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An Analysis of Some Levels of Rainwater Pollution in Al-Amarah City, Southeastern Iraq

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Abstract:
This study analyzes the impact of air pollution in the atmosphere of Al-Amarah City on certain physical and chemical properties of rainfall, with a focus on the spatial variation of pollution levels within the city. The research was conducted at six selected sites across Al-Amarah, located in the southeastern part of Iraq, characterized by a dry climate and low precipitation. The analytical results revealed noticeable pollution in rainwater, as evidenced by elevated levels of total suspended solids (TSS) and carbon dioxide (CO_2), which contributed to increased rainwater acidity and had adverse effects on the environment and infrastructure. High concentrations of cadmium were also detected in some samples, particularly at Site 1, posing risks to public health and the local environment. The study demonstrated significant spatial variability in pollution levels, attributed to differences in the intensity and distribution of pollution sources such as vehicular emissions and other environmental factors. Based on these findings, the study recommends establishing a continuous monitoring system for rainwater quality, adopting policies to reduce vehicular emissions, developing governmental programs for monitoring and treating heavy metals, improving rainwater treatment technologies, and enhancing community awareness of environmental conservation.

Keywords: Rain pollution, heavy metals, acidity, Al- Amarah, total suspended solids.

تحليل بعض مستويات تلوث مياه الأمطار في مدينة العمارة جنوب شرق العراق

رافد صالح مهدي
قسم الجغرافيا/ كلية الآداب / جامعة الكوفة/ النجف / العراق

المستخلص:
تناولت الدراسة تحليل تأثير تلوث الهواء في أجواء مدينة العمارة على بعض الخصائص الفيزيائية والكيميائية لمياه الأمطار المتساقطة، مع التركيز على التغير المكاني لمستويات التلوث داخل المدينة. أُجريت الدراسة في ستة مواقع مختارة داخل مدينة العمارة الواقعة في الجزء الجنوبي الشرقي من العراق، التي تتميز بمناخ جاف وقليل الأمطار. أظهرت نتائج التحاليل وجود تلوث واضح في مياه الأمطار، تجلى بارتفاع مستويات المواد العالقة الكلية(TSS) وثاني أكسيد الكربون(CO_2)، مما أدى إلى زيادة حموضة مياه الأمطار وتأثير سلبي على البيئة والمباني. وتسجيل تركيزات مرتفعة من معدن الكادميوم في بعض العينات، خصوصاً في الموقع الأول، ما يشكل خطراً على الصحة العامة والبيئة المحلية. بينت الدراسة تباينات مكانية ملحوظة في مستويات التلوث تعزى إلى اختلاف شدة وتوزيع المصادر الملوثة، مثل: الانبعاثات المرورية والعوامل البيئية الأخرى. واستناداً إلى النتائج، توصي الدراسة بإنشاء منظومة مراقبة مستمرة لجودة مياه الأمطار، وتبني سياسات للحد من الانبعاثات المرورية، وتطوير برامج حكومية لمراقبة المعادن الثقيلة ومعالجتها، إلى جانب تحسين تقنيات معالجة مياه الأمطار وتعزيز التوعية المجتمعية بأهمية الحفاظ على البيئة.

الكلمات الدالة: تلوث الأمطار، المعادن الثقيلة، الحموضة، العمارة، المواد الصلبة العالقة الكلية.

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Introduction:

Rainfall constitutes a fundamental component of the hydrological cycle, serving as the primary source for replenishing surface water and certain groundwater aquifers. However, the quality characteristics of rainwater are not constant; they are influenced by various factors that differ over time and space. Among the most significant of these factors are urban pollutants, which increase in proportion to the city's size, population density, and industrial activities. In this context, Al-Amarah City was selected as an urban model to examine the influence of air pollution on the characteristics of rainfall, especially given the city's location within an arid climate zone, where precipitation is scarce yet environmentally and economically vital. The study employed a set of physical and chemical indicators to analyze rainwater properties and assess pollution levels, aiming to diagnose the impact of urban atmospheric pollution on rainwater quality.

Research Problem:

Does air pollution in the atmosphere of Al-Amarah City affect the physical and chemical properties of the rainwater? And to what extent does this impact vary spatially?

Research Hypothesis:

It is hypothesized that pollutants carried in the urban atmosphere have a clear effect on altering certain physical and chemical properties of rainwater, with spatial variations in the extent of this impact depending on the intensity and distribution of pollution sources.

Significance of the Study:

1- Revealing Rainwater Quality: This study sheds light on the extent to which rainwater quality is affected by air pollution, providing a scientific basis for understanding the relationship between airborne pollutants and the characteristics of precipitation.
2- Identifying Pollution Sources and Their Effects: The study's findings contribute to diagnosing the main sources of pollution in the city of Al-Amarah, such as vehicular traffic and industrial activities, and illustrate their direct impact on the physical and chemical properties of rainwater.
3- Highlighting Environmental and Health Risks: The study uncovers the presence of hazardous elements, such as cadmium and elevated acidity levels, thereby enhancing the understanding of potential negative effects on both the environment and public health.
4- Supporting Local Environmental Policies: The research provides relevant authorities and environmental stakeholders with accurate and reliable data that can be used to develop effective strategies and plans to mitigate air and water pollution.
5- Emphasizing Spatial Variability of Pollution: The study helps clarify the spatial distribution of pollution within the city, aiding in directing monitoring and remediation efforts toward the most affected areas.
6- Importance in Arid Regions: Given the rarity of rainfall in arid regions like Al-Amarah, any contamination in rainwater can have amplified effects. This underscores the importance of preserving high-quality rainwater to maximize its potential use.

