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A Comparative Study of the Water Quality of the Tigris River and Rainwater in Mosul City: Evaluating Rainwater Harvesting as a Sustainable Water Resource

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ABSTRACT

The quality of rainwater falling on the city of Mosul was studied by collecting rainwater samples from three locations on both sides of the city during the rainy season between December 2018 and May 2019. The physical and chemical characteristics of the rainwater were measured based on internationally recognized standard methods. The pH values reached up to 9.3 in the spring season, and positive ions dominated over negative ions in the atmosphere. The alkalinity reached its highest level of 88mg/ L in winter. The hardness values reached 90mg/ L as the highest level in winter. The concentrations of negative ions (NO_3^{-1}, SO_4^{-2}, PO_4^{-3}, Cl^-) reached their highest values (39, 0.55, 1.8, 58) mg/L, respectively, in spring. Meanwhile, the concentrations of positive ions (Ca, Mg, Na, K) reached 32, 16, 9, 2.4mg/ L as the highest level in the winter.

INTRODUCTION

Rain is one of the main forms of precipitation in the natural water cycle, as water droplets fall from clouds to the Earth's surface. It is considered an essential element in the process of ecological balance **(Forti *et al.*, 1990)**.

Rain has the ability to remove many pollutants suspended in the atmosphere, so rainwater is used as an effective indicator for determining the quality and concentration of air pollutants **(Mahmoud *et al.*, 2007)**. Although rainwater is originally pure and free of impurities, it is capable of dissolving gaseous and solid pollutants circulating in the air, such as nitrogen and sulfur oxides, which are among the primary components that cause acid rain **(Al-Saadi, 2008)**.

These pollutants arise from human sources, such as fuel combustion and industrial waste, as well as natural sources, such as volcanic activity and earthquakes, as well as biological particles such as pollen carried by the wind. When rainwater mixes with these particles—whether solid, gaseous, or metamorphic—it leads to rainwater pollution, a direct indicator of ambient air pollution **(Qasim *et al*., 2012)**. In recent decades, Mosul has enjoyed a unique environment characterized by its purity and clean air. However, ongoing urban, industrial, and social expansion has contributed to increased levels of environmental pollution, leading to a significant deterioration in the quality of the Tigris River's water **(Al-Safawi *et al*., 2009)**.

Rain helps stabilize surface soil and prevent sandstorms. It also cools the air, reducing dust and chemical pollutants **(Kulshrestha *et al*., 2003)**. However, rain can also be harmful, such as in the case of acid rain, which forms when air moisture reacts with gaseous pollutants like sulfur and nitrogen oxides in the atmosphere **(Suchocl, 2001)**. Acid rain affects the pollution of lakes and streams, posing a danger to aquatic life. It also contaminates plant water, leading to reduced plant growth due to a decrease in the absorption of available nutrients **(Colls, 2000)**. Moreover, its effects extend to marble and limestone buildings, as well as historical statues, even damaging paints **(Galloway *et al*., 1982)**.

Study area location

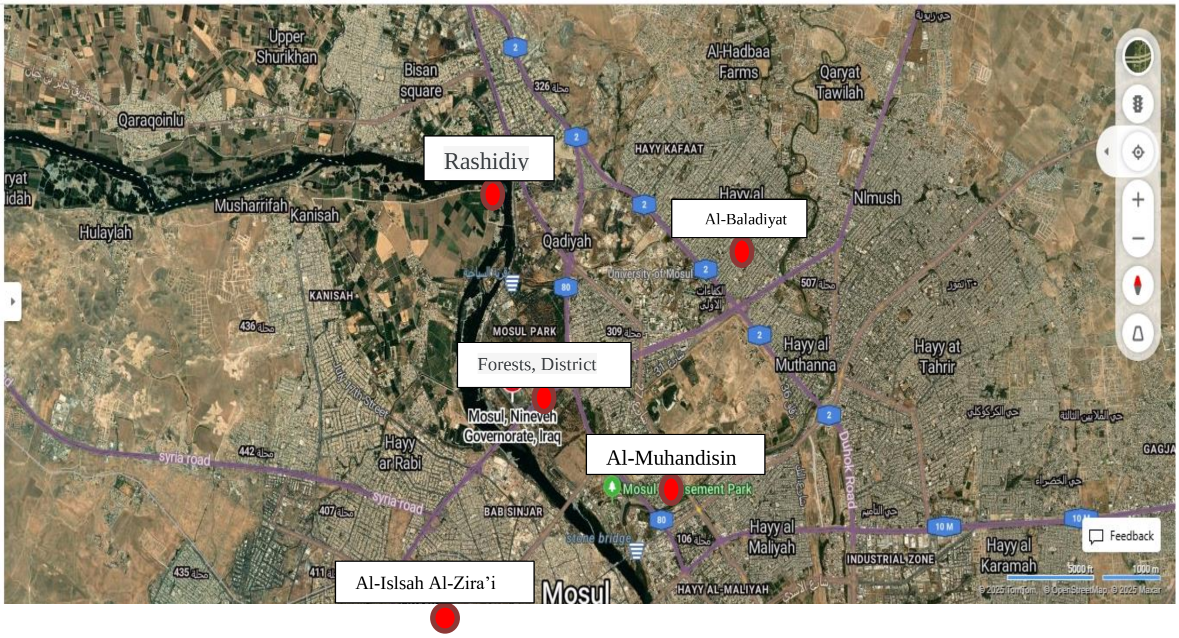
The city of Mosul is located in northern Iraq, between longitudes 43°16' and 43°30' E and latitudes 36°15' and 36°27' N. It is the second-largest city in Iraq in terms of population, with estimated inhabitants of 1,739,800 for the year 2023 **(World Meter, 2023)**.

