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Study Of The Concentration Of Gaseous Pollutants And Assessment Of Air Quality In Some Selected Urban Areas Of Anbar Governorate

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Abstract

This study evaluated the air quality in some areas of Anbar Governorate based on the concentrations of air pollutants such as carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3). The study results showed varying concentrations of some air pollutants (SO_2 and NO_2) exceeded the national and international standards at 0.36 ppm and 0.0193 ppm, respectively. The concentrations of CO and NO_2 were below the permissible limits. The results of the study revealed regional differences in the concentrations of pollutants. The industrial areas had the highest NO_2 concentrations, while the commercial areas had the highest CO and SO_2 concentrations, and the residential areas had the highest O_3 concentrations. The study evaluated the health effects of air pollutants in the examined area by utilizing the Air Quality Index (AQI), which is a standardized numerical scale designed to indicate air pollution levels and their implications for public health. Pollutants within the study were categorized on a scale ranging from 0 to 350. Findings revealed differences in pollution levels across the sites, with nitrogen dioxide falling under the "good" category, while sulfur dioxide reached the "hazardous" category.

Keywords: Include air pollution, Air pollutant gases, Air quality.

Introduction

Air pollutants are one of the environmental issues that have received wide attention from researchers and specialists in countries around the world because of their direct impact on the stability of ecosystems and human health, especially in urban areas that are witnessing industrial expansion, economic growth, and population density, becoming one of the most prominent environmental and health challenges in the modern era. [1].

Gaseous pollutants such as carbon monoxide, sulfur dioxide, nitrogen dioxide, and ozone are among the most widespread and dangerous pollutants to the environment. Their increased concentrations affect the quality of air in the environment, as statistics indicate that approximately 6.5 - 7 million deaths occur annually in the world due to their significant contribution to the increased incidence of heart, blood vessel, and respiratory diseases. **[2]**، In addition to its role in climate change, the phenomenon of global warming is significant **[3].**

This field study was launched to understand the reality of gaseous pollution in some selected areas (industrial, residential, commercial) in Anbar Governorate. It relied on a descriptive approach that focuses on studying the spatial and temporal variation of pollutant levels and comparing them with national and international determinants, converting them into qualitative indicators using the air quality index standards to contribute to classifying air quality in each region in a scientific and simplified manner. Based on that, this study aimed to:-

1- Analyzing the concentration of gaseous pollutants (CO, O_3, NO_2, SO_2) in different areas of Anbar Governorate and comparing them with national and international standards.

2- Study of Air Quality Index standards to help improve local air quality

Working Methods

Research Duration

The study covered four months, starting in November 2024 and continuing through January, March, and April 2025.

Study Site :-

The study was conducted in Anbar Governorate, located in western Iraq. Twenty-one air pollutant monitoring stations were selected, distributed as follows: 10 industrial, 6 residential, 4 commercial, and 1 control station within the districts of Anbar Governorate, as shown in **Table 1.**

Table (1) Locations of the areas selected for measuring air pollutants.

Region	Station number	Station Description	Region	Station number	Station Description
Industrial	A9	Haditha	Residential	A4	Residential complex in Kubisa district
	A5	Inside the Haditha refinery, at its center		A8	Haditha Refinery Residential Complex K3
	A6	Outside the Haditha refinery, upwind		A11	Haditha
	A7	Outside the Haditha refinery, downwind		A14	Hit
	A12	Hit		A17	Ramadi
	A1	Inside the Kubisa Cement Factory at its center		A20	Fallujah
	A2	Outside the Kubisa cement factory, upwind	Commercial	A10	Haditha
	A3	Outside the Kubisa cement factory, downwind		A13	Hit
	A15	Ramadi		A16	Ramadi
	A18	Fallujah		A19	Fallujah
***Control station (A21) was selected in a rural location far from pollution sources**					

Air Gas Concentration Measurement

Pollutant concentrations were measured, and readings were collected using specialized devices. A German-made Dräger 6500 and a Chinese-made Air Quality Detector were used to measure the concentration of gaseous air pollutants, including CO, SO_2, NO_2, and O_3, which were measured in parts per million.

Number of Recorded Readings

To ensure accurate measurements, pollutants were measured at the same time each month for all stations. Three readings were taken per week, or 12 readings per month for each pollutant. The average of these readings was then calculated to represent the monthly average. This applied to all 21 stations throughout the study period.

Evaluating Air Pollutants Using the Air Quality Index

It is well known that air pollutants have a direct impact on human health, increasing the risk of heart and respiratory diseases. Acute, short-term inhalation of pollutants can lead to changes in lung function and the cardiovascular system, potentially leading to death. The measured concentrations of pollutants at the study sites do not provide a complete picture of the nature and severity of pollution. To provide an accurate and comprehensive picture of pollution levels, the

Air Quality Index (AQI) was used as a pollution assessment tool.

The Air Quality Index (AQI) is a standardized measure of air quality that uses numbers to describe the air quality in a given location and to express the level of health risks associated with gaseous and particulate air pollutants. **Table 2,** according to the US Environmental Protection Agency (EPA), shows the AQI values based on the concentrations of major pollutants (carbon monoxide, nitrogen dioxide, ozone, and sulfur dioxide) **[4].**

Table (2) Air Quality Index values and corresponding concentrations of each pollutant [4]

Value AQI	The category to which each pollutant corresponds in units of measurement parts per million (ppm)			
	SO_2	O_3	NO_2	CO
0-50	0-0.035	0-0.058	0-0.035	0 -4.4
51-100	0.036-0.075	0.059-0.074	0.036-0.1	4.5-9.4
101-150	0.076-0.185	0.075-0.094	0.101-0.360	9.5 -12.4
151-200	0.186-0.304	0.095-0.114	0.361-0.649	12.5- 15.4
201-300	0. 305-0.604	0.115-0.373	0.650-1.244	15.5- 30.4
301-500	0.605-1.004	0. 374واكثر	1.245-2.049	30.5-50.4

To distinguish between air quality and poor air quality, **Table (3)** sets the agency's six categories for AQI values (good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous) and for each category (green, yellow, orange, red, purple, and dark red) respectively, to provide a description of that region and its effects on human health **[5].**

Table (3) Values and description of the air quality index and health effects of air pollutants [5]

Value AQI	Air Pollution Level	Health Implications
0 -50	Good	Poses little or no risk human health.
51-100	Moderate	Very few symptoms in people at high risk of allergies.
101-150	Unhealthy for sensitive groups	Minor symptoms may occur in people with allergies, and some healthy people may develop symptom
151-200	unhealthy	members of sensitive groups may experience more serious health effects
201-300	Very unhealthy	Exacerbation of symptoms in people most and decreased tolerance in healthy members of the population, which may require taking emergency measures for and members of sensitive .
301-500	Hazardous	Healthy people suffer from decreased endurance and negative symptoms that affect normal activity. In addition, patients must stay at home.