Study Area:

The study area is located in the southeastern part of Iraq, within the eastern side of the Mesopotamian Plain, specifically in the center of Maysan Governorate, represented by the Al-Amarah District, as shown in Map(1). The area of Al-Amarah City is

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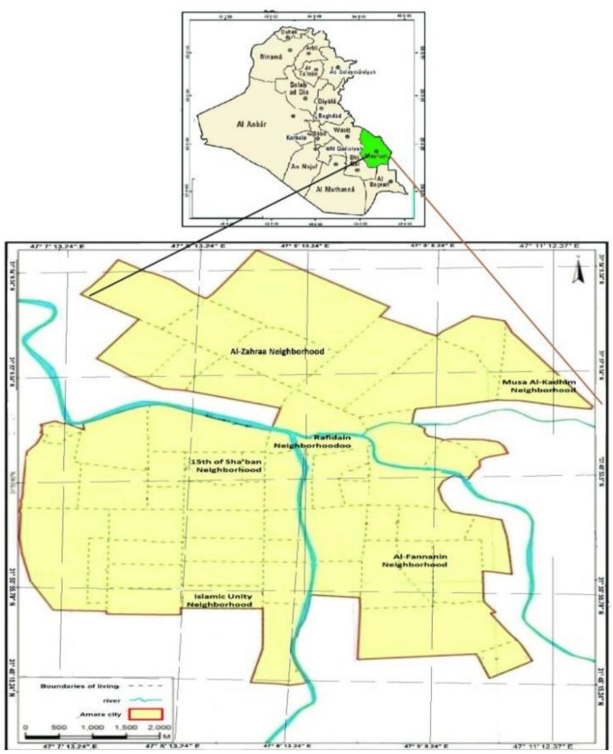
approximately 2,979 km², which constitutes about 0.68% of Iraq's total area. The city's population is estimated at around 638,860 inhabitants [1]. Climatically, the region is classified as arid with low rainfall. The annual average precipitation is approximately 195 mm/year, while the annual evaporation rate reaches about 3,056.7 mm/year, according to data from the Al-Amarah meteorological station[2:41-44]. To study the characteristics of rainwater, six different sites within the study area were selected for rainwater sampling on March 9,2025 (Table1). The collection containers were fixed at a height of 0.50 meters above ground level, as shown in the following table.

Table (1): Geographical and Astronomical Coordinates of Sampling Locations in Al-Amarah City

Sample number	Sample location	**Longitude**	**Latitude**
1	Al-Zahraa Neighborhood	47° 8′ 34.08″ E	31° 52′ 9.34″ N
2	Musa Al-Kadhim Neighborhood	47° 11′ 12.37″ E	31° 51′ 45.07″ N
3	Al-Rafidain Neighborhood	47° 9′ 8.24″ E	31° 51′ 8.32″ N
4	15th of Sha'ban Neighborhood	47° 8′ 13.24″ E	31° 50′ 55.79″ N
5	Al-Fannanin Neighborhood	47° 10′ 18.8″ E	31° 49′ 53.5″ N
6	Islamic Unity Neighborhood	47° 8′ 36.33″ E	31° 49′ 15.24″ N

.Source: Field study using GPS device.



Map (1): The geographical location of the study area and the distribution of sampling sites in Al-Amarah City

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Rain Pollutants:

Rainwater pollutants vary depending on the regions where precipitation occurs, influenced by the prevailing human and economic activities in each area. Each type of activity has a distinct impact on the atmosphere, which in turn affects the qualitative characteristics of rainwater. In some cases, pollution levels can reach degrees that raise concerns among researchers and relevant authorities due to the environmental and health threats they pose. To gain a more accurate understanding of the nature of these pollutants, the researcher analyzed several qualitative properties of the falling rainwater, aiming to determine the extent of its impact by the surrounding urban environment.

