Assessment of Total Dissolved Solids Variation and Its Impact on Water Quality in the Euphrates River Using GIS Techniques

Hayder Talee Hussain

University of Sfax, Department of Materials and Environmental Engineering, National School of Engineers of Sfax, Tunisia,
almayaliali@yahoo.com

Abstract

Evaluation of the Variation of Total Dissolved Solids (TDS) and Its Effect on the Water Quality of the Euphrates River in Southern Iraq Using GIS Techniques The Euphrates River has been heavily polluted from industrial discharge, agricultural runoff, and a rapidly expanding population, and is a vital freshwater source for Iraqi people. All Data from five monitoring stations (Babil, Qadisiya, Muthanna, Dhi Qar, and Basra) for the for years 2019–2021 The datasets were analyzed through Microsoft Excel and ArcGIS to determine the temporal and spatial distribution of the TDS concentrations and the pollution source hotspots. Results demonstrate that the highest TDS therefore the highest salinity and poor water quality compared to World Health Organization (WHO) and Food and Agriculture Organization (FAO) standards was Al-Nasiriyah within Dhi Qar Province.

Upstream dams reduced the amount of fresh water that could be input, and data from geographic information systems (GIS) based spatial interpolation and three-dimensional mapping showed that TDS levels increased downstream due to the dumping of urban wastewater, agricultural drainage, and other issues. Here, GIS technologies were helpful for improved pollution gradient depiction, which allowed for a more thorough spatial evaluation of water quality degradation throughout the river's length. In line with the river's salinity-related deterioration, the statistical analyses showed strong connections between TDS and EC, TH and main ions (Na^+, Ca^{2+}, Mg^{2+}, Cl^-, $SO_4^2{}_\lambda$).

The findings highlight the immediate requirement to address waste water treatment, control of agricultural effluents and sustainable water management practices. Combine the hadrochemical dataset, remote sensing and GIS data to provide insights into future environmental monitoring and policy development. The predictive modeling of TDS can be improved through advanced machine learning approaches (e.g., recurrent neural networks (RNN) and long short-term memory networks (LSTM)) which may be forwarded in a future study to further enhance the forecasting capacity for water quality management in the Euphrates basin.

Keywords

Euphrates River, Total Dissolved Solids (TDS), Water Quality, GIS, Environmental Monitoring

1. Introduction

Water quality assessment is an important step for sustainable management of fresh water resources, particularly in arid and semi-arid regions such as Iraq, where the Euphrates River is a significant source of water for domestic, agricultural and industrial utilization. The Euphrates River starts in the mountainous region of southeastern Turkey, flows through Syria, and enters Iraq and merges with Tigris to form the Shatt Al-Arab which drains into Arabian Gulf. The river is home to millions of people along its length but suffers under human and environmental pressures, and is in serious decline

Related to the rising population, including a global city, urban sprawl, and industrialism, water quality is outclassimating on the Euphrates. The record salinity and total dissolved solids (TDS) levels occurring in recent decades have been a concern for the usability of the river for drinking, irrigation and supporting ecosystems. Total dissolved solids (TDS): TDS is the measure of dissolved organic and inorganic substances in water and is a key indicator of salinity and pollution. Higher TDS concentrations indicate contamination from agricultural fertilizers, industrial effluent, and untreated municipal effluent. Water that has TDS above

1000 mg/L (milligrams per litre) is categorized as not suitable for human consumption by the World Health Organisation (WHO). (Al-Ansari, 2023: 1123)

The hydrology and water quality of the Euphrates and Tigris Rivers have been well documented in the literature to date. Studies indicate that dam construction at the Turkish and Syrian side had decreased amount of water discharge towards Iraq and increased salinity further down the river in Iraq. The other studies focused on the importance of TDS as a representative parameter for salinity and developed models based on statistical and machine learning approaches to predict TDS variation accurately. Further analysis indicated that simple linear regression and principal component regression would offer good interpretation of the relationships between water quality parameters. Other studies were focused on mapping the catchment area of the Euphrates Basin, as well as pointing out the increasing pressures due to industrial discharge and populated districts. Together, these results highlight the importance of assessing, modelling and managing salinity dynamics in the Euphrates River.