Calculating the Air Quality Index Value

The recorded concentrations of each pollutant are converted to index values by limiting them between two values, as shown in Table 10. Then, the Air Quality Index value is calculated by applying the following linear equation **[6]**:-

$$\mathbf{IP = \frac{(I_{Hi}-I_{LO})}{(BP_{Hi}-BP_{Lo})}(CP-BP_{Lo})+I_{Lo}}$$

Whereas:

IP = Pollutant Index

CP = Approximate Pollutant Measurement Concentration

I_{Hi} = AQI value corresponding to BP_{Hi}

I_{Lo} = AQI value corresponding to BP_{Lo}

BP_{Hi} = Breakpoint value above CP

BP_{Lo} = Breakpoint value above CP

AQI = Maximum (IP)

Based on the linear equation, the concentration data of each pollutant is calculated to obtain the value of the air quality index at that location separately. The highest value of the index during the study months for that location becomes the final value of the air quality index.

Statistical Analysis

SPSS [7] was used to conduct appropriate statistical tests on the recorded pollutant concentrations. Some descriptive statistics were used to calculate the overall mean and standard deviation, the one-way variance test, and the (Tukey) test. To calculate the quality index value, a linear equation was used to determine the index value for each pollutant.

Results and Discussion.

1-Environmental Assessment of Pollutants by Concentrations

Carbon Monoxide Concentration

The findings presented in Table (4) indicate that the average concentration of carbon monoxide (CO) was 2.74 ppm, with a standard deviation of 1.35. The maximum and minimum values for the recorded gas concentrations were 0.28 and 7.63 ppm, respectively, indicating a relative dispersion between the concentrations.

As noted in the same table, there is a temporal variation in gas concentrations and study months. The highest concentration was recorded in January at 7.63 ppm at station (A16 Ramadi Residential), followed by the months of March and November. With concentrations of (6 and 5.88) ppm, respectively, at (A19 Ramadi Commercial). The lowest concentration was recorded in April at 2.82 ppm at station (A16 Ramadi Residential). Conversely, the highest temporal average for the study months was recorded in January at (3.477) ppm, while the lowest monthly average was recorded in April at (2.134) ppm. As a result of the decrease in temperatures this month, along with the relative stability of wind movement and the occurrence of the phenomenon of thermal inversion, it contributed to the accumulation of gas close to the Earth's surface and its non-dispersal. This is consistent with the results of the study **[8]**, which indicated the role of climatic factors in increasing the concentration of CO gas during climate change. While April recorded the lowest monthly average, the gradual rise in temperatures, along with the increase in wind speed, led to the dispersion of gas concentrations, and this is consistent with **[9].**

Table (4) shows carbon monoxide concentration in the study regions and months.

Region	Station number	Nov.	Jan.	Mar.	Apr.	Spatial Average
Industrial	A9	1.83	2.18	1.58	0.9	1.623
	A5	1.75	3.18	2.68	2.66	2.568
	A6	1.5	2.68	2.25	1.85	2.07
	A7	1.58	3.35	3.18	1.07	2.295
	A12	4.16	2.6	2.75	1.13	2.66
	A1	1.49	3.68	2.17	2.28	2.405
	A2	1.46	3.1	1.66	2.48	2.175
	A3	1.81	2.43	2.75	1.05	2.01
	A15	2.83	4.73	3.83	3.93	3.83
	A18	2.68	4.38	4.85	2.28	3.548
Residential	A4	1.58	3.05	2.08	0.28	1.748
	A8	0.75	2.88	3.08	0.71	1.855
	A11	0.41	2.13	4.25	1.95	2.185
	A14	1.25	3.08	2.08	2.02	2.108
	A17	2.14	4.3	3.92	2.26	3.155
	A20	2.54	3.48	3.92	2.62	3.14
Commercial	A10	5.83	2.97	2.25	1.93	3.245
	A13	1.83	3.97	3.33	1.82	2.738
	A16	4.75	7.63	4.91	2.82	5.028
	A19	5.88	3.75	6	2.79	4.605
Time Average		2.402	3.477	3.027	2.134	2.762
Control (A21)		0.21	0.41	0.85	0.96	0.21
Local Environmental Determinant			35 ppm According to the Iraqi Ministry of Health and Environment (2018)			
Global Environmental Determinant			35ppm Global standard according to the Environmental Protection Agency (2024)			

Minimum	Maximum	Mean	Std. Deviation	Variance
0.28	7.63	2.74	1.35	1.84

According to the results of the statistical analysis shown in **Table 5** for the one-way variance test between carbon monoxide concentration and study months, the value of P = 0.005, indicating the presence of statistical significance. The Tukey test for pairwise comparison between months showed a value of ($p < 0.05$) between November - January, January - April, indicating the presence of a statistically significant difference between those months. While the probability values of (P > 0.05) were recorded for the pairwise comparison of the remaining months to indicate the absence of statistical significance between them .