1- pH Level

The pH scale is used to determine the acidity or alkalinity of substances. Pure water is considered neutral due to the balance between hydrogen ions (H^+) and hydroxide ions (OH^-), giving it a pH value of 7. Solutions with pH values less than 7 are classified as acidic, while those above 7 are considered alkaline, with the scale reaching up to 14. Water droplets in clouds are assumed to be in equilibrium with carbon dioxide (CO_2) present in the atmosphere, which causes their acidity to drop to a pH of 5.7 at a temperature of 25°C. Although this value does not represent exact chemical neutrality, it is commonly used as a general reference point when examining changes resulting from the addition of various ions and cations. Accordingly, rainwater is considered acidic when its pH is 5.7 or lower [3:p.8].The analysis results presented in Table (2) and Fig (1) show that the average pH of the samples under study was 6.53, which is higher than the general average for rainwater. The highest recorded pH was 7.74 in the first sample, while the lowest was 6.05 in the fourth sample. This elevation is attributed to the geographical nature of the city of Amarah, which is surrounded by vast stretches of desert and arid lands. The soils in these areas are rich in limestone (calcium carbonate - $CaCO_3$)[4:p.85] which, upon reacting with carbon dioxide(CO_2), forms bicarbonate ions (HCO_3^-). These ions play a role in neutralizing the acidity of rainwater [5:p.146]. The dust rising from these soils is a major source of such compounds, thereby contributing to the moderation of rainwater acidity in the region. According to Table (3), all pH values fall outside the permissible limits except for the first and third samples, which classifies the rainwater acidity levels within urban areas as significantly polluted.

Table 2. Some Physicochemical Properties of Rainwater in Al-Amarah City

Parameter	S1	S2	S3	S4	S5	S6	Average
pH	7.74	6.36	6.82	6.05	6.09	6.14	6.53
µS/cm EC	106.9	540	174.5	65.2	107.8	88.2	180.43
mg/l TDS	64.14	324	104.7	39.12	64.68	52.92	108.26
TSS mg/l	24	22	14	16	60	36	28.67

Source: The samples were analyzed at U-Science Laboratory, following standard laboratory protocols.

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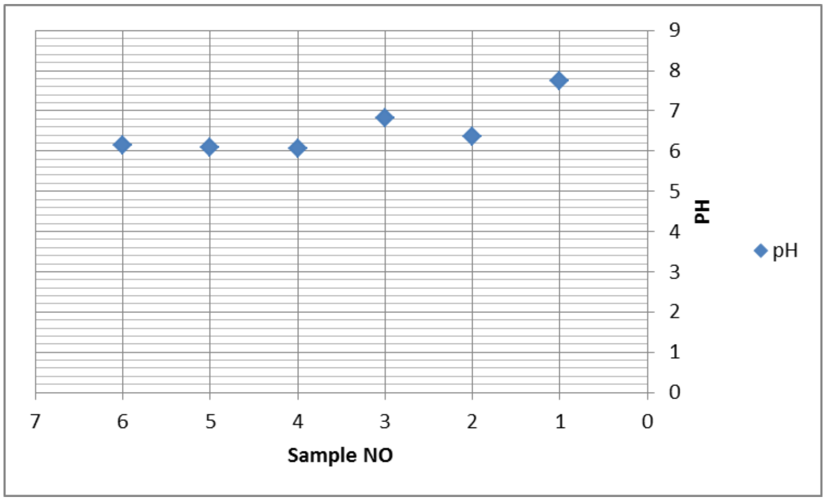

Figure 1. pH levels in rainwater samples from Al-Amarah City.

Table 3. Drinking Water Standards According to Iraqi Specifications and WHO Guidelines

Parameter	Iraq Standards	WHO Standards
pH	8.5-6.5	8.5-7
µS/cm EC	2000	1000
mg/l TDS	1000	1000
TSS mg/l	No specific guideline values have been established for TSS	10
CO_2 mg/l	3-2 Associated with pH values(DANIEL ,2019.p177)	Associated with pH values
SO_4 mg/l	250	500
mg/l NO_3^-	50	50
Pb mg/l	0.01	0.01
Cd mg/l	0.003	0.003
Hg mg/l	0.001	0.001

Source: 1-World Health Organization, Guidelines for drinking-water quality (4th ed.). Geneva:World Health Organization. Central Organization for Standardization and Quality Control,(2017).
2- Iraqi standard for drinking water No. 417. Baghdad: COSQC, (2009)

2- Electrical Conductivity (EC):

Electrical conductivity is a numerical expression of a medium's ability to conduct electric current, and it is closely related to the concentration of dissolved salts in aqueous solutions. Therefore, it is commonly used as an indicator of the amount of dissolved salts in water samples [6:p.5]. According to the data presented in Table (2) and Fig (2), the overall average electrical conductivity was 180.43 µS/cm. The highest value was recorded in sample No.(2), reaching 540 µS/cm, while the lowest value was observed in sample No.(4), measuring 65.2 µS/cm. The marked increase in EC value for sample No. (2) is attributed to its location on the eastern outskirts of the city of Al-Amarah. The soils

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in the adjacent northern areas are characterized by high salinity levels, reaching up to 28 dS/m [7:p.141], and lack vegetative cover. Additionally, this sample is located near the southern zones of oil wells and extraction activities (Field Study,4/4/2025), which contribute to increased air pollution. This is further exacerbated by the prevalence of northerly winds, which have the highest frequency in the area [2:p.38], consequently leading to elevated EC levels. Nevertheless, all sample values fall within the range of slightly saline freshwater, as classified in Table (3).

