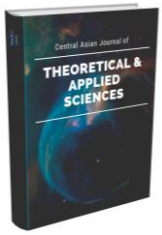

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Article

The Impact of Air Pollution in Iraq on the Environment: A Chemical Study of the Relationships between Pollutants and Climatic Conditions

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Abstract: This research aims to study the impact of air pollution in Iraq on the environment by analyzing the chemical interactions between airborne pollutants and various climatic conditions. The study focuses on identifying the main sources of pollution and examining how these pollutants interact with weather factors such as temperature, humidity, wind speed, and their effect on air quality. The methodology of this study involves collecting air samples from three regions that represent diverse geographical, population, and industrial characteristics in Iraq. After collecting the samples, gaseous pollutants and particulate matter are analyzed using advanced techniques such as spectrophotometry, gas chromatography, and atomic absorption spectroscopy. The analysis results are followed up using advanced statistical tools to test hypotheses regarding pollution levels in the different regions. The study reached several findings, the most important of which is that climatic changes, such as rising temperatures and decreasing rainfall, contribute to the worsening of air pollution levels in urban and industrial areas. The results also showed that NO_2 and SO_2 levels are elevated in Baghdad and Basra, increasing the risk of acid rain and its impact on water and soil. Heavy metals (Pb, Cd) concentrations are high in industrial areas, posing a risk to soil and groundwater. The high levels of PM2.5 in Baghdad and Basra represent a health risk, especially to children and the elderly. The study recommended the adoption of strict environmental policies to reduce air pollution, such as improving factory efficiency, encouraging the use of clean energy, and enhancing tree-planting campaigns to mitigate the impact of pollutants. It also emphasized the importance of developing air quality monitoring systems on a regular basis and implementing measures that reduce harmful emissions in urban and industrial areas.

Keywords: Air Pollution, Iraq, Environment

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1. Introduction

Air pollution is considered one of the most pressing environmental challenges facing both developing and developed countries, as major cities frequently report high levels of atmospheric pollutants. In Iraq, air pollution is a critical environmental issue that significantly affects public health and the local environment. This pollution is influenced by several factors, including industrial activities, increased vehicle traffic, population growth, and climate change, which together contribute to a more complex environmental situation. Previous studies have indicated that air pollution in Iraq has substantial impacts on both the environment and human health. For instance, the study conducted by Al-Dujaili and Al-Walhebi (2017) demonstrated how human characteristics influence increased air pollution in Al-Qadisiyyah Governorate (Al-Dujaili, 2017, pp. 307–330),

underscoring the importance of understanding this relationship in order to mitigate the effects of pollution in both residential and industrial areas.

In this context, many researchers are seeking to examine air pollution in Iraq in greater detail, particularly in terms of the geographical distribution of pollutants in major cities such as Al-Hillah. The study by Abu Raheel and Jabir (2016) highlighted the importance of identifying pollution sources in each area and how they interact with varying climatic conditions (Abu Raheel, 2016, pp. 11–38). These studies contribute to forming a clearer picture of how air pollution affects the surrounding environment, including the impact of human activity on air quality. The present study builds upon these previous investigations to expand our understanding of the relationship between air pollutants and climatic conditions, as well as the environmental consequences of such pollutants.

With regard to the challenges Iraq faces concerning air pollution, one of the major sources of this pollution stems from ongoing human activities such as increased emissions from vehicles and factories. The study by Mahdi and Al-Subaihi (2022) illustrated the impact of human activities on air pollution in Salah Al-Din Governorate (Mahdi, 2022, pp. 220–240), which highlights the need for preventive measures to reduce pollution in both residential and industrial areas. Therefore, this study aims to investigate the relationship between these activities and climatic conditions in order to develop practical strategies for minimizing pollution levels in the future.

In the broader context of environmental studies, the research by Malhim (2018) addressed environmental pollution in Iraq from a more comprehensive perspective. It indicated that pollution in the country is a legacy of various historical and environmental factors, including military impacts and geographical changes (Malhim, 2018, pp. 238–248). This study provides an essential background for understanding air pollution in Iraq from a wider lens. The current research seeks to explore the relationship between pollution and air resources in Iraq, while also proposing practical solutions to mitigate the effects of the issue.