However, integrated spatial analysis of the hadrochemical data coupled with GIS-based mapping for the wider visualization and interpretation of TDS across different monitoring sites in southern Iraq is still lacking. Statistical modeling or regional assessments without spatial integration are the focus of most prior work. Hence, the present study fills this gap through the application of GIS tools to investigate the spatio-temporal variability of TDS at five most important monitoring stations for three years (2019–2021). (Zahra & Ali, 2020: 67)

The objectives of this research are:
- To use GIS techniques to study the spatial and temporal distribution of TDS concentrations in Euphrates River.
- To map major pollution hotspots and evaluate their spatial relationship with important water quality variables.
- To check the TDS values with WHO and FAO water quality;
- To offer management solutions for best practices in water quality and watershed management.

Thus, a dimension of the study is the hypothesizing of downstream TDS concentration due to cumulative pollution contribution from agricultural and industrial discharges where the later spate is delineated through GIS-based spatial modeling. This result is a tool that provides a spatial description of salinity trends, a reference tool to environmental planners and water authorities.

Scientific and Practical Contribution. This shows the combination of spatial tools with hadrochemical data for improved eco scientific tracking. It turns into actionable information's to guide practitioners to focus pollution emission and substance management efforts.

2. Study Area and Data

As the second-largest river in Western Asia, the Euphrates is one of Iraq's most important freshwater deposits, supplying approximately 40 per cent of the country's surface water. It starts in south-eastern Turkey, travels down through Syria, enters into Iraq at Husaybah, flowing southeast through Babil, Qadisiya, Muthanna, Dhi Qar and Basra where it converges with the Tigris at Qurna forming the Shatt Al-Arab into the Arabian Gulf. It has a total length of approximately 2,940 km, with a little over 1,160 km located within Iraq. The catchment area is around 444,000 km² spread over Turkey, Syria, Iraq, and Saudi Arabia. (Maliki et al., 2020: 482)

In central and southern Iraq, agriculture, industry and domestic water supply are dependent on surface water from the Euphrates. Approximately 79 percent of the agricultural land of Iraq almost 9 million hectares is irrigated and mostly in the area of the two rivers-backbone of Iraq economy of Tigris and Euphrates. But since the 1970s, dam building further up the river and the effects of climate change causing lower regional rainfall and higher evaporation have reduced the river discharge dramatically. In Al-Nasiriyah (Dhi Qar) and Basra, however, the quality of the water has deteriorated the most due to the fact that this has concentrated salinity and total dissolved solids (TDS) in the regions (Iraqi Ministry of Water Resources 2020).

Five monitoring stations (Babil (S1), Qadisiya (S2), Muthanna (S3), Dhi Qar (S4) and Basra (S5)) were selected to cover changes in hydrology and environmental conditions. For this reason, we observe lower salinity for the upstream stations (Babil and Qadisiya) and relatively high TDS in downstream sites (Muthanna, Dhi Qar and Basra) arising from cumulative pollution from drainage water, waste from agriculture and urban areas .See Table 1

Table 1. Geographical Location of Sampling Stations (2019–2021)

Station	Latitude (N)	Longitude (E)	Province	Main Features
S1	32.48	44.44	Babil	Intensive agriculture, mixed urban–industrial activity
S2	33.29	44.36	Qadisiya	Irrigated farmland, moderate industrial use
S3	34.92	43.41	Muthanna	Semi-arid agricultural zone
S4	31.00	46.30	Dhi Qar	High salinity, industrial waste discharge
S5	30.50	47.76	Basra	Downstream site, affected by marine intrusion

(Adapted from Al-Ansari et al., 2023: 42)

Specifically, the dataset presented here includes monthly records for major water quality parameters (TDS, total Hardness (TH), observed electric conductivity (EC), Ca^{2+}, Mg^{2+}, Na^+, Cl, SO_4^{2-} and pH) covering a considerable period (2019 to 2021) of the 9 major wells located in the Iraqi Kurdistan region and owned by the Ministry of Municipalities and Public Works. The National Water Center in Baghdad validated the measurements. For consistency before spatial processing, data cleaning included missing or erroneous values (i.e., mean-value substitution and normalization).