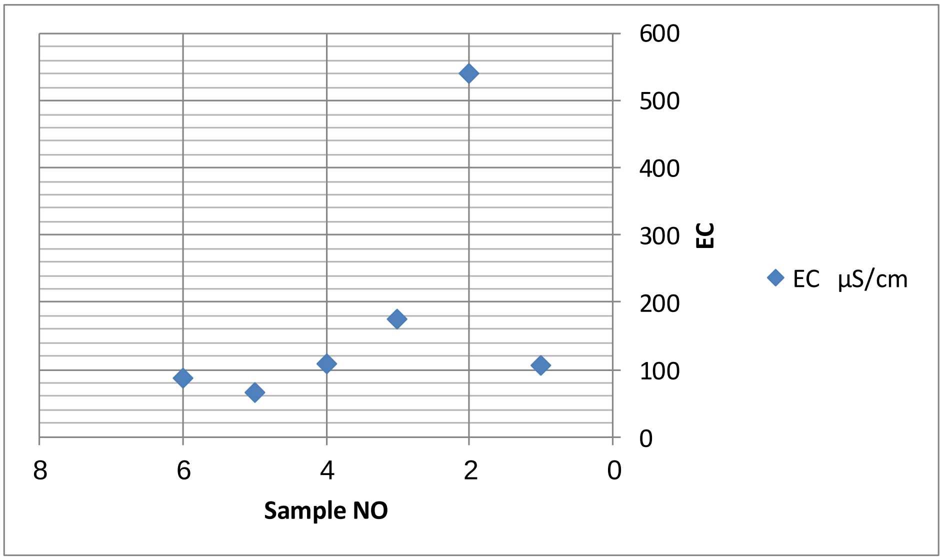

Figure 2. Electrical conductivity (EC) values in rainwater samples from Al-Amarah City.

3- Total Dissolved Solids (TDS):

It is important to note the distinction between Total Dissolved Solids (TDS) and salinity. While all salts are fully dissolved solids, not all dissolved solids are salts. Salinity refers specifically to the concentration of dissolved salts in water, whereas TDS represents the total concentration of all dissolved solids, encompassing both salts and other substances dissolved in the water [8:p.58]. The average TDS concentration in rainwater is reported to be 9.5 mg/l [9:p.58]. Based on Table (2) and Fig (3), the average TDS concentration in the collected samples was 108.26 mg/l, which is relatively high but still within the range classified as freshwater. Sample No. 2 recorded the highest value at 324 mg/l, while the lowest value of 39.12 mg/l was recorded in Sample No. 4. The elevated TDS in Sample No.2 is attributed to the same factors responsible for the increase in Electrical Conductivity (EC). All samples from the study area fall within the acceptable limits set by the Iraqi standards and the World Health Organization (WHO).

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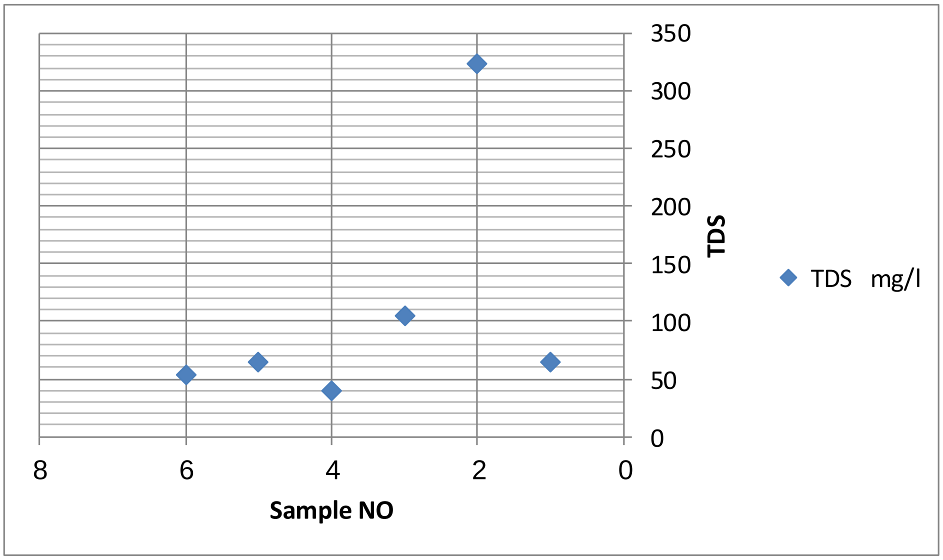

Figure 3. Total dissolved solids (TDS) in rainwater samples from Al-Amarah City.

4- Total Suspended Solids (TSS):

This parameter reflects the concentration of suspended solid particles in water, resulting from the mixing of rainwater with dust, organic and inorganic materials, salts, and other pollutants [10:p.487]. According to Table (2) and Fig (4), the average TSS concentration in the studied samples was 28.67 mg/L. The highest value (60 mg/L) was recorded in Sample No.5, which was collected from an area near construction and road rehabilitation activities [Field Study,2025-04-05]. The intense vehicular movement in that area contributed to the resuspension of large amounts of dust into the surrounding atmosphere. In contrast, the lowest value (14 mg/L) was observed in Sample No.3, taken from the city center-an area characterized by low construction activity and fully paved streets, which limited the accumulation of suspended materials. These suspended solids, along with other pollutants, are believed to have contributed to the recurring phenomenon of smog in Al-Amarah City in recent years, rendering the TSS values of all samples beyond the safe limits specified in Table (3).