Table (5) Results of statistical analysis of CO concentration for study areas and months

	Month	Mean	Comparison Between Two Months	Mean Difference	Std. Error	p-value
Monthly Concentration			Nov._ Jan.	-1.07500*	.40235	0.045
	November	2.402	Nov. _ Mar.	-.62487	.40761	0.423
	January	3.477	Nov. _Apr.	.26774	.39753	0.907
	March	3.027	Jan._ Mar.	.45013	.40761	0.688
	April	2.134	Jan_ Apr.	1.34274*	.39753	0.006
			Mar._ Apr	.89261	.40285	0.128
ANOVA p =0.005 F = 4.615						
Region Concentration	**Region**	**Mean**	**Comparison Between Two Regions**	**Mean Difference**	**Std. Error**	**p-value**
	Residential	74.75	Ind. _ Com.	39.088*	6.116	0.001
	Commercial	83.56	Ind. _Res.	47.900*	7.007	0.001
	Industrial	122.65	Com._ Ind.	-8.813	7.646	0.485
ANOVA p=0.001 F=8.778						

Regarding spatial variation, **Table (4)** showed a disparity between CO concentration and the study areas, where the highest concentration was recorded in industrial areas at 4.85 ppm in April for station (A18 Ramadi). In residential areas, the highest recorded concentration was 4.3 parts per million in (A17 Hit) for January, while in commercial areas, station (A16 Fallujah) recorded the highest concentration at 7.63 ppm in January. The highest spatial rate of CO was recorded in commercial areas at 3.903 ppm, while the lowest spatial rate was recorded in residential areas at 2.365 ppm. Commercial areas witness heavy traffic and obvious vehicle congestion. As a result of incomplete fuel combustion in their engines, carbon monoxide gas is emitted from their exhausts. With the presence of tall buildings, ventilation is impeded, and the gas is dispersed, contributing to high concentrations being recorded in those areas. This is consistent with the study **[10]**, which concluded that commercial areas with high traffic density record high concentrations similar to those in industrial areas.

The results of the statistical analysis in **Table 5** showed that there is a significant statistical relationship between the concentration of carbon monoxide gas and the study areas. The probability value is P = 0.001 for the one-way variance test. When conducting a pairwise comparison of the average differences between the areas, the two areas (industrial-residential, commercial-residential) showed a probability value of ($P < 0.05$), which confirms the existence of significant statistical differences between them, while (industrial-commercial) had a value of ($P > 0.05$), indicating that despite the existence of differences between the averages of the two areas, they are not considered statistically significant differences. Based on the results of the CO concentration recorded in **Table 4**, all levels in the study stations and their spatial and temporal rates were above the rate of the control station (A21). When comparing the recorded concentrations with the national gas limit of 35 parts per million according to **[11]**, and the global limit of 35 parts per million according to **[12]**. It was shown that all stations did not exceed the permissible national and global limits.

Sulfur Dioxide Gas Concentration

The results in **Table 6** showed that the overall average for sulfur dioxide gas was 0.18 ppm, with a standard deviation of 0.07. The minimum and maximum values recorded were 0.06 and 0.36 ppm, respectively, indicating a relative dispersion between values due to the combined influence of climatic factors and various human activities.

Table (6) noted a temporal variation between sulfur dioxide gas concentrations and the study months. The highest concentration was recorded in January, at 0.36 ppm, in A15 (Commercial Ramadi), followed by March and April, at 0.32 ppm, in A12 (Haditha Industrial) and A15 (Commercial Ramadi), respectively. The lowest gas concentration was recorded in April, at 1.18 ppm, in the A10 (Haditha Commercial) station. While the highest temporal average was recorded in January, with an average of 0.255 ppm, the lowest monthly average was recorded in April, with an average of 0.120 ppm.

In January, the highest median value was recorded, with a wide variation between the values of the upper and lower limits. Naturally, the decrease in temperatures in this month led to a lack of dispersion of the gas, which contributed to the increase in its recorded concentrations **[13]**. Meanwhile, April recorded the lowest rate as a result of the decrease in the median rate value and its proximity to the upper and lower limits. This decrease is explained by the increase in the average wind speed with the rise in temperatures, which contributed to the dispersion of the gas and the reduction of its rates. This is consistent with what was concluded by **[14]**. Who confirmed that climatic factors have a clear role in recording an increase or decrease in the concentrations of sulfur dioxide gas?

Table (6) Concentration of sulfur dioxide in the study areas and months

Region	Station number	Nov.	Limit		Jan.	Limit		Mar.	Limit		Apr.	Limit		Spatial Average
			National	Global		National	Global		National	Global		National	Global	
Industrial	A9	0.17			0.32			0.27			0.14			0.225
	A5	0.15			0.31			0.26			0.17			0.223
	A6	0.17			0.34			0.15			0.11			0.193
	A7	0.19			0.31			0.22			0.13			0.213
	A12	0.23			0.3			0.32			0.16			0.253
	A1	0.14			0.28			0.29			0.12			0.208
	A2	0.09			0.19			0.15			0.06			0.123
	A3	0.13			0.24			0.22			0.11			0.175
	A15	0.32			0.3			0.27			0.12			0.253
	A18	0.31			0.2			0.31			0.1			0.23
Residential	A4	0.11			0.12			0.19			0.08			0.125
	A8	0.08			0.11			0.18			0.12			0.123
	A11	0.1			0.2			0.25			0.07			0.155
	A14	0.14			0.26			0.19			0.14			0.183
	A17	0.11			0.23			0.17			0.14			0.163
	A20	0.13			0.27			0.11			0.09			0.15
Commercial	A10	0.19			0.22			0.16			0.18			0.188
	A13	0.23			0.27			0.11			0.09			0.175
	A16	0.21			0.36			0.14			0.15			0.215
	A19	0.09			0.27			0.07			0.17			0.15
Time Average		0.164			0.255			0.208			0.12			0.187
Control (A21)		0.04			0.08			0.04			0.02			0.045
Local Environmental Determinant			35 ppm According to the Iraqi Ministry of Health and Environment (2018)											
Global Environmental Determinant			35ppm Global standard according to the Environmental Protection Agency (2024)											
The red color indicates that the concentration exceeds the national and international permissible limit.						The green color indicates that the concentration does not exceed the national and international permissible limit.								

