and meteorological analysis for quantitative assessment.

The photograph was taken on 24 May 2026

Figure 2. Emissions from an Electric Power Generation Station in the Study Area

Potential Influence of Regional Power-Generation Sources

Fossil-fuel-based power-generation facilities are potential regional sources of SO_2, NO_x, CO_2, CO, and particulate matter. Under suitable meteorological conditions, emissions from regional facilities, including the Baiji power stations, may influence air quality within the broader study area. However, their specific contribution to pollution levels in Samarra cannot be quantified without detailed meteorological data, emission inventories, and atmospheric-dispersion or source-apportionment analysis. Therefore, they are considered potential regional sources rather than confirmed direct contributors to the measured pollution levels [15].

Emissions Associated with Daily Human Activities

Daily activities such as private electricity generation, fuel use in bakeries and restaurants, domestic combustion, and open waste burning represent potential sources of urban air pollution. These activities may emit CO, CO_2, NO_x, particulate matter, hydrocarbons, and other combustion-related pollutants, depending on fuel type, combustion efficiency, operating conditions, and waste composition. Private generators and uncontrolled waste burning are particularly relevant local environmental pressures. However, since their emissions were not measured separately, they are treated as potential anthropogenic sources rather than independently quantified contributors to the pollution levels recorded at the monitoring sites.

The photograph was taken on 24 May 2026

Figure 3. Emissions Resulting from Waste Burning at the Landfill Site :The photograph provides qualitative field evidence of open waste burning within the study area, a potential source of smoke, particulate matter, carbon monoxide (CO), hydrocarbons, and other combustion-related emissions. However, it does not provide quantitative information on pollutant concentrations or emission rates. When considered

alongside the field measurements and questionnaire findings, the observations suggest that air quality in Samarra may be associated with multiple anthropogenic pressures, including transportation, industrial and commercial activities, electricity generation, private generators, and waste burning. Because no source-apportionment analysis was conducted, the independent contribution of individual sources cannot be quantified. Therefore, improved waste management, control of open burning, emission monitoring, traffic management, and cleaner energy practices are important measures for reducing urban environmental pressures.[16]

Discussion of Results

The findings reveal clear spatial variation in the relative levels of the selected atmospheric indicators across the five monitoring sites in Samarra City. Muraidi Market exhibited the highest overall relative pollution profile, followed generally by Al-Alwa and Al-Razzaq, whereas Al-Qadisiyah and Al-Istishariyah recorded comparatively lower levels. However, individual indicators did not follow an identical spatial pattern; notably, Al-Alwa recorded a slightly higher relative NO_2 level (53%) than Muraidi Market (50%). These differences suggest that local traffic characteristics, commercial activity, surrounding land use, and other site-specific urban activities are relevant to interpreting spatial variations in atmospheric conditions. The observed pattern is broadly consistent with Ding et al. (2024), who demonstrated spatial differences in urban air pollution under limited monitoring conditions and emphasized the relevance of traffic-related variables. It also corresponds with Yu et al. (2023), who identified traffic volume and road-network characteristics as important factors associated with spatial variation in $PM_{2.5}$. Although $PM_{2.5}$ was not measured in the present study, both studies highlight the importance of transportation characteristics in interpreting intra-urban variations in air pollution. From a methodological perspective, the integration of field measurements, urban characteristics, questionnaire data, and spatial representation follows the broader direction identified by Ma et al. (2024), who emphasized the increasing use of monitoring and land-use information for assessing intra-urban air-pollution variation. Similarly, the application of GIS is consistent with Dheekwal et al. (2025), who highlighted its usefulness for integrating environmental and spatial information and identifying urban pollution hotspots. The present study applies these principles at a local scale but remains descriptive and spatially comparative rather than predictive. Questionnaire findings provide complementary evidence regarding residents' perceptions of anthropogenic environmental pressures. Heavy vehicular traffic ranked first among the perceived sources of air pollution (mean = 2.622), followed by traffic congestion and frequent vehicle stops (2.583) and the movement of trucks and heavy-duty vehicles (2.511). This perception-based pattern broadly corresponds with the field observations showing comparatively elevated atmospheric indicator levels at more intensively trafficked and commercially active locations. Nevertheless, questionnaire responses represent residents' perceptions and should not be interpreted as direct atmospheric measurements. The findings should also be considered within the temporal and methodological limitations of the study. Field measurements were conducted during morning, midday, and evening peak periods on **22 May 2026** and therefore represent conditions observed during the monitoring periods rather than annual or seasonal air-quality conditions. Moreover, the absence of continuous traffic counts, comprehensive meteorological observations, and quantitative source-apportionment analysis prevents determination of the independent contribution of individual emission sources.Overall, the results indicate that the spatial organization and intensity of human activities are associated with variations in the relative levels of selected atmospheric indicators across Samarra City. Transportation, commercial activity, surrounding land use, and other anthropogenic pressures provide an important geographical context for interpreting these variations. Future research should incorporate longer monitoring periods, additional monitoring sites, continuous traffic data, meteorological observations, and advanced GIS-based modeling to provide a more comprehensive assessment of urban air pollution.