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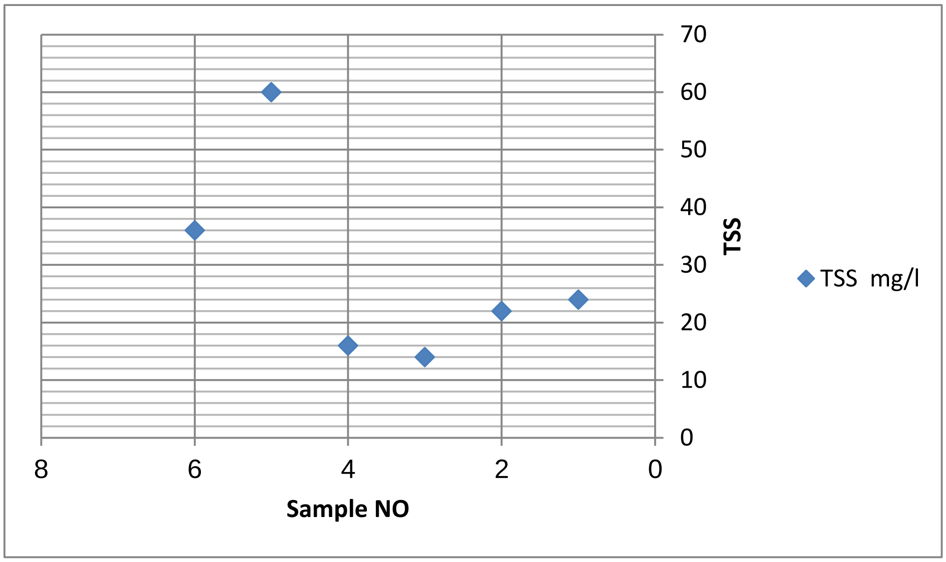

Figure 4. Total suspended solids (TSS) in rainwater samples from Al-Amarah City.

5- Carbon Dioxide (CO_2):

Its primary source is anthropogenic emissions that contribute significantly to the phenomenon of climate change. This gas is mainly released as a result of burning fossil fuels such as coal, oil, and natural gas. Human society relies heavily on these energy sources, which supply approximately 80% of the world's total energy consumption. This dependency results in total anthropogenic carbon dioxide emissions estimated at about 9.5 gigatons of carbon, equivalent to a global average of 1.4 tons per capita [11:p.163]. Carbon dioxide is one of the most important greenhouse gases affecting urban temperatures due to its ability to absorb infrared radiation, thereby contributing to the increase in Earth's surface temperatures. It also possesses acidic properties; when it reacts with water in the atmosphere, it forms carbonic acid (H_2CO_3), which is one of the primary contributors to acid rain [12:p.82]. Although the effect of this acid is relatively weak, its impact intensifies with increasing atmosphericCO_2 concentrations, exacerbating the acidity of precipitation. I n terms of laboratory values, the results shown in Table (4) and Fig (5) indicate that the overall average concentration of carbon dioxide was 4.79 mg/L. The highest recorded value was 11.44 mg/L in Sample 2, which is characterized by elevated electrical conductivity and total dissolved solids, indicating a high level of pollution compared to the other samples. Conversely, the lowest value was 2.62 mg/L in Sample 4. According to the Fourth Assessment Report issued by the Intergovernmental Panel on Climate Change (IPCC), it is expected that approximately 50% of the current increase in atmospheric CO_2 concentrations will be absorbed within 30 years, while an additional 30% may be absorbed over the next several centuries. However, about 20% of these emissions may persist in the atmosphere for thousands of years [13:p.167]. This presents a serious warning, as it indicates that the accumulation of this gas will intensify with the continued expansion of urban areas in the future, thereby amplifying the impact and severity of acid rain. All sample values were found to be outside the permissible limits according to Table(3), with the exception of Sample 4, which serves as an

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important indicator since CO_2 is one of the key greenhouse gases responsible for global warming.

Table 4. Concentrations of CO_2, SO_4^{2-}, and NO_3^- (mg/L) in Rainwater Samples from Al-Amarah City

Parameter	S1	S2	S3	S4	S5	S6	Average
CO_2 mg/l	3.52	11.44	3.52	2.64	3.22	4.4	4.79
SO_4^{2-} mg/l	57.94	112.13	61.73	22.24	24.94	23.86	50.47
NO_3^- mg/l	1.023	6.37	2.999	0.829	3.485	2.75	2.91

Source: The samples were analyzed at U-Science Laboratory, following standard laboratory protocols