Variance	Std. Deviation	Mean	Maximum	Minimum
0.06	0.36	0.18	0.078	0.006

The results of the statistical analysis in **Table (7)** showed that there is a significant statistical relationship between the concentration of sulfur dioxide gas and the months of the study, as the probability value P = 0.001 was recorded for the one-way analysis of variance test. When conducting a pairwise comparison of the average differences between the months, (November - January, January - April, March - April) showed a probability value of ($P < 0.05$), which confirms the existence of significant statistical differences between them, while the rest of the months showed ($P > 0.05$), indicating that despite the existence of differences between the averages of the two regions, they are not considered statistically significant differences.

Table (7) Results of statistical analysis of SO_2 gas concentration for the study areas and months

	Month	Mean	Comparison Between Two Months	Mean Difference	Std. Error	p-value
Monthly Concentration			Nov._ Jan.	-0.09050*	0.0191	0.001
	November	0.1645	Nov. _ Mar.	-0.04392	0.0193	0.115
	January	0.2550	Nov. _Apr.	0.04450	0.0188	0.095
	March	0.2084	Jan._ Mar.	0.04658	0.0193	0.085
	April	0.1200	Jan_ Apr.	0.13500*	0.0188	0.001
			Mar._ Apr	0.08842*	0.0191	0.001
ANOVA p =0.001 F = 18.736						
	Region	**Mean**	**Comparison Between Two Regions**	**Mean Difference**	**Std. Error**	**p-value**
Region Concentration	Residential	0.1496	Ind. _ Com.	0.15325	0.3202	0.882
	Commercial	0.1819	Ind. _Res.	−1.38550*	0.3668	0.001
	Industrial	0.2093	Com._ Ind.	−1.38550*	0.3668	0.001
ANOVA p=0.04 F=3.344						

The results in **Table (6)** show that there is a spatial variation between the concentration of SO_2 gas and the study areas, where the highest concentration of 0.36 ppm was recorded in the commercial areas of station A16 (Fallujah), followed by the industrial areas with 0.28 ppm for station A1 (Kubisa Cement Factory Center), and then the residential areas, where the highest recorded concentration was 0.27 ppm in A20 (Residential Fallujah) for the month of January. While the highest spatial rate of SO_2 gas was recorded in the industrial areas, reaching 0.2093 ppm, the lowest spatial rate was recorded in the residential areas with a concentration of 0.1496 ppm. The reason for the high concentrations of SO_2 in industrial areas may be due to industrial processes and fuel combustion, similar to the study by **[15]**. Commercial areas recorded higher concentrations than residential areas due to vehicle emissions. This study is consistent with the findings of **[16]**. The results of the statistical analysis in **Table (7)** showed a significant relationship between the concentration of sulfur dioxide and the study areas, as the probability value was recorded at P = 0.04 for the one-way variance analysis of variance test. When conducting a pairwise comparison of the mean differences between the areas, the two areas (industrial-residential, commercial-residential) showed a probability value of $P < 0.05$, confirming the presence of significant statistical differences between them. Meanwhile, the industrial-commercial comparison showed a probability value of $P > 0.05$, indicating that despite the existence of differences between the averages of the two areas, they are not considered statistically significant differences. When comparing SO_2 gas concentrations between the stations selected for the study and the monitoring station, it was found that all gas concentrations recorded in the selected stations were higher than the values recorded for the control station during the study months. Most of the study stations showed that they exceeded the **[17].** except for A2 outside Kubisa Cement Factory, A11 Haditha Residential, and A19 Fallujah Commercial. A comparison with the local limit showed varying exceedances according to the regions and months, as the red color in **Table (6)** indicates that the concentration exceeded the nationally and globally permissible limit, while the green color indicates that the concentration did not exceed the nationally and globally permissible limit.

Nitrogen Dioxide Concentration

The results in **Table (8)** showed that the overall average for nitrogen dioxide gas was (0.007318) ppm , with a standard deviation of 0.003399, while the minimum and maximum values for the recorded concentrations were (0.0014 and 0.0193)ppm, respectively. The discrepancy between the recorded values is explained by the overlapping influence of climatic factors and various human activities.

While the results of the study in **Table (8)** showed the presence of temporal variation between the concentration of nitrogen dioxide gas and the study months, the highest concentration was recorded in January with a concentration of (0.0193) ppm at the station (A18 Fallujah Industrial), followed by the months of (November, April) with concentrations of (0.0124, 0.0089ppm at (A18 Fallujah Industrial, A13 Hit Commercial), respectively. Meanwhile, the lowest concentration of (0.0088) ppm was recorded in March at the station (A16 Ramadi Commercial). On the other hand, the highest temporal average for the study months was recorded in January with (0.01101) ppm, while the lowest monthly average was recorded in April with (0.01101) ppm. The increase in NO_2 concentration in January is attributed to increased human activities, fossil fuel consumption, and climatic conditions that hinder the dispersal of the pollutant, such as thermal inversion, which contributes to the trapping of the pollutant in the lower atmosphere. Furthermore, the decrease in wind movement reduces the dispersal of the pollutant. A study by **[17]**. Confirmed that the winter months are more polluted with NO_2

due to increased gas emissions from activities and poor ventilation. Conversely, a relative rise in temperatures, coupled with increased wind movement in April, enhanced the dispersal of the gas in the atmosphere, while a decrease in fuel consumption reduced NO_2 emissions. This is consistent with a study by **[18]** that found increased temperatures lead to a decrease in NO_2 concentration due to the influence of climatic and human factors.