Mosul lies within the Low Folded Zone, part of the Arabian Plate, along the southern margin of the Zagros Fold-Thrust Belt **(Jassim & Goff, 2006; Bulmer, 2019)**. The northern and southern parts of the city are characterized by low and undulating terrain. The area is traversed by several narrow, elongated, and nearly parallel valleys that drain toward the Tigris River**,** making the study area topographically low **(Farhhan *et al*., 2025)**. The lowest point lies within the floodplain of the Tigris, at an elevation of 215 meters above sea level. The Tigris River flows from north to south through the middle of this broad depression. The valleys of Mosul are located on both sides of the river **(Yacoub *et al*., 2012)**.

This study aimed to conduct a comparative analysis of the physical and chemical properties of both rainwater and the Tigris River water within the urban area of Mosul. The research focuses on evaluating a number of qualitative parameters, including pH, alkalinity, total hardness, and the concentration of various ions, to determine the water quality of both sources. The study also seeks to explore the environmental and practical feasibility of rainwater harvesting as an alternative and sustainable water resource, in light of the increasing environmental challenges and pressures on traditional water sources. This, in turn, highlights the need to adopt integrated approaches to water resource management in urban areas, particularly in Mosul.

MATERIALS AND METHODS

Three representative sites within the urban area of Mosul were selected for the purpose of collecting rainwater samples, as shown in Map (1). The selected sites included areas with different spatial characteristics to represent the geographical and environmental diversity within the urban area, and the samples for this study were collected during the winter and spring seasons. The first site was selected in the Al-Baladiyat neighborhood located in the southeastern part of the city, while the second site was identified near the Al-Islah Al-Zira'i neighborhood in the eastern part. The third site is Al-Muhandisin located in the western side of Mosul, on the right bank of the Tigris River. This geographical distribution aims to ensure the comprehensiveness of the results and their representation of the climatic and environmental characteristics of the city's different areas. In addition, three points (Al-Qayyarah, Rashidiya and Al-Ghabat) along the Tigris River within Mosul were selected for the collection of surface water samples. Samples were collected during the period from December 2018 to May 2019, using clean plastic bottles, immediately after rainfall to ensure they accurately represent the chemical and physical properties of the water at the moment of rainfall., and they were collected immediately after rainfall. Physical and chemical tests were conducted on the samples, including pH, electrical conductivity (E.C), temperature (Temp), dissolved oxygen concentration (D.O), total dissolved solids (T.D.S), turbidity (Turb), alkalinity (Alk.), total hardness (T.H), dissolved cat ions (Cat.), and dissolved anions (Ano), according to the standards outlined in the references **(APHA, 2005)**.