CONCLUSION

Fundamental Finding: The study clearly shows that there was spatial variation in the levels of air pollution in Samarra City, where the highest levels of air pollution were recorded in the Muraidi Market area, while the lowest levels were recorded in the Al-Istishariyah area. **Implication:** These spatial variations are related to the variations in traffic density and human, services and industry activities spatial distribution in the city. The findings showed that vehicular movements and transport are other important factors contributing to the degradation of the air quality in addition to emissions of electric generators, industry and commercial activities, and waste burning, each having varying impacts depending on their location. Therefore, the implementation of continuous programs for air pollution monitoring and expansion of such measurements in time and space to generate more information about the pollution levels should be considered. Also, traffic control, reduction of vehicle and generator emissions, environmental control of industry and commercial activities and prevention of burning of wastes inside the urban areas should be considered. Additionally, development of green areas and consideration of environmental issues in urban planning should be considered, along with GIS utilization for detecting pollution areas and their sources in addition to monitoring their spatial variations. **Limitation:** The study does not explicitly state a limitation regarding the temporal coverage, measurement duration, or the range of pollution sources assessed. **Future Research:** Future research should expand air pollution measurements across different time periods and spatial locations and use GIS to further identify pollution sources and monitor their spatial variations.

REFERENCES

[1] S. Al-Aqili and B. Jarrar, Air Pollution. Riyadh, Saudi Arabia: Arab Bureau of Education for the Gulf States, 1990. [In Arabic].

[2] S. A. Al-Fadhli and A. M. Madkhan, "Noise pollution in Basra City," Journal of Basra Arts, College of Arts, University of Basra, vol. 1, no. 54, p. 147, 2010. [In Arabic].

[3] A. S. M. Al-Kalabi, "Spatial variation of visual pollution in Al-Samawah City and its health impacts," Journal of Geographical Research, University of Kufa, no. 22, p. 426, 2011. [In Arabic].

[4] A. A. Al-Sabounji and A. M. Al-Sabounji, Human Environment. [Place of publication not provided]: Al-Haddad Printing and Publishing Press, 2005. [In Arabic].

[5] M. K. Al-Zouka, The Environment, Dimensions of Its Degradation, and Its Effects on Human Health. [Place of publication not provided]: Dar Al-Ma'rifa Al-Jami'iyya, 1996. [In Arabic].

[6] M. K. Al-Zouka, Geography of Transportation: Its Significance and Scope. Alexandria, Egypt: Dar Al-Ma'rifa Al-Jami'iyya, 2000. [In Arabic].

[7] R. W. Dwidari, The Environment: Its Contemporary Scientific Concept and Intellectual Heritage. Damascus, Syria: Dar Al-Fikr, 2004. [In Arabic].

[8] J. Hamdan, Geography of Cities, vol. 2. Cairo, Egypt: Alam Al-Kutub Library, 1977. [In Arabic].

[9] H. H. Naas, "Air pollution caused by automobiles and traffic movement in Damascus City," Faculty of Arts, Damascus University, 2008. [In Arabic].

[10] United Nations Environment Programme (UNEP), Actions on Air Quality: A Global Summary of Policies and Programmes to Reduce Air Pollution. Nairobi, Kenya: United Nations Environment Programme, 2021.

[11] A. Dheekwal, K. Singh, and A. Sharma, "GIS-based modeling of traffic-related air pollution and public health risks: A systematic review with an emphasis on developing urban contexts," Computational Urban Science, vol. 5, p. 65, 2025, doi: 10.1007/s43762-025-00225-6.

[12] J. Ding, C. Ren, J. Wang, Z. Feng, and S.-J. Cao, "Spatial and temporal urban air pollution patterns based on limited data of monitoring stations," Journal of Cleaner Production, vol. 434, p. 140359, 2024, doi: 10.1016/j.jclepro.2023.140359.

[13] X. Ma, B. Zou, J. Deng, J. Gao, I. Longley, S. Xiao, B. Guo, Y. Wu, T. Xu, X. Xu, X. Yang, X. Wang, Z. Tan, Y. Wang, L. Morawska, and J. Salmond, "A comprehensive review of the development of land use regression approaches for modeling spatiotemporal variations of ambient air pollution: A perspective from 2011 to 2023," Environment International, vol. 183, p. 108430, 2024, doi: 10.1016/j.envint.2024.108430.

[14] C. Yu, Y. Deng, Z. Qin, C. Yang, and Q. Yuan, "Traffic volume and road network structure: Revealing transportation-related factors on $PM_{2.5}$ concentrations," Transportation Research Part D: Transport and Environment, vol. 124, p. 103935, 2023, doi: 10.1016/j.trd.2023.103935.

[15] World Health Organization (WHO), WHO Global Air Quality Guidelines: Particulate Matter ($PM_{2.5}$ and PM_{10}), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide. Geneva, Switzerland: World Health Organization, 2021, ISBN 978-92-4-003422-8.

[16] F. A. J. Karkaja, "The impact of manifest (bale) vehicles on the streets of Mosul City: A field study in urban geography," Journal of Research of the College of Basic Education, University of Mosul, 2007. [In Arabic].

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