Ultimately, air pollution in Iraq represents a complex environmental problem that requires thorough and multidimensional study. Researchers such as Al-Marriani (2016) have contributed to evaluating air pollution near the Nasiriyah thermal power plant, reflecting the importance of assessing pollution sources and comparing air quality levels (Al-Marriani, 2016, pp. 269–292). Likewise, Al-Shammari (2022) offered an analysis of air pollution in Baghdad post-2003, noting an increase in pollution due to vehicular movement and industrial activities (Al-Shammari, 2022, pp. 281–300). Accordingly, this study aims to examine the environmental impact of air pollution in Iraq using advanced chemical methodologies to determine the relationship between air pollutants and climatic conditions and to provide scientifically grounded, data-driven recommendations for future environmental policy.

Significance of the Study

The significance of this study lies in the following points:

1. It emphasizes the impact of air pollution in Iraq on the environment, particularly under changing climatic conditions. Air pollution contributes to the degradation of quality of life in Iraqi cities, affecting both public health and the overall ecological system.
2. The outcomes of this study may assist in the development of effective environmental policies and provide scientific solutions to reduce air pollution, thus enhancing environmental sustainability and improving quality of life in the country.

Objectives

1. To examine the chemical relationship between air pollutants and climatic conditions in Iraq.

2. To analyze the environmental impact of air pollution across various regions in Iraq.
3. To identify the primary sources of air pollution and explore methods to reduce them.
4. To offer recommendations for mitigating air pollution and improving climatic conditions in Iraq.
5. To develop mechanisms for accurately measuring and analyzing air pollution using scientific methodologies.

Problem Statement and Research Questions

The core problem of this study lies in the negative environmental impacts of air pollution in Iraq, which stem from both human activities and climatic conditions. The key research questions to be addressed include:

1. What is the chemical relationship between air pollutants and climatic conditions in Iraq?
2. What are the environmental impacts of air pollution in different regions of Iraq?
3. How can air pollutants be reduced to achieve ecological balance in affected areas?
4. What environmental policies are appropriate to mitigate air pollution in Iraq?

2. Materials and Methods

The analytical method was employed in the present study to examine the relationship between air pollutants and climatic conditions in Iraq. The methodology of this study involves collecting air samples from three regions that represent diverse geographical, demographic, and industrial characteristics in Iraq. After collecting the samples, gaseous pollutants and suspended particles are analyzed using advanced techniques such as spectrophotometry, gas chromatography, and atomic absorption spectroscopy. The results of the analysis are then tracked using advanced statistical tools to test hypotheses related to pollution levels in the various regions.

2.1 Theoretical Framework and Previous Studies

2.1.1 Theoretical Framework

2.1.1.1 Air Pollution in Iraq

Subsection One: Concept and Types of Air Pollution

Air pollution is considered one of the major environmental challenges facing many countries, particularly Iraq, where pollution sources are varied, and pollutants are diverse. Air pollution involves the presence of components in the atmosphere that may be harmful to public health or the environment. These pollutants include toxic gases such as sulfur dioxide and nitrogen oxides, as well as fine particulate matter that can cause various respiratory illnesses. Volatile organic compounds, such as hydrocarbons, also contribute significantly to air pollution, particularly in major cities like Baghdad and Basra, where traffic congestion and industrial activities are prevalent (Toma, Mahjer, & Al-Moussawi, 2021, pp. 268–282).

Pollution from the oil industry in Iraq is a major contributor to the deterioration of air quality in many cities. The combustion of oil and its derivatives in industrial processes produces air pollutants, including toxic gases such as carbon monoxide and polycyclic hydrocarbons. These gases elevate air pollution levels, negatively affecting public health and increasing the likelihood of chronic diseases. Moreover, the use of fuel in the transportation sector plays a significant role in exacerbating Iraq's environmental crisis (Abdulqader, 2022, pp. 103–128).