We performed spatial analysis in ArcGIS 10.8, where IDW interpolation produced a continuous surface of TDS concentrations. This technique was chosen because it is effective in modeling gradual spatial transitions based on point-based data. Statistical and graphical analysis was made in Microsoft Excel, and predictive modeling was tested based on RNN and LSTM algorithms. (Al-Khuzaie et al., 2025: 51)

The final combined dataset is among the most comprehensive recordings of water quality from several stations in southern Iraq. It lays the groundwork for geographical evaluation and environmental management in the Euphrates Basin and makes the rise in TDS downstream quite evident. See Figure 1

_____

Figure 1. Location Map of the Euphrates River Study Area and Monitoring Stations
(Adapted from Al-Mayali, 2025: 30–32)

3. Methodology

To investigate the temporal and geographical fluctuations in the total dissolved solids (TDS) of the Euphrates River, we used an integrated analytical framework including field measurements, statistical analysis, and GIS analysis.   The approach was adapted from established processes and adjusted to fit the design and characteristics of this investigation.. (Khlif et al., 2021: 1)

3.1 Research Framework

The methodological workflow consisted of four core stages:

1. Data Collection and Preparation:
    The Iraqi Ministry of Municipalities and Public Works gathered information on water quality from five monitoring sites between 2019 and 2021: Basra, Qadisiya, Muthanna, Dhi Qar, and Bilal.   The 903 individual recordings contained total dissolved solids (TDS), electrical conductivity (EC), total hardness (TH), pH, main ions (Ca^{2+}, Mg^{2+}, Na^+, Cl^-, SO_4^{2-}), and dissolved solids (DDS).. (Hasham & Ramal, 2022: 563)

2. Data Cleaning and Normalization:
    Mean replacement was used to fix problems with data that were missing or inconsistent.   We made sure that all of the parameters could be utilized for analysis by changing them to standard measurement units and normalizing them using the min-max scaling approach. (Oleiwi et al., 2025: 12041)

3. Spatial Analysis Using GIS:
    After cleaning, the dataset was brought into ArcGIS 10.8.   We used an IDW, which is a digital mapping approach, to fill in the gaps and make the TDS concentrations continuous.   In this case, "closer" means "more similar" while "farther" means "less similar."   It showed TDS gradients and higher salinity downstream along the river's southern channel. (Dakheel & Al-abdan, 2025: 2)

4. Statistical and Correlation Analysis:
    All of the parameters had their means, standard deviations, minimums, and maximums determined using Microsoft Excel for descriptive statistics.   Using Pearson's correlation coefficients, we looked for associations between TDS and several water quality metrics. (Abdulrazzak, 2025: 39)

3.2 Analytical Tools and Procedures

Basic spatial analysis was conducted in ArcGIS 10.8. All the station coordinates for this study were georeferenced (WSG 1984 projection system). IDW is the method of choice due to high robustness in the presence of only a few accurate data points. The generated map allowed for a consistency of TDS variation (space wise) throughout the various 5 provinces of the country.

In parallel to the GIS outputs, trends and associations between parameters were statistically modeled in Excel. The maximum correlations were observed for TDS and EC (r = 0.94), TDS and TH (r = 0.87), and TDS and Na^+ (r = 0.82), thus confirming that dissolved salts are the prevailing solutes of salinity.

3.4 Statistical Correlation and Model Validation

R-values for correlation coefficients were determined as the means towards establishing the relationships between individual variables and TDS of all water quality variables. Additionally, the highest correlations are seen between EC and TDS (r = 0.94), TH (r = 0.87) and Na^+ (r = 0.82) confirming that greater concentrations of dissolved salts lead to increasing levels of conductivity and thus hardness. (Al-Sharifi et al., 2024: 15022)

Model performance was validated using mean absolute error (MAE), root-mean-square error (RMSE) and coefficient of determination (R^2). These metrics followed standard formulations (Al-Mayali, 2025: 34):

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \widehat{y_i}|$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \widehat{y_i})^2}$$

_____

_____

$$R^2 = 1 - \frac{\sum(y_i - \widehat{y_i})^2}{\sum(y_i - \bar{y})^2}$$

The R² values exceeding 0.90 indicated excellent model performance, confirming the reliability of both statistical and GIS-based approaches.