Map 1. Locations in the city of Mosul selected for rainwater sampling

Table 1. Chemical and physical analysis

Parameter	Method	Reference
Total Dissolved Solids (TDS)(mg/l)	Gravimetric Analysis at 108 C°	**APHA, 2005**
Alkalinity (mg/l)	Titration with Sulfuric Acid	
Calcium Ca^{+2}(mg/l)	EDTA Titration	
Magnesium Mg^{+2}(mg/l)	Calculation	
Chloride Cl^{-1}(mg/l)	Argentometric Titration	
Total Hardness(mg/l)	EDTA Titration	
Sodium (Na^{+2})(mg/l)	Flame Photometry	
Potassium ($K^{+)}$(mg/l)	Flame Photometry	
Phosphate PO_3^{-4}(mg/l)	Spectrophotometry	
Nitraten^{-3} (mg/l)	Multiparameter Bench Photometer	
Sulfate SO_4^{-2}	Spectrophotometry	
Electrical Conductivity (EC) (µ s/cm)	Electrical Conductivity meter	**APHA, 2005**
Turbidity (N.T.U)	Turbidimeter	
pH	pH – meter	**APHA, 2005**

RESULTS

Table (2) shows the results of tests on rainwater samples during the study period, where the chemical properties of rainwater were measured, represented by the concentrations of positive and negative ions, as well as the physical properties of the areas of AL-Mohandeseen (Engineers), AL- Baladiyat and AL- Islah AL-Zirai(Agricultural Reform).

Table 2. Chemical and physical properties of rainwater samples collected from Al-Mohandeseen, Al-Baladiyat, and Al-Islah Al-Zirai areas during the study period

Study area / Examinations	Al-Islah Al-Zira'i district	Al-Baladiyat district	Al-Mohandeseen district
PH	7.27	6.89	6.91
E.C(ms)	72.26	60.83	71.21
Temp(c°)	18.5	17.52	18.04
Turb(N.T.U)	4.02	6.74	4.07
T.H(mg/l)	49.2	49.81	43.85
T.H $CaCo_3$(mg/l)	31.6	25.45	29.42
D.O(mg/l)	7.33	7.40	7.44
No_3(mg/l)	1.212	2.42	0.83
SO_4(mg/l)	32.11	40.30	12.10
CL^-(mg/l)	24.47	19.17	13.10
$PO4^{-2}$(mg/l)	0.12	0.02	0.01
Na^+(mg/l)	4.42	2.21	2.72
Ca^{+2}(mg/l)	12.68	10.28	11.69
K^+(mg/l)	0.94	0.71	0.49
Mg+(mg/l)	4.28	5.94	4.68
ALK(mg/l)	40.4	32	32.71
T.H Mg(mg/l)	17.6	24.36	15.00
T.DS(mg/l)	43.34	36.49	44.79

Table (3) shows the results of a study of Tigris River water samples and comparing them with international specifications for drinking water in the Rashidiya, Al-Ghabat and Al-Qayyarah areas.

Table 3. Comparison of Tigris River water quality in Rashidiya, Al-Ghabat, and Al-Qayyarah areas with international drinking water standards

Study area / Examinations	W.H.O (2006)	Average	Al-Qayyarah	Rashidiya	Al-Ghabat
PH	9.5-6.5	7.7	8.05	7.59	7.48
E.C	400	499.3	565	454	479
T.H	500	234.6	224	240	240
SO_4	250	27.0	70	7.93	3.08
PO_4	0.4	1.57	4.7	0.0086	0.0086
Ca^{+2}	75	104.1	160	64.2	88.3
Mg^{+2}	100	41.98	64	57.14	4.8
T.D.S	1000	331	313	269	413

Table 3. Global standards for rainwater quality

Parameter	**Maximum Allowable Limit (WHO)**	**Unit**	**Notes**
pH	6.5 – 8.5	—	Rainwater tends to be acidic, often below 6.5.
Turbidity	< 5	NTU	Should not exceed 5 NTU for safe drinking water.
Total Dissolved Solids (TDS)	< 1000	mg/L	Ideal levels are below 500 mg/L.
Nitrate (NO_3^-)	< 50	mg/L	Higher levels are harmful, especially to infants.
Ammonia (NH_3)	< 0.5	mg/L	Presence may indicate organic contamination.
Iron (Fe)	< 0.3	mg/L	Affects taste, smell, and color.
Lead (Pb)	< 0.01	mg/L	Toxic metal — should be near zero.

Arsenic (As)	< 0.01	mg/L	Carcinogenic and highly hazardous.
Chloride (Cl^-)	< 250	mg/L	Affects taste but not toxic at low concentrations.
Sulfate (SO_4^{2-})	< 250	mg/L	High levels may cause digestive issues.
E. coli (Coliforms)	0	Count/100 mL	Any presence indicates serious microbial contamination.