Table (8) Nitrogen dioxide concentration in the study areas and months

Region	Station number	Nov.	Jan.	Mar.	Apr.	Spatial Average
Industrial	A9	0.0086	0.0115	0.004	0.0061	0.00755
	A5	0.0045	0.0156	0.0055	0.0057	0.007825
	A6	0.0054	0.0151	0.0067	0.0049	0.008025
	A7	0.0084	0.011	0.0036	0.0057	0.007175
	A12	0.0065	0.0133	0.0068	0.0071	0.008425
	A1	0.0097	0.0161	0.009	0.0046	0.00985
	A2	0.0072	0.0113	0.0041	0.005	0.0069
	A3	0.007	0.0157	0.0042	0.0048	0.007925
	A15	0.0059	0.0118	0.0051	0.0052	0.007
	A18	0.0124	0.0193	0.0081	0.006	0.01145
Residential	A4	0.0073	0.0089	0.0043	0.0041	0.00615
	A8	0.0082	0.0114	0.004	0.0018	0.00635
	A11	0.0069	0.0074	0.0059	0.0028	0.00575
	A14	0.0072	0.0091	0.0051	0.0023	0.005925
	A17	0.0065	0.0079	0.0014	0.0044	0.00505
	A20	0.0065	0.0093	0.0064	0.0035	0.006425
Commercial	A10	0.009	0.0096	0.0068	0.0059	0.007825
	A13	0.0089	0.004	0.0074	0.0089	0.0073
	A16	0.0083	0.0066	0.0088	0.0079	0.0079
	A19	0.0045	0.0052	0.0064	0.0061	0.00555
Time Average		0.00745	0.01101	0.00564	0.0052	0.00732
Control (A21)		0.0015	0.0015	0.0017	0.0019	0.00165
Local Environmental Determinant				0.1 ppm According to the Iraqi Ministry of Health and Environment (2018)		
Global Environmental Determinant				0.1ppm Global standard according to the Environmental Protection Agency (2024)		

Minimum	Maximum	Mean	Std. Deviation	Variance
0.0014	0.0193	0.007318	0.003399	0.0001

The results of the statistical analysis in **Table (9)** showed that there is a significant statistical relationship between the concentration of nitrogen dioxide gas and the months of the study, as the probability value P = 0.004 was recorded for the one-way analysis of variance test. When conducting a pairwise comparison of the average differences between the months, (November - January, November - April) as well as (January - March, January - April) showed a probability value of ($P < 0.05$), which confirms the existence of significant statistical differences between those months. Meanwhile, it showed insignificant differences for the pairwise comparison between the rest of the months, as it was ($P > 0.05$), indicating that despite the existence of differences between the averages of the two regions, they are not considered statistically significant differences.

Table (9) Results of statistical analysis of NO_2 gas concentration for the study areas and months

	Month	Mean	Comparison Between Two Months	Mean Difference	Std. Error	p-value
Monthly Concentration			**Nov._ Jan.**	**-.003560***	**.0008058**	**0.001**
	November	0.00744	Nov. _ Mar.	.0018029	.0008163	0.130
	January	0.01100	Nov. _Apr.	.0022450*	.0007961	0.031
	March	0.00564	Jan._ Mar.	.0053629*	.0008163	0.001
	April	0.00520	Jan_ Apr.	.0058050*	.0007961	0.001
			Mar._ Apr	.0004421	.0008068	0.947
ANOVA p =0.004 F = 21.552						
Region Concentration	**Region**	**Mean**	**Comparison Between Two Regions**	**Mean Difference**	**Std. Error**	**p-value**
	Residential	0.00594	Ind. _ Com.	.0022708*	0.00085	0.025
	Commercial	0.00714	Ind. _Res.	0.00107	0.00097	0.519
	Industrial	0.00821	Com._ Ind.	0.001202	0.498	0.498
ANOVA p=0.032 F=3.593						

The results in **Table (8)** show that there is a spatial variation between the concentration of SO_2 gas and the study areas, where the highest concentration of 0.0193 ppm was recorded in the industrial areas of the station (A18 Fallujah), followed by the residential areas with 0.0114 ppm for the station (A8 residential neighborhood for employees of the K3 refinery), and then the commercial areas (0.0096 ppm) in (A10 Haditha). While the highest spatial rate of SO_2 gas was recorded in the industrial areas, reaching 0.008213 ppm, the lowest spatial rate was recorded in the residential areas with a concentration of 0.005942 ppm.

Industrial human activities that rely heavily on fossil fuels, especially large vehicles (trucks, machinery), lead to increased pollution levels. A study by **[19]**. Indicates that industrial emissions represent one of the primary sources of NO_2 pollutants in the air. Residential areas recorded the lowest concentrations of the gas due to reduced human activities, which are limited to the use of private vehicles. According to a study by **[20]**. Residential areas recorded lower levels of NO_2 compared to areas with high industrial or commercial density.

The results of the statistical analysis in **Table (9)** showed the existence of a significant statistical relationship between the concentration of nitrogen dioxide gas and the study areas, as the probability value was recorded at P = 0.032 for the one-way analysis of variance test. When conducting a pairwise comparison of the average differences between the areas, the two areas (industrial - residential) showed a probability value of ($P < 0.05$), which confirms the existence of significant statistical differences between them, while (industrial - commercial, residential - commercial) showed a probability value of ($P > 0.05$), indicating that despite the existence of differences between the averages of the two areas, they are not considered statistically significant differences.

Ozone Gas Concentration

The results in **Table (10)** showed that the overall average ozone gas level was 0.045790 ppm, with a standard deviation of 0.003399. The values ranged between 0.021 and 0.0891 ppm. The dispersion of values is explained by the combined influence of climatic factors and various human activities.

The results of the study in **Table (10)** showed temporal variation between nitrogen dioxide concentrations and the study months. The highest concentration was recorded in April, at 0.0705 ppm, at Station A5 inside the Haditha Refinery. This was followed by March, January, and November, with concentrations reaching 0.0586, 0.0479, and 0.0446 ppm in A17 Ramadi Residential, A4 Kubisa Residential Complex, and A16 Ramadi Commercial, respectively. On the other hand, the highest temporal average for the study months was recorded in April, with a concentration of 0.0891 ppm, while the lowest monthly average was recorded in January, with a concentration of 0.03481 ppm.

Temperature and solar radiation intensity activate photochemical reactions between nitrogen oxides and volatile organic compounds in the nearby atmosphere, contributing to ozone formation **[21]**. Therefore, high temperatures in April contribute to increased activity of these reactions, leading to a gradual increase in ozone concentration in the atmosphere with increasing temperature **[22]**. Meanwhile, low temperatures coupled with decreased solar radiation intensity in January reduce photochemical reactions, contributing to a decrease in ozone concentration in the atmosphere, consistent with the study by **[23]**.