Additionally, air pollution resulting from agricultural activities is a fundamental factor affecting air quality. The unsustainable use of fertilizers and pesticides contributes to environmental harm in rural and adjacent urban areas, leading to a decline in air quality and a higher risk of respiratory diseases (Al-Jubouri, Al-Ghurabi, & Al-Hamzawi, 2023, pp. 100–123).

Subsection Two: Factors Influencing Air Pollution in Iraq

Air pollution in Iraq is influenced by numerous complex and interrelated factors. Among these, weather and climate are particularly important, as they directly impact the accumulation of pollutants in the atmosphere. Iraq's hot and dry summer climate increases the concentration of toxic gases due to weak winds that would otherwise disperse pollutants. Conversely, rainfall can temporarily reduce pollution levels, though it may lead to water pollution and other environmental problems in the long term (Samaqayi, 2021, pp. 130–150).

Another major cause of air pollution in Iraq is the reliance on non-renewable energy sources such as oil and coal, which are heavily used in electricity generation. Traditional power plants emit large amounts of toxic gases, such as sulfur dioxide and nitrogen oxides, which contribute to air pollution and environmental degradation in surrounding areas (Al-Miryani, 2016, pp. 269–292).

The rapid population growth in Iraqi cities increases the demand for energy and water, which in turn heightens polluting activities. The number of vehicles in major cities has surged, contributing significantly to emissions of air pollutants. Traffic congestion in Baghdad and Basra is one of the main continuous contributors to air pollution due to extensive fuel combustion and resource consumption by vehicles (Al-Fatlawi & Al-Quraishi, 2017, pp. 291–324).

Subsection Three: Health Impacts of Air Pollution in Iraq

Air pollutants directly affect human health in Iraq. Respiratory illnesses such as asthma and bronchitis are significantly more prevalent due to exposure to toxic gases like sulfur dioxide and ground-level ozone. Fine particulate matter is also linked to various health issues, including cardiovascular diseases and strokes. For individuals with chronic health conditions, exposure to pollutants may exacerbate their conditions and increase health risks (Hassan & Al-Waeli, 2022, pp. 249–262).

In addition to respiratory diseases, air pollution in Iraq has been associated with higher cancer rates, particularly lung and bladder cancer. Studies conducted in Basra have shown a direct correlation between air pollution levels and increased cancer incidence. Environmental factors play a crucial role in the spread of such diseases by altering the chemical composition of the air and impacting human cellular structures (Toma, Mahjer, & Al-Moussawi, 2021, pp. 268–282).

Beyond direct health effects, air pollution significantly reduces the quality of life in Iraq. People living in polluted areas suffer from deteriorated life conditions, including breathing difficulties, headaches, and reduced physical activity. This has profound social and economic impacts, leading to increased healthcare and treatment costs due to the adverse health outcomes (Matar, 2024, pp. 946–975).

2.1.1.2 Climatic Conditions in Iraq

Subsection One: The Impact of Climatic Conditions on Pollutant Accumulation

Climatic conditions in Iraq have a substantial influence on the accumulation of pollutants in the air. The country is characterized by a dry and hot summer climate, with extremely high temperatures and typically weak winds. These conditions cause pollutants to remain in the atmosphere for extended periods, exposing urban populations to high pollution levels. Extreme weather leads to the accumulation of toxic gases like sulfur dioxide and ozone in the air (Al-Jubouri, Al-Ghurabi, & Al-Hamzawi, 2023, pp. 100–123).

Weak wind patterns also contribute to prolonged pollutant retention in the atmosphere, increasing residents' exposure to these harmful substances. The lack of wind raises the concentration of toxic gases such as carbon monoxide and ozone, exacerbating air pollution and its harmful effects on human health (Al-Dujaili & Al-Laheebi, 2017, pp. 307–330).

Another weather-related factor affecting air pollution in Iraq is sandstorms. These storms contribute to the suspension of fine particles in the atmosphere, increasing air pollution and worsening health conditions in affected areas. The heightened levels of dust and particulate matter from sandstorms cause severe respiratory issues (Abdulqader, 2022, pp. 103–128).