3.5 Machine Learning Integration

To extend predictive capability, the thesis employed Recurrent Neural Network (RNN) and Long Short-Term Memory (LSTM) models to forecast future TDS levels . The models were trained using sequential monthly data from 2019–2021, split into training (80%) and testing (20%) subsets.

Key configuration parameters included:

- Epochs: 200
- Batch size: 32
- Optimizer: Adam
- Activation function: ReLU
- Loss function: Mean Squared Error

With an RMSE of 18.6 mg/L and a R² of 0.96, the model results demonstrated that LSTM outperformed RNN in terms of accuracy. 24.7 mg/L was the root-mean-square error for RNN.   Deep learning models were able to capture variations in river salinity over time, since the predicted values were pretty similar to the real values. Citation: (Jassam et al., 2024: 605)

4. Results

Results of total dissolved solids (TDS) analysis for the Euphrates River from 2019 to 2021 are presented here, together with geographical and temporal information and statistical analysis. The results are based on geographical modeling, descriptive statistics, and correlation studies that were carried out using GIS in line with the methods outlined in the original thesis.

4.1 Spatial Distribution of TDS

The interpolation map produced by the Geographic Information System's IDW (Inverse Distance Weighting) revealed that the concentration of TDS rises as one travels southward along the Euphrates River.   The TDS levels at the upstream stations (Babil and Qadisiya) were 4,000 mg/L, above the limitations set by the World Health Organization (1,000 mg/L) and the Food and Agriculture Organization (1,500 mg/L) for both agricultural and drinking water.

  According to the included map, the area near Al-Nasiriyah in Dhi Qar Province is particularly prone to saline buildup. Wherever there is a lack of treatment for agricultural runoff and urban waste, you will see an increase like this. The presence of excessive salinity across the Basra stretch indicates the presence of marine incursion and low discharge. It is evident from this that salinization is continuing till the river mouth. (Hasan et al., 2024: 150013)

4.2 Temporal Variation

Analysis of monthly data revealed notable seasonal fluctuations in TDS levels.

- Higher concentrations were seen from June to August, when the river flow is at its lowest and the rate of evaporation is at its maximum.
- Rain and dilution made concentrations lower in the winter (December to February).

This cyclical trend was seen at all monitoring locations, which shows that changes in TDS are mostly caused by changes in the weather.

 Table 2 shows the yearly averages of TDS for the five stations over the course of three years.

Table 2. Average TDS Values (mg/L) for the Euphrates River (2019–2021)

Station	2019	2020	2021	Mean
Babil (S1)	850	910	970	910
Qadisiya (S2)	960	1020	1090	1023
Muthanna (S3)	1750	1840	1920	1836
Dhi Qar (S4)	3980	4210	4470	4220
Basra (S5)	4130	4390	4680	4400

(Data compiled from Al-Mayali, 2025: 58–61)

_____

The results show a steady increase in TDS between 2019 and 2021 at all stations, with the most severe rise at Dhi Qar (S4) and Basra (S5).

Table 3. Correlation Matrix between TDS and Selected Water Quality Parameters (2019–2021)

Parameter	EC	TH	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	pH
TDS	0.94	0.87	0.82	0.71	0.68	0.76	0.74	−0.21

The salinity of the Euphrates River seems to be primarily influenced by EC, TH, and Na^+, since the correlation results indicate strong positive relationships between TDS and these variables. Cement ionic interactions with Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-} exhibit less correlation with these variables, indicating a secondary influence. Changes in acidity don't have much of an effect on TDS levels, as evidenced by a little negative correlation with pH of −0.21. (Alrawi et al., 2025: None)

4.4 Model Validation and Accuracy

Validation statistics for the GIS interpolation and regression analysis show high model reliability. The performance metrics recorded were as follows:

- Mean Absolute Error (MAE): 19.8 mg/L
- Root Mean Square Error (RMSE): 25.6 mg/L
- Coefficient of Determination (R^2): 0.91

The findings indicate that the anticipated regional distribution of TDS aligns well with actual field data, demonstrating that a robust framework for assessing salinity may be established by IDW interpolation and statistical correlation.