DISCUSSION

pH values

The pH of rainwater is directly affected by the concentration of atmospheric pollutants, which in turn depends on the geographical characteristics of the area and the pattern of human activities, whether urban, industrial, or agricultural. This effect is attributed to the interaction of rainwater with positive and negative ions suspended in the atmosphere **(Al-Adili *et al*., 2008)**.

The results of the current study showed that the pH values of rainwater in the study areas ranged between 5.1 and 6.7 during the winter. These values indicate that rainwater in most locations tends to be slightly acidic, with values ranging between 5.0 and 6.5 being within the normal limits for unpolluted rain. This results from the interaction of rainwater with atmospheric carbon dioxide, forming carbonic acid (H_2CO_3) **(Hang & Wang, 2011)**. It is noted that winter witnesses an increase in the emission of polluting gases, especially sulfur and nitrogen oxides, as a result of the intensive use of heating methods and vehicle emissions **(Abdullah, 2010)**. Based on the observed values, rainwater in Mosul can be classified as mildly acidic, as all readings remained above the severe acidity threshold (pH < 5.0).

During the spring, a significant increase in pH values was observed, ranging between 6.0 and 9.3. This potential increase is attributed to the frequency and intensity of rainfall, which removed a large portion of atmospheric anions before they dissolved in rainwater, thus reducing their effect on lowering pH. The increase may also be attributed to the dominance of positive ions, such as calcium (Ca^{2+}) and magnesium (Mg^{2+}), over negative anions in the atmosphere **(Khan, 2014)**.

In addition to seasonal variation, spatial variations in pH values were also recorded between the two sides of Mosul. The highest recorded value was 8.8, close to the upper limit of the normal range for water (6.6–8.0), as indicated by **Al-Safawi (2012)**. However, it rose to 9.3 on the right side of the city after a continuous rainy period that lasted for about a month.

Comparing the results of rainwater with those of the Tigris River, it was found that the highest pH value in the river water was recorded during winter in the Qayyarah area, reaching 8.05, which is within the permissible limits according to World Health Organization (WHO) standards, as shown in Table (2).

Alkalinity

Alkalinity was analyzed as an indicator of the ability of rainwater to neutralize basic ions, such as hydroxide (OH^-), carbonate (CO_3^{2-}), and bicarbonate (HCO_3^-), whose concentrations are affected by the presence of airborne particles, especially dust **(Khan, 2014).** Alkalinity concentrations ranged between 20 and 88mg/ L during the study period, calculated based on calcium carbonate. The highest values were recorded in the Agricultural Reform and Mohandessin areas during December and January, while these values decreased in the spring, reaching 12mg/ L. This decrease is attributed to atmospheric washing processes that remove carbon dioxide and other carbon oxides due to rainfall, reducing the formation of bicarbonate ions, which are responsible for raising alkalinity **(Lindberg, 1982)**. The highest alkalinity value was recorded in the Agricultural Reform area, located on the right side of Mosul City **(Shehab *et al*., 2024)**. This is attributed to the geographical characteristics of the area and increased dust levels resulting from human activities, including gypsum factories and the accumulation of debris resulting from the destruction caused by the recent war, which contributed to increased concentrations of suspended particles in the air.

As for the electrical conductivity of rainwater, recorded values ranged from a minimum of 19 microsiemens/cm, recorded in the Agricultural Reform area during April, to a maximum of 135 and 187 microsiemens/cm in the Baladiyat and Al-Muhandisin areas, respectively. This variation in values is attributed to the effect of dust storms and dust-laden rain, which contributed to the dissolution of various salts, especially carbonates and chlorides **(Ganor & Mamane, 1982)**.

These results are consistent with those of **Abdullah (2010)**. However, the current results differ from the results of previous studies, such as **Saleh (1990)**, which recorded electrical conductivity values ranging from 33 to 559 microsiemens/cm. This variation can be explained by the different time periods of the studies and the varying amounts of rainfall, which directly affect the concentration of dissolved ions in rainwater **(Forte, 1990)**.

As for the Tigris River, the study results showed that the average electrical conductivity values exceeded the limits recommended by the World Health Organization **(WHO, 2006)**. The highest conductivity value (565 microsiemens/cm) was recorded in the Qayyarah area during the winter and spring seasons, coinciding with the rise in the river level **(Al-Hadidi, 2018)**.

Temperature

Temperature affects the solubility of gases in rainwater **(Abawi & Hassan, 1990)**. The temperature of rainwater varies depending on the weather conditions. Moreover, water is characterized by its ability to retain temperature **(Al-Saadi, 2008)**.