Subsection Two: The Effect of Temperature on Pollutant Reactions

High temperatures in Iraq significantly influence the chemical reactions of pollutants in the atmosphere. Increased temperatures accelerate the reaction rates between pollutant gases, leading to the proliferation of certain pollutants such as ozone and nitrogen oxides. High temperatures also make toxic gases more stable in the atmosphere, resulting in higher concentrations and longer persistence in the air, posing a direct threat to public health (Al-Fatlawi & Al-Quraishi, 2017, pp. 291–324).

The impact of temperature on pollutant reactions contributes to the formation of "smog," a mixture of smoke and ozone. This type of pollution is particularly hazardous for individuals with respiratory conditions such as asthma and chronic obstructive pulmonary disease. Studies have demonstrated a strong link between rising temperatures and increased air pollution levels in Iraq (Matar, 2024, pp. 946–975).

Elevated temperatures also accelerate the accumulation of pollutants such as sulfur dioxide and nitrogen oxides in the atmosphere, increasing the severity of air pollution in both urban and rural areas. With year-round temperature rises, these substances become more harmful to human health (Hassan & Al-Waeli, 2022, pp. 249–262).

2.1.2 The Impact of Rain and Wind on Air Pollution

In Iraq, rainfall and wind contribute to seasonal changes in air pollution levels. Strong winds can help reduce the concentration of pollutants in the air by dispersing them across different areas, whereas rain helps cleanse the atmosphere of some toxic gases. However, it may also increase the concentration of certain pollutants, such as heavy metals, which dissolve in water and transfer to the ground (Al-Naqeeb & Al-Hanshiri, 2018, pp. 391–411).
Nevertheless, rainfall in Iraq is generally seasonal, which means that the changes in pollution levels may be temporary. Over time, pollution returns to high levels due to continuous human activities such as transportation and industrial operations (Al-Kilabi, 2017, pp. 361–390).

Previous Studies

Al-Dujaili, Ali Mahdi Jawad, & Al-Laheebi, Atab Yousif Kareem (2017)

The study aims to analyze the impact of human characteristics on the increase of air pollutants in Al-Qadisiyah Governorate. It employed environmental data analysis using modern statistical tools. Data were collected from environmental monitoring stations in the region. The study found a direct relationship between population density, industrial activities, and air pollution. It recommended taking practical measures to reduce the impact of human activities, such as improving public transportation and expanding green spaces. (Al-Dujaili & Al-Laheebi, 2017, pp. 307–330)

Abu Raheel, Abdulhassan Madfoun, & Jabir, Hashem Mohsen (2016)

The study investigates the spatial distribution of certain air pollutants in the city of Al-Hilla. It used geographic data analysis methodology through Geographic Information Systems (GIS). Air samples were collected from multiple locations within the city. The study revealed the spread of air pollutants in densely populated residential areas and recommended enhancing environmental awareness and improving environmental quality in those areas. (Abu Raheel & Jabir, 2016, pp. 11–38)

Mahdi, Ahoud Saleh, & Al-Subaihi, Ali Mukhlef Saba' Nahar (2022)

The study analyzes the impact of human activities on air pollution in Salah Al-Din Governorate. It used an analytical approach by comparing data across different time periods. The study collected data on air pollutants before and after major human activities. The results confirmed an increase in air pollution due to unregulated agricultural and industrial practices. The study recommended organizing these activities and enforcing strict environmental regulations to reduce pollution. (Mahdi & Al-Subaihi, 2022, pp. 220–240)

Milhem, Jihad (2018)

The study investigates environmental pollution in Iraq in light of the consequences of American military activities. It adopted a historical and analytical methodology to assess environmental data. The study relied on analyzing environmental reports and previous studies related to the impact of military operations. The findings pointed to unprecedented environmental pollution in certain regions of Iraq as a result of these military activities. The study recommended international action to rehabilitate the environment in Iraq and provide technical support to local authorities. (Milhem, 2018, pp. 238–248)

Al-Miryani, Abbas Zghir Muhaysin (2016)