Table (10) Ozone gas concentration in the study areas and months

Region	Station number	Nov.		Jan.	Mar.	Apr.	Spatial Average
Industrial	A9	0.0289		0.0291	0.0322	0.0393	0.03237
	A5	0.0342		0.0293	0.0519	0.070	0.04647
	A6	0.0359		0.03	0.0397	0.0471	0.03817
	A7	0.0253		0.0319	0.0506	0.0607	0.04212
	A12	0.0384		0.0288	0.0516	0.0552	0.0435
	A1	0.0243		0.0351	0.0449	0.0605	0.0412
	A2	0.0376		0.0263	0.045	0.0531	0.0405
	A3	0.0299		0.0227	0.0512	0.0685	0.04307
	A15	0.0352		0.0312	0.0582	0.0557	0.04507
	A18	0.043		0.0285	0.0503	0.0675	0.04732
Residential	A4	0.0431		0.0474	0.0576	0.0634	0.05287
	A8	0.041		0.041	0.0483	0.0773	0.0519
	A11	0.0438		0.0452	0.0422	0.0617	0.0482
	A14	0.0437		0.0434	0.0565	0.0651	0.05217
	A17	0.0414		0.0436	0.0586	0.0682	0.05295
	A20	0.038		0.0452	0.0397	0.0891	0.053
Commercial	A10	0.0326		0.0313	0.0551	0.0535	0.04312
	A13	0.0437		0.0353	0.0506	0.075	0.05115
	A16	0.0446		0.029	0.0483	0.0599	0.04545
	A19	0.021		0.0419	0.0523	0.0653	0.04512
Time Average		0.03628		0.03481	0.04907	0.06232	0.04562
Control (A21)		0.0025		0.0020	0.0264	0.0464	0.01932
Local Environmental Determinant				0.1 ppm According to the Iraqi Ministry of Health and Environment (2018)			
Global Environmental Determinant				0.070ppm Global standard according to the Environmental Protection Agency (2024)			
Minimum	Maximum	Mean		Std. Deviation		Variance	
0.0021	0.0891	0.045790		0.0140316		0.001	

The results in **Table (11)** showed that the probability value of the one-way variance test was recorded ($P = 0.001$), indicating the existence of a significant relationship with statistical significance between the concentration of ozone gas and the study months. Meanwhile, all pairwise comparisons of the Tukey test between the study months recorded a probability value of ($P < 0.05$), confirming the existence of significant differences with statistical significance between those months. However, the comparison between November and January showed a non-statistical significance, as it was ($P > 0.05$).

Table (11) Results of statistical analysis of O_3 gas concentration for the study areas and months

	Month	Mean	Comparison Between Two Months	Mean Difference	Std. Error	p-value
Monthly Concentration			Nov._ Jan.	0.0014700	0.002661	0.946
	November	0.03628	Nov. _ Mar.	-0.0127989*	0.002696	0.001
	January	0.03481	Nov. _Apr.	-0.0260486*	0.002629	0.001
	March	0.04907	Jan._ Mar.	-0.0142689*	0.002696	0.001
	April	0.06232	Jan_ Apr.	-0.0275186*	0.002629	0.001
			Mar._ Apr	-0.0132496*	0.002665	0.001
ANOVA p =0.001 F = 47.846						
Region Concentration	**Region**	**Mean**	**Comparison Between Two Regions**	**Mean Difference**	**Std. Error**	**p-value**
	Residential	0.05185	Ind. _ Com.	-0.0098717*	0.003492	0.016
	Commercial	0.04621	Ind. _Res.	-0.0042300	0.004001	0.543
	Industrial	0.04198	Com._ Ind.	-0.0056417	0.004365	0.404
ANOVA p=0.032 F=3.593						

In contrast, the results in **Table (10)** noted a spatial variation between the concentration of O_3 gas and the study areas, where the highest concentration of 0.0891ppm was recorded in the residential areas of the station (A20 Fallujah), followed by the industrial areas with 0.0705 ppm at the station (A5 inside the Haditha refinery), and then the commercial areas with 0.0653 ppm in (A19 Fallujah). While the highest spatial rate of O_3 gas was recorded in the residential areas, reaching 0.051854 ppm, the lowest spatial rate was recorded in the industrial areas, with a rate of 0.041983 ppm. This is due to the nature of the interactions and emission levels of primary pollutants that control ozone formation. Although industrial areas are the main source of nitrogen oxides (NO_x) emissions as a result of increased industrial activities or vehicle movement in them, the concentration of (NO) interacts with ozone, which contributes to a decrease in its concentration in industrial areas. This was confirmed by a study**[24]**.In contrast, residential areas record the highest concentration of ozone gas as a result of decreased industrial activities and vehicle movement, which leads to a decrease in the concentration of (NO) and thus results in an increase in the concentration of ozone gas in these areas, which is what was concluded by **[25]**.

The results in **Table (11)** showed a significant, statistically significant relationship between NO_2 concentration and the study areas. The probability value (P) = 0.032 for the one-way variance test was recorded. When pairwise comparisons were made of the mean differences between the areas, (Industrial - Residential) showed a probability value of ($P < 0.05$), confirming the presence of statistically statistically significant differences between them. Meanwhile, (Industrial-Commercial, Residential-Commercial) showed a probability value of ($P > 0.05$), indicating that despite the presence of differences between the averages of the two areas, these differences are not considered statistically significant.

Although the residential areas recorded the highest values of ozone gas concentration, the study results for all study areas did not exceed the nationally permissible limit. However, they exceeded the global standard at two stations (A5 inside the Haditha refinery with a concentration of 0.0705ppm and A20 Fallujah residential with a concentration of 0.0891ppm), while the concentration of the control station was lower than the concentrations of all the stations selected for the study.

2- Environmental Assessment of Pollutants by Air Quality Index Values

Air Quality Assessment for Carbon Monoxide

Table (12) shows that the results of calculating the Air Quality Index (AQI) in the study areas and months vary temporally and spatially. Based on the Air Quality Index (AQI) classification, it was noted that the pollutant index (IP) ranged in November from 5 to 65, in January from 24 to 82, while in March it ranged from 18 to 65, and in April it ranged from 3 to 45. This means that all study months, based on the pollutant index values, were recorded as moderate. This indicates that carbon monoxide gas (CO) can be considered moderate, with little impact on human health.