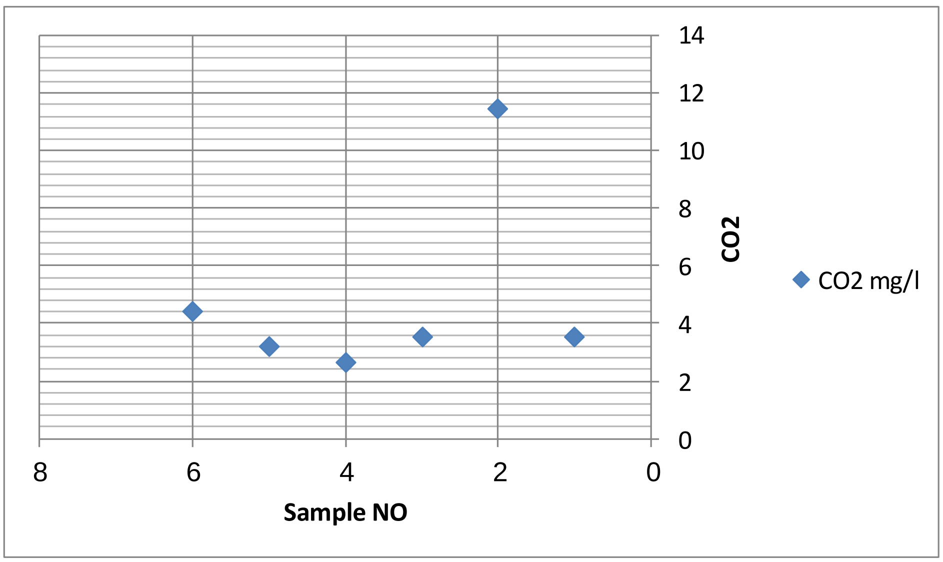

Figure 5. Total CO_2 concentration in rainwater samples from Al-Amarah City.

6- Sulfate Ion (SO_4^{2-})

Sulfate ion represents the most common form of sulfur found in natural waters, where it combines with cations such as calcium and magnesium to form salts that contribute to the permanent hardness of water. Sulfates are also among the compounds responsible for increasing water salinity, with a noticeable sensory effect in imparting a salty taste to water when their concentration exceeds 200 mg/L [14:p.290]. The primary sources of sulfates stem from the combustion of oil and its derivatives, petroleum distillation processes, and various industries such as tanning and fertilizer production. These activities predominantly generate sulfur dioxide (SO_4), which undergoes several chemical reactions and transformations. This compound contributes to increased water acidity and elevates electrical conductivity due to the formation of conductive ions [15:p. 102]. According to the data presented in Table(4) and Fig(6), the highest sulfate concentration was recorded in Sample2, amounting to 112.13 mg/L, while the lowest was observed in Sample 4, with a concentration of 22.24 mg/L. The overall average sulfate concentration across the studied samples was 50.47 mg/L, indicating variability in

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pollution levels across different locations in the city. This variability reflects the influence of local pollution sources on water quality. All sample values fall within the safe limits as specified in Table (3).

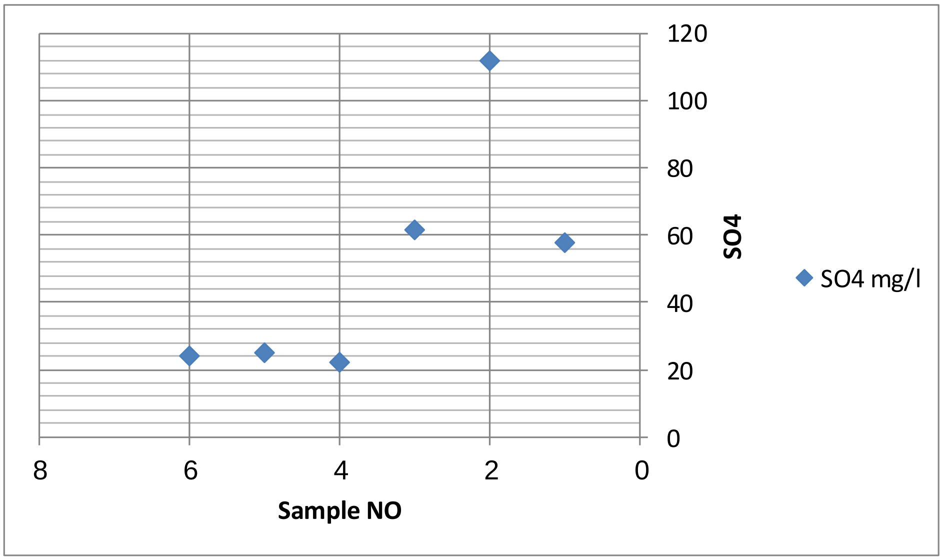

Figure 6. Sulfate ion (SO_4^{2-}) concentrations in rainwater samples from Al-Amarah City

7- Nitrate Ion (NO_3^-)

The nitrate ion is primarily produced in the environment as a result of emissions from the combustion of fossil fuels (oil, gas, and coal) in vehicles and power plants. These processes release nitrogen oxides (NO and NO_2) into the atmosphere, which subsequently undergo chemical transformations leading to the formation of nitrate (NO_3^-). Nitric oxide (NO) is considered one of the key geochemical agents in these transformations, as it gradually converts into nitrate under atmospheric and photochemical conditions [16:p.367]. Nitrate is regarded as a toxic compound to living organisms when it accumulates at high concentrations [17:p.19]. As indicated in Table (4) and Fig (7), the highest recorded concentration of nitrate was found in sample No.(2), reaching 6.37 mg/L, which suggests a high level of contamination in that area. In contrast, the lowest concentration was recorded in sample No.(4), at 0.829 mg/L. The overall average concentration of nitrate across all samples was 2.91 mg/L. All values fall within the permissible limits set by Iraqi standards and the World Health Organization (WHO).