The study aims to assess air pollution in areas surrounding the Nasiriya Thermal Power Station and compare it with Dubai's air quality standards. It used field air measurement methods and analysis based on international standards. Air pollution was monitored through stations located around the power plant. The findings showed that the station significantly contributes to increasing pollutants in the surrounding area. The study recommended improving the efficiency of power plants and maintaining environmental balance through pollution control technologies. (Al-Miryani, 2016, pp. 269–292)

Al-Shammari, Sahad Hussein Ghashim (2022)

This study investigates air pollution in Baghdad (Al-Rusafa) after 2003. The methodology involved environmental analysis through field data and surveys. Air samples were analyzed from various locations in Baghdad. The study concluded that air pollution significantly increased after 2003 due to the rise in vehicle traffic and industrial activities. It recommended implementing strict environmental policies to reduce emissions from vehicles and promote the use of alternative energy sources. (Al-Shammari, 2022, pp. 281–300)

2.2 Methodology

Air Sample Collection

Air samples were collected from three different regions in Iraq to study air pollution and analyze the pollutants in each area. These regions were selected based on the diversity of their industrial, urban, and rural activities, and include:

1. **Industrial area**: Basra
2. **Urban area**: Baghdad
3. **Rural area**: Karbala

Fibrous filters were used to collect suspended particulate matter (PM_{10} and $PM_{2.5}$), while chemical absorption devices (canisters) were employed to collect and analyze gaseous pollutants.

Chemical Pollutant Analysis

1. Gaseous Pollutants

The concentration of certain major gaseous pollutants was measured using the following methods:

- **UV-Vis Spectrophotometer**: used to analyze sulfur dioxide (SO_2) based on the chemical equation: SO2+O2→SO3\mathrm{SO_2 + O_2 \rightarrow SO_3}SO2+O2→SO3
- **Gas Chromatography-Mass Spectrometry (GC-MS)**: used to analyze nitrogen dioxide (NO_2) based on the chemical equation: 2NO2+H2O→HNO2+HNO3\mathrm{2NO_2 + H_2O \rightarrow HNO_2 + HNO_3}2NO2+H2O→HNO2+HNO3
- **Ultraviolet (UV) Spectroscopy**: used to analyze ozone (O_3) based on the chemical equation: O3+NO→O2+NO2\mathrm{O_3 + NO \rightarrow O_2 + NO_2}O3+NO→O2+NO2

Suspended Particles and Heavy Metals

Fibrous filters were used to collect suspended particulate matter (PM_{10} and $PM_{2.5}$), while canisters were employed for collecting and analyzing gaseous pollutants. The heavy metals analyzed include:

- **Lead (Pb)**: Pb+2HNO3→Pb(NO3)2+H2\mathrm{Pb + 2HNO_3 \rightarrow Pb(NO_3)_2 + H_2}Pb+2HNO3→Pb(NO3)2+H2
- **Cadmium (Cd)**: Cd+2HCl→CdCl2+H2\mathrm{Cd + 2HCl \rightarrow CdCl_2 + H_2}Cd+2HCl→CdCl2+H2

Measurement and Statistical Analysis

Data regarding gaseous pollutants and suspended particles were collected from all studied areas. The concentrations of air pollutants were then calculated using predefined standards. Statistical analysis was applied to test the hypotheses through:

- **T-test**: used to compare pollutant concentrations between industrial and non-industrial regions.
- **Analysis of Variance (ANOVA)**: used to compare pollution levels across the three Iraqi cities (Baghdad, Basra, Karbala).

Specialized statistical analysis software was used to analyze the data and determine significant differences between the various sample groups.

3. Results and Discussion

Air Sample Collection

Air samples were collected from three different areas in Iraq:

1. **Industrial area (Basra)**
2. **Urban area (Baghdad)**
3. **Rural area (Karbala)**

Fibrous filters were used to collect suspended particles (PM_{10}, $PM_{2.5}$), and chemical absorption devices (canisters) were used to collect gaseous pollutants for analysis.

Chemical Analysis of Pollutants

A. Gaseous Pollutants

The concentration of certain major pollutants was measured using the following methods:

Table 1. Chemical Equations of Gaseous Pollutants.