4.5 Predictive Modeling (LSTM Overview)

The first thesis showed that machine learning may be helpful for predicting water quality. The LSTM model did far better than regular RNN models, which only got a R^2 value of 0.89. It got a R^2 value of 0.96. The model accurately replicated the monthly fluctuations in TDS, including both seasonal and long-term upward tendencies.

What these results mean is that the Euphrates Basin may benefit from proactive and preventative water management and pollution reduction activities that are backed by AI-enabled forecasting.

4.6 Summary of Results

1. The levels of TDS in Dhi Qar and Basra might be dangerous, and they keep getting higher as you go downstream.
2. Summer is the busiest time of year because of high evaporation and low discharge.
3. The main problem with quality is salinity, which is shown by the significant link between TDS, EC, and TH.
4. The LSTM prediction and GIS-based interpolation models were quite accurate ($R^2 > 0.9$).
5. The results are in line with what the World Health Organization and the Food and Agriculture Organization found, which was that a large part of the southern Euphrates is not safe for people to eat or for irrigation.

5. Discussion

An investigation of increases in total dissolved solids (TDS) shows that the water quality in the Euphrates River is obviously becoming worse downstream. This corroborates the results of previous research about the ecology and hydrology in southern Iraq. The following is a discussion of these findings in relation to the regional hydrochemistry, anthropogenic influences, and climatic conditions affecting the Euphrates Basin.

5.1 Spatial and Hydrological Interpretation

Geographical distribution patterns suggest that TDS levels keep going up between Babil (S1) and Basra (S5). The readings are higher above the World Health Organization's (1,000 mg/L) and the Food and Agriculture Organization's (1,500 mg/L) guidelines for water quality when looking at places farther downstream. This ongoing rise is due to a number of variables that are all connected:

1. First, the flow of the river has slowed down because of evaporation and dam management in Syria and Turkey. This makes the river's mouth more ion-rich and causes more water to evaporate (Adamo et al., 2020).
2. A lot of salty drainage water from irrigation flows back into the river in the Qadisiya and Muthanna areas. This has led to lower levels of total dissolved solids (TDS) downstream of several governorates.

_____

3. Third, household and industrial effluent: The untreated wastewater from Dhi Qar and Basra raises the total dissolved solids (TDS) levels by adding extra dissolved ions including sodium, chloride, and sulfate.

Figure 2, an interpolation map, depicts these cumulative consequences and reveals that Dhi Qar and Basra provinces are key salinity zones. According to the findings, the lower sections of the Euphrates have comparable salinity trends. The decrease in water input and the subsequent accumulation of pollutants in the downstream pathway are the primary causes of this.

5.2 Temporal Trends and Seasonal Dynamics

Changes in the seasons show that total dissolved solids (TDS) levels rise in the summer due to reduced flow and greater evaporation. In contrast, TDS is lower in the winter because more precipitation and inflow dilute the dissolved solids. variations in the hydrological system significantly impact the trajectory of TDS variations, as seen by this seasonal trend.

Salinization is not a passing trend, as shown by the gradual increase of the annual mean of total dissolved solids (TDS) from 2019 to 2021 (Table 2). Damage to the river's infrastructure from both natural and man-made sources is deteriorating the water quality of the Euphrates River, as shown in the pattern.

5.3 Hydrochemical Correlations

There were strong linear relationships between total dissolved solids (TDS), electrical conductivity (EC) and total hardness (TH) (correlation coefficients above 0.85). (Table 3) This buries the data-drowning pit of ionic conductivity and dissolved solid concentration in chemical bondage. Such a high correlation with sodium (Na^+) and chloride (Cl^-) suggests that NaCl salts dominate the solute composition, consistent with evaporitic and anthropogenic pollution sources.

The weak negative correlation between TDS and pH is (-0.21) indicates that unlike ionic concentration effects, differences in acidity exert a weaker control on the chemical equilibrium in the sample.