Turbidity

The turbidity value in rainwater is affected by the amount of particulate matter in the atmosphere, particularly dust and fine particles. As the amount of particulate matter increases, the turbidity value also increases (a direct relationship). In the current study, turbidity values ranged from 0.6 - 14.4 N.T.U.

The results show that with repeated rainfall, turbidity values tend to decrease. However, the highest turbidity was recorded in the Al-Baladiyat area at the beginning of the spring season, with a value of 14.4 N.T.U. This may be attributed to the occurrence of dust-laden winds and the interruption of rainfall, which allowed the accumulation and increase of dust particles in the air. When comparing the results of the current study with global guidelines **(WHO, 2006)**, it was found that all turbidity values fall within the acceptable range for drinking water.

Total hardness

The study results showed that total water hardness concentrations ranged between 18 and 90mg/ L, as $CaCO_3$. This is directly related to calcium and magnesium hardness concentrations, with calcium values ranging from 10 to 80mg/ L, while magnesium values ranged from 2 to 50mg/ L. The highest total hardness concentration was recorded in the Al-Muhandisin neighborhood on the left side of Mosul, reaching 90mg/ L during the winter, as shown in Table (1).

Gor the Tigris River, total hardness values ranged between 220 and 240mg/ L, measured in units of calcium carbonate, along the riverbed, which is within the permissible limits according to World Health Organization recommendations. The highest hardness value was recorded in the forest area, attributed to the discharge of industrial, human, and agricultural waste into the river **(Al-Nama & Al-Obaidi, 2013)**.

Total dissolved solids (TDS)

The results of the current study showed that total dissolved solids (TDS) concentrations recorded their highest values in December, reaching 88.7mg/ L in the agricultural reform area, then gradually decreased during the study months, reaching their lowest value of 15mg/ L in May within the municipalities area. Relatively high concentrations of 72.26 and 43.3mg/ L were also recorded in the agricultural reform area, as shown in Fig. (1).

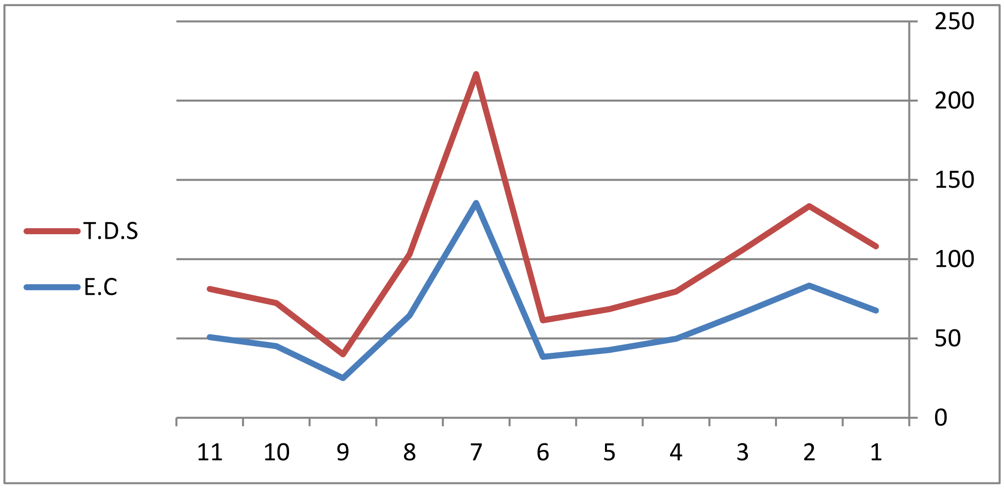


Fig. 1. Relationship between E.C and TDS

Regarding the Tigris River water, the highest TDS value reached approximately 413mg/ L in the forest area during the spring, which is within the permissible limits according to the World Health Organization (WHO) guidelines. This increase is attributed to the increased river flow during this season, which contributes to raising the concentration of dissolved substances **(Jamil & Shehab, 2021)**.

Dissolved oxygen (DO)

The study results showed that the concentration of dissolved oxygen increased during the winter, reaching its highest value of 7.9mg/ L in the Agricultural Reform area, and then began to gradually to decrease over the following months, reaching 7mg/ L in May in the Mohandessin area. The results also showed an inverse relationship between the concentration of dissolved oxygen and air temperature in winter, which was also indicated by **Al-Adili *et al*. (2008)**.