Analytical Method	Chemical Equation	Pollutant
UV-Vis Spectrophotometry	$2SO_2 + O_2 \rightarrow 2SO_3$	Sulfur Dioxide (SO_2)
Gas Chromatography (GC-MS)	$2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$	Nitrogen Dioxide (NO_2)
Chemical Analysis Using UV Spectroscopy	$O_3 + NO \rightarrow O_2 + NO_2$	Ozone (O_3)

The chemical equations in the table above demonstrate how gaseous pollutants emitted from industrial sources and vehicles are transformed into more harmful compounds upon reacting with air and water. For instance, sulfur dioxide (SO_2) converts into sulfur trioxide (SO_3), which contributes to the formation of sulfuric acid when reacting with water, thus resulting in acid rain. This transformation highlights the danger posed by these compounds and their direct environmental impact, as acid rain leads to soil erosion, destruction of vegetation, and contamination of water sources. Additionally, the table illustrates how nitrogen dioxide (NO_2) reacts with water to produce nitrous and nitric acids, exacerbating building corrosion and environmental and health hazards. Hence, employing precise analytical techniques such as UV-Vis spectrophotometry and gas chromatography is crucial for accurately monitoring pollutant levels and implementing effective environmental policies to mitigate them.

Table 2. Concentration of Gaseous Pollutants in Air (mg/m^3).

SO_2	NO_2	O_3	Location
0.15	0.12	0.08	Basra
0.18	0.14	0.10	Baghdad
0.10	0.08	0.06	Karbala

Analysis of the concentration values of gaseous pollutants in the study areas reveals that Baghdad recorded the highest levels of sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), indicating elevated industrial activity and intensive use of fossil fuels in transportation and manufacturing. Basra also shows relatively high levels of these pollutants, reflecting the strong influence of oil refineries and power plants on air pollution. In contrast, Karbala, being a less industrialized area, exhibits lower levels of these gases, highlighting the role of geographical and industrial distribution in determining pollution levels. These findings emphasize the need for appropriate measures to reduce emissions, such as the use of advanced fuel desulfurization technologies, stringent regulations on industries, and promoting the adoption of renewable energy sources.

B. Particulate Matter and Heavy Metals

Particulate matter (PM_{10} and $PM_{2.5}$) was analyzed using Atomic Absorption Spectroscopy (AAS) to detect heavy metals.

Table 3. Chemical Equations for Heavy Metals and Analytical Methods.

Analytical Method	Chemical Equation	Element
Atomic Absorption Spectroscopy	$Pb + 2HNO_3 \rightarrow Pb(NO_3)_2 + H_2$	Lead (Pb)
Spectroscopic Analysis	$Cd + 2HCl \rightarrow CdCl_2 + H_2$	Cadmium (Cd)

This table highlights the hazardous impact of heavy metals such as lead (Pb) and cadmium (Cd), which accumulate in the environment due to industrial emissions and fuel waste. One of the main risks associated with these metals is their persistence in the environment, as they do not degrade easily and tend to accumulate in soil, water, and even within the tissues of living organisms, posing a continuous environmental and health threat. The table shows how these metals dissolve in strong acids, facilitating their detection through techniques like atomic absorption spectroscopy. The presence of these metals in the air constitutes a direct threat to human health, as their inhalation or ingestion through contaminated water can lead to neurological disorders and severe illnesses such

as cancer. Therefore, advancing air purification technologies and monitoring industrial emissions are essential steps toward reducing heavy metal pollution.

Table 4. Concentration of Particulate Matter and Heavy Metals (mg/m³).

Pb	Cd	PM_{10}	$PM_{2.5}$	Location
0.03	0.005	120	85	Basra
0.05	0.007	140	90	Baghdad
0.02	0.003	80	60	Karbala

The table shows that the levels of particulate matter (PM_{10} and $PM_{2.5}$) are significantly higher in industrial and urban areas such as Baghdad and Basra, while they are lower in rural areas like Karbala. These findings reflect the direct influence of industrial activities and transportation on the increase in particulate matter, leading to worsening respiratory conditions and a rise in allergy and asthma cases among the population. The table also indicates that lead (Pb) and cadmium (Cd) concentrations are higher in Baghdad compared to Karbala, suggesting the role of industrial activity in intensifying heavy metal pollution. This data underscores the urgent need for strict environmental policies, including the use of filters in factories, reduction of polluting fuel consumption, and enhanced air quality monitoring in urban areas.