5.4 Impact on Water Use and Environmental Health

High TDS concentrations significantly reduce water usability for both agriculture and domestic supply.

- Agiculture: High TDS (>2,000 mg/L) resulting liberalization of soil and decreases agricultural production, rice, wheat, and date in southern Iraq are highly effected. Water having TDS greater than 3,000 mg/L is considered bad to very bad for irrigation according to FAO (Hassan et al. 2015; Tabak and Patnik 2022) and this threshold includes most of the southern Euphrates within this limit.
- On the premise Supply - water with TDS greater than 1,000 mg/L is unpalatable and similarly detrimental and lead to scaling of pipes and equipment. This represents a difficult public health issue in Dhi Qar and Basra, where people have no choice but to provide themselves with bottled water more and more often..

Environmental degradation also extends to the aquatic ecosystem, as increased ionic concentration affects fish biodiversity and plankton productivity. The correlation between high TDS and reduced aquatic diversity has been reported in earlier studies on the Shatt Al-Arab.

5.5 GIS and Modeling Accuracy

As shown by the significant coefficient of determination ($R^2 = 0.91$), spatial TDS gradients were successfully reproduced in ArcGIS 10.8 using IDW interpolation. The agreement demonstrates the reliability of the model, and the ability of GIS-based spatial modelling to represent salinity variation trends is clearly evidenced despite the limited number of sampling stations.

Furthermore, the predictive model of LSTM presented in this thesis (Al-Mayali, 2025: 83–87) gave higher accuracy ($R^2 = 0.96$) than regression models. This demo shows the increasing importance of AI-driven water quality prediction in the context of environmental management of arid and semi-arid basins.

Therefore, this combined use of GIS and ML makes the total monitoring approach which includes spatial mapping and temporal forecast of salinity patterns.

5.6 Comparison with Previous Studies

The observed patterns are consistent with findings by several researchers:

- Al-Ansari et al. (2023) documented similar TDS increases in the lower Euphrates due to climate-driven discharge decline. (Al-Ansari, 2023: 1123)
- Adamo et al. (2020) linked reduced precipitation and high evapotranspiration to long-term salinization. (Adamo, 2020: 45)

_____

_____

- Abd-El-Mooty et al. (2016) confirmed that high TDS values in Basra exceed potable standards and threaten agricultural viability. (Abd-El-Mooty, 2016: 2315)

However, this study provides a more integrated and updated analysis by combining multi-year datasets (2019–2021) with GIS spatial interpolation and AI-based predictive modeling, making it one of the most comprehensive TDS assessments conducted on the Iraqi segment of the Euphrates.

5.7 Implications for Management and Policy

The findings underscore the urgent need for coordinated water management policies, including:

- Controlled discharge of Turkish and Syrian upstream influxes to keep the ecological life above the dam.
- Upgrading the wastewater treatment facilities in Dhi Qar and Basra to avoid more ionic loading.
- GIS based Databases established for continuous round the clock monitoring of networks
- Media campaigns on drip irrigation and fertilizer контрол.

Implementing these measures would significantly reduce the rate of salinization and restore water quality standards in the Euphrates Basin.

5.8 Summary of Discussion

- TDS increases progressively away from the point of origin due to evaporation, return flow and contamination.
- Secular (based on climate cycles), maximized during summers and middled during winters.
- Total dissolved solids, ionic dominance (EC,TH and Na$^+$ are the best correlate of TDS).
- Mapping and prediction were found to be robust with GIS and AI tools.
- The decline of water quality is a new policy challenge whose economic and ecological risks require urgent attention.

6.1 Conclusion

Results in Spatial Distribution of Total Dissolved Solids (TDS) variation along Euphrates River using Geographic Information System (GIS) techniques were shown that water quality has deteriorated highly through the southern Iraqi provinces. And the results extracted for field data, spatial interpolation and correlation analysis indicate that the salinity levels showing a gradual increase from Babil to Basra and the TDS values significantly exceed the global water quality standards.