In contrast, spatial variation showed that the industrial areas for the months of November and April had pollutant values ranging between 17-30 and 10-45 according to the air quality index, which falls within the good category. In April, site A15 Ramadi recorded the highest index value of 53, followed by March with a value of 54 at site A18 Fallujah, which falls within the moderate category. Meanwhile, in residential areas, the pollutant index values for all study areas ranged between 3-48 during the study months, which falls within the good category. As for commercial areas, their stations showed pollutant index values between 26-82 in the months of November, January, and March, which places them within the moderate value of the air quality index. In April, commercial areas showed a value between 21-32, which falls within the good category.

Based on the above results, carbon monoxide, according to the Air Quality Index, falls between the "good" and "moderate" categories. Therefore, it can be considered to have no direct impact on human health in all study areas and stations. This result is consistent with the study by **[26],** who concluded that carbon monoxide falls within the "moderate" category and is the least harmful to human health in the study areas.

Table (12) Results of air quality index values for CO gas in the study areas and months based on the linear equation

Region	Station number	IP Nov.	IP Mar.	IP Mar.	IP Apr.	Indicator Description	Impact on public health
Industrial	A9	21	25	18	10	Good	Poses little or no risk human health.
	A5	20	36	30	30	Good	
	A6	17	30	26	21	Good	
	A7	18	38	36	12	Good	
	A12	47	30	31	13	Good	
	A1	17	42	25	26	Good	
	A2	17	35	19	28	Good	
	A3	21	28	31	12	Good	
	A15	32	53	44	45	Moderate	Very few symptoms in people at high risk of Allergies.
	A18	30	50	54	26	Moderate	
Residential	A4	18	35	24	3	Good	
	A8	9	33	35	8	Good	
	A11	5	24	48	22	Good	
	A14	14	35	24	23	Good	
	A17	24	49	45	26	Good	
	A20	29	40	45	30	Good	
Commercial	A10	64	34	26	22	Moderate	
	A13	21	45	38	21	Good	
	A16	54	82	55	32	Moderate	
	A19	65	43	66	32	Moderate	
Time Average		Moderate	Moderate	Moderate	Good	Moderate	

Air Quality Assessment of Sulfur Dioxide

Table (13) indicates variations in the Air Quality Index (AQI) calculation results across the study regions and months. Based on the AQI classification for the study months, the values in November ranged between103-206, and in January between117-219, both falling within the (unhealthy, sensitive, and hazardous) category. The values in March were 94-206, which fall within the (moderate-hazardous) category, while the values in April were 81-148, which fall within the (moderate-unhealthy) category, according to the AQI. On the other hand, it was noted that the highest value of the gas index in industrial areas was recorded at Station A6, Haditha Refinery, upwind, with the highest value of 214 for the air quality index (hazardous), which affects people, especially the respiratory system, particularly asthma. The lowest value was recorded at Station A2, Cement Factory, upwind, with 82, which falls within the moderate quality index. In residential areas, the highest index value was 186 at station A20 in Fallujah, which is considered unhealthy, while the lowest value was recorded at station A11 in Haditha, with 94, which falls within the moderate category. In commercial areas, the highest value was recorded at station A16 in Ramadi, with 219, which falls within the dangerous category, while the lowest index value was recorded at 94 at station A11 in Fallujah, which falls within the moderate category. Based on the above air quality calculation results, SO_2 can be considered in the study areas, which means it has a direct impact on the health of residents (children, adults, and the elderly) as it has a direct impact on the health of residents (children, adults, and the elderly) as well as workers in those areas,

especially regarding respiratory diseases (asthma). This is consistent with the study **[27],** where the results of their study of Brazilian urban areas showed a high rate of children suffering from acute respiratory diseases due to the high quality index and the recorded risk ratio for those areas.

Table (13) Results of air quality index values for SO_2 gas in the study areas and months based on the linear equation

Region	Station number	IP Nov.	IP Mar.	IP Mar.	IP Apr.	Indicator Description	Impact on Public Health
Industrial	A9	143	206	186	130	Very unhealthy	Exacerbation of symptoms in people most and decreased tolerance in healthy members of the population, which may require taking emergency measures for and members of sensitive.
	A5	134	203	182	143	Very unhealthy	
	A6	143	214	134	117	Very unhealthy	
	A7	153	203	165	126	Very unhealthy	
	A12	170	198	206	139	Very unhealthy	
	A1	130	190	194	121	Unhealthy	Members of sensitive groups experience more serious health effects
	A2	108	153	134	81	Unhealthy	
	A3	126	174	165	117	Unhealthy	
	A15	206	198	186	121	Very unhealthy	
	A18	203	157	203	112	Very unhealthy	
Residential	A4	117	121	153	103	Unhealthy	
	A8	103	117	148	121	Unhealthy for sensitive groups	Minor symptoms may occur in people with allergies, and some healthy people may develop symptom.
	A11	112	157	178	94	Unhealthy	
	A14	130	180	153	130	Unhealthy	
	A17	117	170	143	130	Unhealthy	
	A20	126	186	117	107	Unhealthy	
Commercial	A10	153	165	139	148	Unhealthy	
	A13	170	186	117	108	Unhealthy	
	A16	161	219	130	134	Very unhealthy	
	A19	108	186	94	143	Unhealthy	
Time Average							

Air Quality Assessment of Nitrogen Dioxide

Table (14) indicates that the results obtained show that the pollutant index values for nitrogen dioxide for all stations and study months did not exceed the (0-50) category according to the air quality classification. Accordingly, the air quality index value for NO_2 can be considered to fall within the good category, indicating the absence of any health effects on humans within the study areas.