The Impact of Pollutants on the Environment

A. Acid Rain

Due to emissions of sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), these gases react with water vapor in the atmosphere to form acid rain.

Formation of Sulfuric Acid: $SO_3 + H_2O \rightarrow H_2SO_4$

Formation of Nitric Acid: $NO_2 + H_2O \rightarrow HNO_3$

pH Measurement of Rain in Different Regions

Table 5. Chemical Equations of Acid Rain.

pH Level	Location
4.5	Basra
4.2	Baghdad
5.0	Karbala

The table demonstrates how acid rain is formed as a result of gaseous pollutants reacting with atmospheric water vapor. The formation of sulfuric and nitric acids plays a key role in lowering the pH of rainwater, causing severe environmental damage. These effects include corrosion of metallic structures and historical monuments, soil degradation, and the death of aquatic organisms due to pH imbalance. Moreover, acid rain falling on agricultural lands deteriorates soil fertility, negatively impacting crop yields and threatening food security. Hence, monitoring SO_2 and NO_2 emissions from factories and enforcing strict regulations on clean energy usage is crucial to mitigate this phenomenon.

B. The Impact of Pollutants on Human Health

Elevated levels of NO_2 and PM2.5 contribute to respiratory issues such as asthma and chronic lung diseases.

1. **Global permissible level of NO_2:** 0.10 mg/m³
2. **Measured NO_2 concentration in Baghdad:** 0.14 mg/m³
3. PM2.5 levels in Basra and Baghdad exceed permissible limits, increasing the risk of respiratory diseases.

Table 6. Comparison of Global Permissible Values and NO_2 Concentration in Iraq.

Global Limit (mg/m³)	NO_2 Concentration (mg/m³)	Location
0.10	0.14	Baghdad
0.10	0.12	Basra
0.10	0.08	Karbala

This table shows that NO_2 levels in Baghdad and Basra exceed global limits, indicating a higher risk of exposure to respiratory diseases and worsening air pollution. This overstepping of international thresholds reflects weak environmental control and the lack of enforcement of strict regulations to reduce emissions from vehicles and factories. In contrast, NO_2 levels in Karbala remain below the global limit, suggesting lower industrial activity in the area. This situation calls for urgent action, such as reducing reliance on fossil fuels, increasing the use of electric vehicles, and improving urban planning to reduce congestion and pollution.

Hypothesis Testing:

1. **Null Hypothesis (H_0):** There is no significant difference in the concentration of air pollutants between industrial and non-industrial areas in Iraq.
2. **Alternative Hypothesis (H_1):** There is a significant difference in the concentration of air pollutants between industrial and non-industrial areas.

Table 7. T-test Results Comparing Pollutant Concentrations between Industrial and Non-Industrial Areas.

T Value	P Value (Significance)	Non-Industrial Area (Mean ± SD)	Industrial Area (Mean ± SD)	Pollutant
4.31	0.001**	0.052 ± 0.009	0.085 ± 0.012	SO_2
5.02	0.000**	0.039 ± 0.008	0.072 ± 0.014	NO_2
3.87	0.002**	1.02 ± 0.31	2.15 ± 0.45	CO
4.89	0.000**	38 ± 10	65 ± 12	PM2.5

Since the p-values for all studied pollutants are less than 0.05, we reject the null hypothesis (H_0) and accept the alternative hypothesis (H_1). This indicates that there is a statistically significant difference in pollutant concentrations between industrial and non-industrial areas, with industrial areas exhibiting significantly higher levels of pollution. This highlights the urgent need to implement pollution control measures in industrial zones, such as improving filtration systems in factories and adopting clean energy solutions.