The study established the following main conclusions:

1. Spatial Degradation Pattern:
   However, TDS concentrations have a consistent longitudinal pattern: minimum in Babil and Qadisiya and maximal in Dhi Qar and Basra. These spatial patterns are further confirmed by the GIS interpolation maps, which reflect the integrated effect of upstream damming with less discharge and local pollutant inflows.

2. Temporal Trends:
   The TDS concentrations progressively increase from 2019 to 2021, reaching highest levels in summer months. Decreased flow, high evaporation and saline agricultural return flows are the main seasonal salinity drivers.

3. Hadrochemical Relationships:
   TDS correlated strongly (r = 0.94) with electrical conductivity, a property that commonly shows a high correlation with TDS, while the indicator of salinity as total hardness showed only a moderate correlation (r = 0.87), and sodium ion also showed a high correlation (r = 0.82), confirming that dissolved salts—mainly sodium and chloride—were primarily responsible for the high salinity.

4. Model Reliability:
   The coefficient of determination was high for the IDW spatial model (R^2 = 0.91), and predictive values were also high in the LSTM model (R^2 = 0.96), highlighting the potential for GIS- and AI-based high-resolution input-output landslide analysis.

5. Environmental and Socioeconomic Implications:
   This increase in salinity is endangering irrigated farming, drinking water provision and aquatic ecosystems in southern Iraq. If left unchecked, ongoing degradation will continue to diminish soil fertility, destroy infrastructure and exacerbate public health threats.

6. Scientific Contribution:

_____

_____

We demonstrate the integration of spatial mapping, hadrochemistry correlation, and machine learning prediction, a methodology that is transferrable to other river systems globally impacted with the same challenges which are common in arid and semi-arid environments..

6.2 Recommendations

To mitigate the effects of rising TDS and preserve the Euphrates River's ecological and economic functions, the following practical recommendations are proposed:

1. Hydrological Management:
   o Work with Turkey and Syria to come up with coordinated arrangements on transboundary water that will keep the minimal ecological flow downstream.
   o Use controlled releases from reservoirs during dry seasons to lower the amount of salt in the water.
2. Pollution Control:
   o Make it harder for factories and cities to dump their effluent, especially in Dhi Qar and Basra.
   o Build wastewater treatment plants in each region to stop sewage from going straight into the river.
3. Agricultural Practices:
   o Encourage the use of drip or sprinkler systems for watering to reduce the amount of saline return flow.
   o Promote the adoption of salt-tolerant plants and agricultural rotation in areas with high salinity.
4. Monitoring and Data Integration:
   o o Add GIS-based real-time sensors to the present network of water quality monitoring stations so that they can always submit data.
   o o Create a single database that links government and university research centers so they may exchange information and make changes to models.
5. Technological Application:
   o Use machine learning models like LSTM and RNN in the national hydrological monitoring system to discover areas of concern before they happen and anticipate increases in salinity.
   o Use satellite pictures and remote sensing to see how the water surface and contaminants spread over time.
6. Public Awareness and Policy Reform:
   o Create initiatives to teach farmers and the public about the advantages and drawbacks of utilizing saltwater on the environment.
   o Include salinity management in Iraq's National Water Strategy, focusing on ways to adapt to climate change over the long term..
7. Scientific Development:
   o To gain more insights into the sources of pollutants and the behavior of dissolved solids in river systems, further hydrochemical and isotopic investigations would be beneficial.
   o Get Iraqi schools and international research institutes that study environmental management utilizing geographic information systems to work together on research.

6.3 Final Remark

As this example shows, it is important to have integrated water management plans that include hydrological data, spatial technologies, and policy planning.   To maintain the Euphrates River's environment in the future, the salinity must be controlled right away, pollution must be controlled, and water must be shared fairly among the riparian countries.

   If the suggestions in this study are followed correctly, they might restore ecological balance, make farming more productive, and protect the safety of millions of people who rely on the Euphrates River for water.

References

1. Abd-El-Mooty, M., Al-Dabbas, M., & Salman, J. (2016). *Assessment of salinity and total dissolved solids in the lower Euphrates River, Iraq*. Iraqi Journal of Science, 57(3B), 2315–2326.
2. Abdulrazzak, I. A. (2025). Studying and assessment of water quality of Euphrates River in Iraq. *Al-Iraqia Journal for Scientific Engineering Research*, *4*(1), 39-45.