Chemical analysis

Negative ions

The study results indicated that sulfate concentrations increased during the last three months, reaching 58.81 - 56.83mg/L, as shown in Table (1), respectively, in the Engineers and Agricultural Reform neighborhoods in April. This may be due to the increase in population density in these areas and the rise in the number of electrical generators. **Mohammed *et al*. (2025)** pointed out that human activities increase sulfur oxide emissions, which convert to sulfuric acid when it rains.

In contrast, during spring, sulfate concentrations in river water samples reached 70mg/ L in the Qayyarah area, which is within the permissible limit for drinking water according to the World Health Organization. The source of sulfates in the water comes from the dissolution of gypsum and anhydrite rocks in the river basin, but they may also come from dissolved components in rainwater **(AL-Bomola, 2011)**.

The concentration of orthophosphate ions varied between months and different areas. The lowest concentration was 0.02mg/ L in the Al-Baladiyat neighborhood in March, while the highest orthophosphate concentration was 0.55mg/ L in the Agricultural Reform neighborhood in December. These concentrations are considered high, possibly due to the presence of suspended phosphorus oxides in the air from dust storms. These results align with those of **Abdullah (2010)**.

Meanwhile, orthophosphate concentrations in river water samples reached 4.7 mg/L in the spring, the highest concentration being in the Qayyarah area, which exceeds the permissible limit set by the World Health Organization. This is attributed to the higher water levels due to rain, which release large amounts of absorbed phosphate (F_2PO_4) from clay and silt. Increased water flow and mixing cause phosphate to dissolve in the water **(Al-Sinjari, 2001; Jamil & Shehab, 2021)**.

As for chloride ion concentrations, they ranged from 2.2 - 39.7mg/L, with the highest concentration in the Al-Baladiyat neighborhood in April. These results are consistent with those of **Al-Safawi (2012)**, suggesting that the elevated chloride ion concentrations may result from dust particles flying off the soil surface during dry periods without rainfall.

Nitrate concentrations ranged from 0.19 -1.817mg/L, with the highest value in the left bank of the city, in Al-Baladiyat, which may be attributed to human activities, heavy traffic, and aircraft emissions in the city's airspace before rainfall. These levels decreased due to heavy rains in winter **(Abdallah, 1988)**.

Positive ions

Positive ions, especially calcium ions, are responsible for the increase in pH levels, and they originate from dust particles in the air **(Mohammed *et al*., 2025)**. The concentrations of calcium and magnesium ions in the study samples ranged from 4.0 - 32.12mg/L and from 0.4 - 16.4mg/L, as shown in Table (1), respectively. Soil particles are the main source of positive ions, especially calcium ions, as these particles are easily eroded and transported in urban areas due to the activity of winds **(Al-Adili, 2008)**. The highest calcium ion concentration was recorded in the Engineers neighborhood (left bank of Mosul city) during the winter season, reaching 32.12mg/ L, and the lowest value was 4mg/ L in the Agricultural Reform neighborhood during the spring. The highest magnesium ion concentration was also recorded in the Engineers neighborhood in the spring season.

The increase in calcium and magnesium ion concentrations in the Engineers neighborhood may be due to its proximity to the Mosul forests and archaeological hills. As for calcium and magnesium ion concentrations, they increased with increased river flow during the winter and spring seasons in the Qayyarah area.

Sodium and potassium ion concentrations ranged from 0.07 – 9mg/L and from 0.05 - 2.4mg/L, respectively. The presence of these ions can be attributed to the geographical composition of the area and human activities, which contribute to the increase in these ion concentrations **(Lin *et al*., 1999)**.

The increase in the concentrations of these ions and their dissolution in rainwater is responsible for raising the pH to its highest level (9.3) in the Agricultural Reform area, as concluded by **Al-Safawi (2012)**.

CONCLUSION

1. **Rainwater quality**: Rainwater is not suitable for drinking due to its nitrate concentrations, but it is suitable for various uses such as irrigation and industry.
2. **pH Levels**: The pH of rainwater reached 9.3 in the spring season and decreased during the summer. Meanwhile, river water samples had pH values within the permissible limits for drinking water according to international standards.
3. **Alkalinity**: The alkalinity of the water reached 8.8mg/ L during the winter season, which was the highest recorded level.
4. **Dissolved oxygen**: The dissolved oxygen concentrations were high, reaching 8.3mg/ L during the winter season.

5. **Ion concentrations**: The study showed that most anion concentrations increased during spring, while cation concentrations reached their highest levels in the winter season.
6. **Tigris river water**: The water from the Tigris River is suitable for drinking.

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