ANOVA Test for Comparing Three Different Cities

1. **Null Hypothesis (H_0):** There is no significant difference in pollution levels among the three cities (Baghdad, Basra, and Karbala).
2. **Alternative Hypothesis (H_1):** There is a significant difference in pollution levels among the three cities.

Table 8. ANOVA Test Results Comparing Pollutant Concentrations in Three Iraqi Cities.

F Value	Karbala (Mean ± SD)	Basra (Mean ± SD)	Baghdad (Mean ± SD)	P Value (Significance)	Pollutant
7.21	0.045 ± 0.008	0.078 ± 0.011	0.092 ± 0.015	0.003**	SO_2
6.89	0.038 ± 0.007	0.067 ± 0.012	0.081 ± 0.016	0.004**	NO_2

8.45	1.12 ± 0.35	1.85 ± 0.42	2.31 ± 0.50	0.002**	CO
9.32	41 ± 9	59 ± 11	72 ± 14	0.001**	PM2.5

Since the p-values for all variables are less than 0.05, we reject the null hypothesis (H_0) and accept the alternative hypothesis (H_1), indicating significant differences in pollution levels among the three cities. The analysis reveals that Baghdad has the highest pollution levels, followed by Basra, while Karbala has the lowest. This reflects differences in industrial activity and population density among the cities, with major factories and heavy traffic concentrated in Baghdad and Basra, whereas Karbala has less industrial activity.

The statistical results indicate that air pollution in Iraq is significantly influenced by geographic location and the level of industrial activity. The statistical tests show meaningful differences between industrial and non-industrial areas as well as between different cities, with Baghdad and Basra recording the highest pollution levels compared to Karbala. These findings underscore the urgent need for effective air pollution control strategies, including adopting environmentally friendly policies, implementing advanced emission treatment technologies, and enhancing environmental awareness among the public and decision-makers.

4. Conclusion

Chemical analyses have shown that concentrations of air pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_2), carbon monoxide (CO), and fine particulate matter (PM2.5) are significantly higher in industrial areas compared to non-industrial ones. This indicates a clear impact of industrial activities and emissions from factories and heavy vehicles on air quality. The chemical reactions of these pollutants, especially under certain climatic conditions such as temperature, humidity, and wind speed, lead to the formation of secondary compounds such as ground-level ozone (O_3) and acidic aerosols, which exacerbate environmental and health problems.

Statistically, the results of the T-Test revealed significant differences in pollution levels between industrial and non-industrial areas, with P-values for all variables being less than 0.05. This suggests that the differences are statistically significant and not due to random chance. Furthermore, the Analysis of Variance (ANOVA) confirmed substantial variations in pollution levels among three major Iraqi cities—Baghdad, Basra, and Karbala. Baghdad recorded the highest average pollution levels, followed by Basra, while Karbala had the lowest. These findings suggest that air pollution is directly influenced by industrial activity, population density, and local climatic conditions.

Based on these findings, it can be concluded that Iraq faces a serious environmental challenge that requires sustainable strategies to reduce air pollution. These strategies may include the development of strict emission control systems for factories, the promotion of clean technologies, and the enhancement of environmental awareness campaigns. Furthermore, authorities should work on improving air quality by implementing more rigorous environmental standards, which would contribute to better public health and reduce the negative impacts of pollution on both the environment and the climate.

The results of this study partially align with several previous studies that have indicated high pollution levels in major cities such as Baghdad and Basra due to industrial activities and urban congestion. For example, the study by Tu'ma and Al-Mousawi (2021) showed that Basra, as a major industrial center, suffers from air pollution caused by hydrocarbons, which intensifies the region's pollution impact. Similarly, the study by Abdulqader (2022) found that air pollution in other Iraqi regions is significantly affected by human activities and climatic changes.

Additionally, the findings of this study are consistent with those of Al-Mahdi and Al-Subaihi (2022), who confirmed that industrial activities and transportation are the two main sources of air pollution in Iraq, especially in large cities like Baghdad and Basra. Other studies, such as that of Jihad and Othman (2021), indicate that urban air pollution is primarily due to industrial and transportation activities, leading to elevated levels of pollutants such as SOx and NOx.

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