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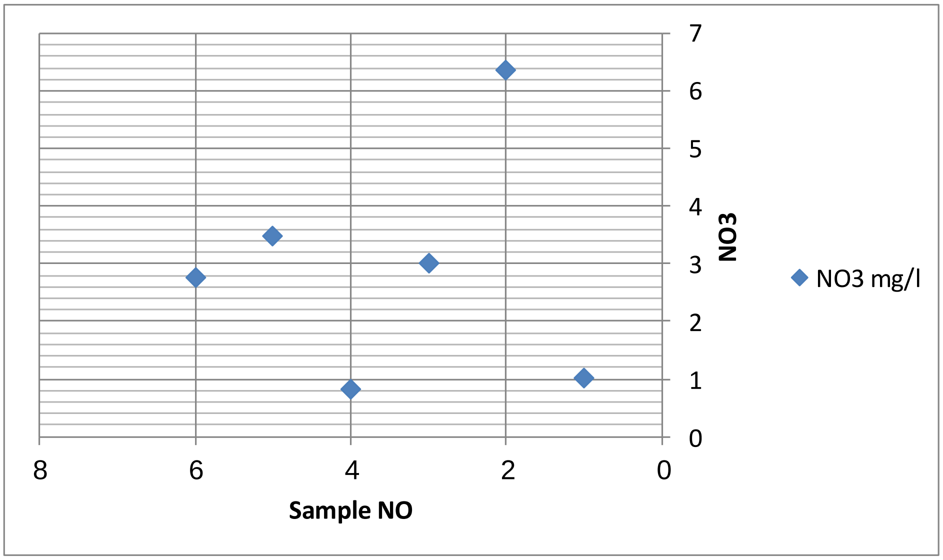

Figure 7. Nitrate ion (NO_3^-)concentrations in rainwater samples from Al-Amarah City.

8- Lead (Pb):

Its sources in the atmospheric environment include lead smelting and manufacturing processes, various types of fittings, welding, and packaging operations. Lead is also used in the production of many sanitary ware items and in numerous pigments [18:p.43]. According to Table (5) and Fig (8), all samples were free of lead contamination except for Sample No.(4), which was found to be noticeably polluted, with a concentration of 0.060 mg/l. The overall average concentration was 0.01 mg/l. Thus, all samples were within permissible limits except for Sample No. (4), which exceeded the allowable limits as indicated in Table (3).

Table 5. Concentrations of Pb, Cd, and Hg (mg/L) in Rainwater Samples from Al-Amarah City.

Parameter	S1	S2	S3	S4	S5	S6	Average
Pb mg/l	0.000	0.000	0.000	0.060	0.000	0.000	0.010
Cd mg/l	0.139	0.000	0.001	0.000	0.019	0.023	0.030
Hg mg/l	0.000	0.013	0.003	0.014	0.000	0.003	0.005

Source: The samples were analyzed at U-Science Laboratory, following standard laboratory protocols

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Figure 8. Lead (Pb) concentrations in rainwater samples from Al-Amarah City (mg/L).

9- Cadmium (Cd):

Cadmium (Cd) is considered one of the toxic heavy metals and holds significant industrial importance due to its wide range of applications, particularly in the production of electrical plates, colored pigments used in paints and plastics, as well as its role in the manufacturing of negative electrodes in batteries. Cadmium is also a common byproduct of zinc and lead mining and smelting processes, making it one of the most hazardous sources of environmental pollution [19:p.349]. According to the data presented in Table (5) and Fig (9), cadmium concentrations were found to be elevated in certain samples compared to other elements. The highest concentration was recorded in Sample 1, reaching 0.139 mg/L, while it was not detected in several other samples. The overall average concentration of cadmium in the studied samples was approximately 0.030 mg/L. Samples 2, 3, 4, and 6 exceed the permissible limits as indicated in Table (3).

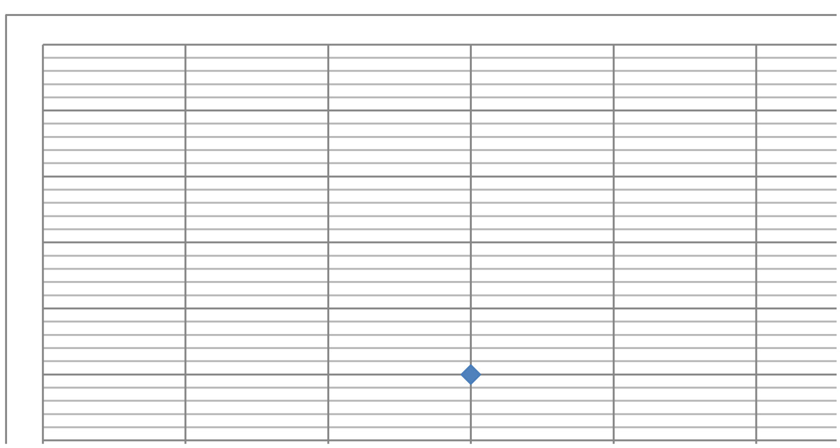

Figure 9. Cadmium (Cd) concentrations in rainwater samples from Al-Amarah City (mg/L).