Table (14) Results of the air quality index values of NO_2 gas in the study areas and months based on the linear equation

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Region	Station number	IP Nov.	IP Mar.	IP Mar.	IP Apr.	Indicator Description	Impact on public health
Industrial	A9	8	11	4	6	Good	Poses little or no risk human health.
	A5	4	15	5	5	Good	
	A6	5	14	6	5	Good	
	A7	8	10	3	5	Good	
	A12	6	13	6	7	Good	
	A1	9	15	8	4	Good	
	A2	7	11	4	5	Good	
	A3	7	15	4	5	Good	
	A15	6	11	5	5	Good	
	A18	12	18	8	6	Good	
Residential	A4	7	8	4	4	Good	
	A8	8	11	4	2	Good	
	A11	7	7	6	3	Good	
	A14	7	9	5	2	Good	
	A17	6	7	1	4	Good	
	A20	6	9	6	3	Good	
Commercial	A10	8	9	6	6	Good	
	A13	8	4	7	8	Good	
	A16	8	6	8	7	Good	
	A19	4	5	6	6	Good	
Time Average		Good	Good	Good	Good	Good	

Air Quality Assessment of Ozone

Table (15) shows that the pollutant index (IP) ranged between 19-41 in November and 21-44 in January. In both cases, according to the quality index, the IP value was within the good category. Meanwhile, the IP value in March was 30-63, which falls within the moderate category, while April showed 36-159, which falls within the unhealthy category according to the air quality index.

Based on the classification of the air quality index, we note that all industrial areas have gas index values (21-99) for the air quality index (good - moderate). Therefore, it was considered that the air quality of ozone gas in most industrial areas does not affect human health or affect very sensitive individuals. As for residential areas, the quality index recorded between (good - unhealthy) for gas index values ranging from (35 - 159), where the station (A8, the residential complex of the refinery) recorded an index value of (123), which falls within the category (100-150) for unhealthy sensitive air quality that affects children, adults, and people suffering from asthma. In the station (A20 Fallujah), the index value was recorded as (159), and according to the quality index, it falls within (150-200), which is unhealthy and affects people with cardiovascular diseases و in addition to those with asthma. Meanwhile, in commercial areas, it showed index values between (17-115), falling within the category (good - unhealthy sensitive).

Based on the above results and the Air Quality Index, it can be considered that ozone concentration has a clear impact on people in residential areas more than in other areas.

Table (15) Results of the air quality index values for O_3 gas in the study areas and months based on the linear equation

Region	Station number	IP Nov.	IP Mar.	IP Mar.	IP Apr.	Indicator Description	Impact on public health
Industrial	A9	27	27	30	36	Good	Poses little or no risk human health.
	A5	32	27	48	99	Moderate	
	A6	33	28	37	44	Good	
	A7	23	30	47	70	Moderate	Very few symptoms in people at high risk of allergies.
	A12	36	27	48	52	Moderate	
	A1	22	32	42	69	Moderate	
	A2	35	24	42	49	Good	
	A3	28	21	47	95	Moderate	
	A15	33	29	61	53	Moderate	
	A18	40	26	47	92	Moderate	
Residential	A4	40	44	59	78	Moderate	
	A8	38	38	45	123	Unhealthy for sensitive groups	Minor symptoms may occur in people with allergies, and some healthy people may develop symptom
	A11	41	42	39	73	Moderate	
	A14	40	40	56	84	Moderate	
	A17	38	40	63	94	Moderate	
	A20	35	42	37	159	Unhealthy	members of sensitive groups may experience more serious health effects
Commercial	A10	30	29	51	50	Good	
	A13	40	33	47	115	Unhealthy for sensitive groups	
	A16	41	27	45	67	Good	
	A19	19	39	30	36	Good	
Time **Average**							

Conclusions

The main conclusion of this work is as follows:

1. The selected industrial sites recorded the highest concentrations of pollutants (SO_2, NO_2), exceeding national limits.
2. Commercial areas recorded average concentrations of most pollutants, although some exceeded permissible limits.
3. Despite the distance of residential areas from industrial activities, they showed high concentrations of some pollutants, attributed to the presence of some commercial establishments (bakeries) and the random spread of private generators.
4. Air quality indicators showed that sulfur dioxide gas was classified as the highest in the (unhealthy-hazardous) category in most of the study areas, indicating its potential health effects on humans.

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دراسة تراكيز الملوثات الغازية وتقييم جوده الهواء في بعض المناطق الحضرية المختارة من محافظه الانبار

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قسم علوم الأحياء، كلية التربية للعلوم الصرفة، جامعة الأنبار، الرمادي، العراق [1،2]

الخلاصة

تناولت الدراسة الحالية الى تقييم البيئي لنوعيه الهواء لبعض المناطق المختارة من محافظة الانبار من خلال قياس تراكيز الملوثات الهوائية شملت غازات (اول أكسيد الكربون CO، ثاني أكسيد الكبريت SO_2، ثاني أكسيد النتروجين NO_2، الأوزون O_3). توصلت نتائج الدراسة الى تجاوز بعض تراكيز الملوثات الهوائية والتي هي (NO_2 ،SO_2) الحدود الوطنية والعالمية المسموح بها والتي سجلت تراكيز بلغت (0.36 ،0.0193) جزء بالمليون على التوالي في حين لم تتجاوز تراكيز غازات (NO_2،CO) الحدود المسموح بها. أظهرت نتائج الدارسة تباين لمستويات تراكيز الملوثات في المناطق اذ سجلت في المناطق الصناعية اعلى تراكيز للملوثات (NO_2) في حين سجلت (SO_2 ،CO) اعلى التراكيز في المناطق التجارية، بينما سجل(O_3) اعلى تركيز في المناطق السكنية. تم تقييم الاثار الصحية لملوثات الهواء في منطقة الدراسة بالاعتماد على مؤشر جودة الهواء (AQI) وهو مقياس رقمي يستعمل لتحديد مستوى تلوث الهواء وتأثيره على الصحة العامة، من خلال تصنيف كل ملوث ضمن فئة تتراوح ما بين (0-350) فأظهرت النتائج وجود تباين في مستويات التلوث في مواقع الدراسة تراوحت بين فئة (جيد) غاز ثاني أكسيد النتروجين الى فئة(خطر) غاز ثاني أكسيد الكبريت.

الكلمات المفتاحية : تلوث الهواء، الغازات الملوثة للهواء، جوده الهواء