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10- Mercury (Hg):

Mercury is a silvery-white liquid metal and is the only metal that remains in a liquid state at room temperature and under normal atmospheric pressure. It evaporates at ambient temperatures, dissolves in diluted nitric acid, but does not dissolve in water. Mercury is toxic, and its vapor concentration in the air should not exceed 0.1 mg/m³. It represents one of the most significant air pollutants. Like water, mercury evaporates and disperses into the atmosphere and may travel great distances before eventually settling in soil, waterways, lakes, and rivers [18:p.195–200.]Data from Table (5) and Fig (10) show a variation in mercury contamination levels in rainwater. The highest concentration was recorded in Sample 4, reaching 0.014 mg/L, while the average value was 0.005 mg/L. Samples 2, 3, 4, and 6 exceeded the permissible limits set by Iraqi standards and the World Health Organization.

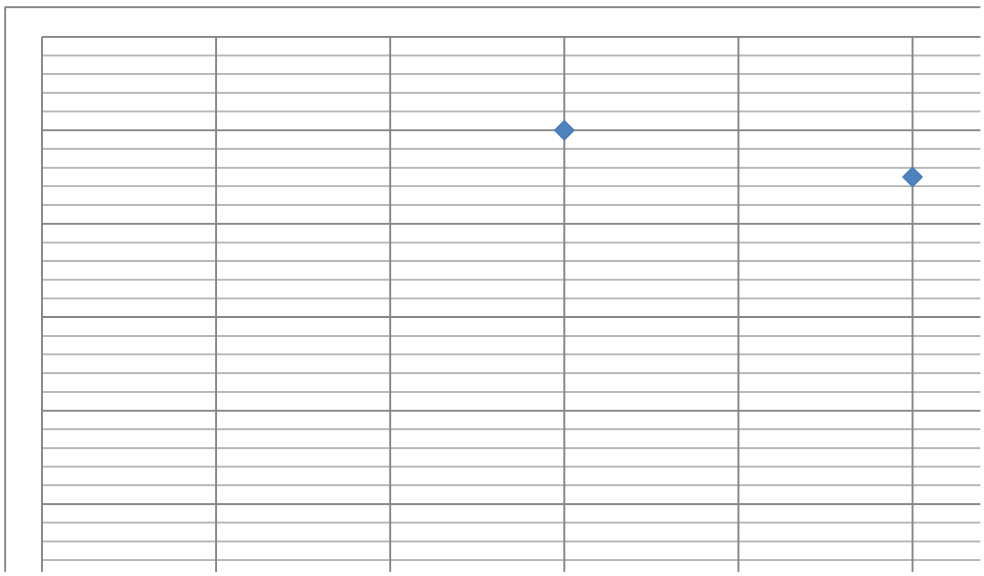

Figure 10. Mercury (Hg) concentrations in rainwater samples from Al-Amarah City (mg/L).

Conclusions:

1- The study's findings revealed multiple indicators of rainwater pollution in the city of Amara, highlighting the urgent need for serious measures to reduce pollution levels due to their impact on the environment and local climate.
2- The analyses showed a significant variation in the type and concentration of pollutants across different locations within the city. Some samples-particularly Sample 1-recorded pollution levels classified as extremely hazardous.
3- The elevated concentrations of Total Suspended Solids (TSS) in rainwater indicate contamination with particulate matter, reflecting the limited efficiency of natural environmental filtration elements such as green spaces, along with the clear influence of dense traffic within the city.
4- Elevated levels of carbon dioxide (CO_2) were observed in rainwater, leading to increased acidity. This contributes to the accelerated erosion of buildings and infrastructure, in addition to negatively affecting the chemical balance of urban soils.

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5- The study recorded remarkably high levels of cadmium in rainwater, especially in Sample 1. This necessitates urgent intervention by relevant authorities to address this form of pollution in order to protect public health and the environment.

Recommendations:

1- Establish a regular monitoring system to assess the quality of rainwater in Amara, incorporating chemical and biological analyses to identify pollution sources and track their temporal variations.
2- Adopt policies to reduce pollution from vehicular emissions by constructing alternative roads, promoting clean transportation methods, and expanding green spaces and parks that contribute to air and water purification.
3- Launch urgent government programs to reduce sources of heavy metals, particularly cadmium, through monitoring of industrial activities and chemical waste, and by enforcing strict standards for safe disposal.
4- Develop technologies for rainwater harvesting and treatment before it infiltrates the soil or is utilized, including the application of neutralizing agents and investment in corrosion-resistant infrastructure.
5- Implement ongoing awareness campaigns to educate the public about the importance of environmental conservation, the impact of daily practices on rainwater quality, and to encourage community participation in protecting the urban environment.

CONFLICT OF IN TERESTS
There are no conflicts of interest

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