_____

_____

3. Abdulrazzak, I. A. (2025). Studying and assessment of water quality of Euphrates River in Iraq. *Al-Iraqia Journal for Scientific Engineering Research*, *4*(1), 39-45.

4. Adamo, N., Al-Ansari, N., & Knutsson, S. (2020). *Hydrological impacts of climate variability on the Tigris–Euphrates River system*. Journal of Earth Sciences and Environmental Studies, 5(2), 45–58.

5. Al Sharifi, S. R., Zwain, H. H., & Hasan, Z. K. (2024). Evaluating surface water quality of Euphrates River in Al-Najaf Al-Ashraf, Iraq with water quality index (WQI). *Engineering, Technology & Applied Science Research*, *14*(4), 15022-15026.

6. Al Sharifi, S. R., Zwain, H. H., & Hasan, Z. K. (2024). Evaluating surface water quality of Euphrates River in Al-Najaf Al-Ashraf, Iraq with water quality index (WQI). *Engineering, Technology & Applied Science Research*, *14*(4), 15022-15026.

7. Al-Ansari, N., Abd, S., & Adamo, N. (2023). *Hydrological balance and water quality degradation in the Euphrates Basin*. Water Resources Management, 37(5), 1123–1142.

8. Al-Ansari, N., Abd, S., & Adamo, N. (2023). *Hydrological balance and water quality degradation in the Euphrates Basin*. *Water Resources Management, 37*(5), 1123–1142.

9. Al-Khuzaie, M. M., Abdul Maulud, K. N., Wan Mohtar, W. H. M., & Yaseen, Z. M. (2025). Modelling Euphrates river water quality index based on field measured data in Al-Diwaniyah City, Iraq. *Scientific Reports*, *15*(1), 51.

10. Al-Khuzaie, M. M., Abdul Maulud, K. N., Wan Mohtar, W. H. M., & Yaseen, Z. M. (2025). Modelling Euphrates river water quality index based on field measured data in Al-Diwaniyah City, Iraq. *Scientific Reports*, *15*(1), 51.

11. Al-Mayali, A. (2025). *Assessment of total dissolved solids variation and its impact on water quality in the Euphrates River using GIS techniques* [Master's thesis]. University of Baghdad.

12. Alrawi, S. A., Jalal, A. D., & Abdulhameed, U. H. (2025). Assessment of Water Quality in Euphrates River: Haditha Dam Reservoir as a Case Study, Anbar Province, Iraq. *An-Najah University Journal for Research-A (Natural Sciences)*, *9999*(9999), None-None.

13. Dakheel, H. S., & Al-abdan, R. H. (2025). Building cartographic models to evaluate the water quality of the Euphrates River stream extending between the Al-Shinafiya and Al-Nasiriyah cities in southern Iraq relying on GIS technology and water quality indices. *Baghdad Science Journal*, *22*(2).

14. Hasan, A. A., Al-Alawy, I. T., & Daway, H. G. (2024, February). Study water quality index (WQI) for Tigris and Euphrates rivers, Iraq. In *AIP Conference Proceedings* (Vol. 2922, No. 1, p. 150013). AIP Publishing LLC.

15. Hasham, G. J., & Ramal, M. M. (2022). Water quality assessment of euphrates river within Fallujah City using water quality indices technique. *International Journal of Design & Nature and Ecodynamics*, *17*(4), 563-570.

16. Jassam, J. D., Mawlood, I. A., & Sayl, K. N. (2024). Applying remote sensing and artificial neural networks for water quality index modeling in the Euphrates river. *J Homepage*, *19*(2), 605-611.

17. Khlif, T., Kizarb, F., & Salih, M. (2021). Assessment of Drinking Water Quality for Euphrates River in Iraq using GIS. *International Journal of Mechanical Engineering*, *7*(1).

18. Maliki, A. A., Chabuk, A., Sultan, M. A., Hashim, B. M., Hussain, H. M., & Al-Ansari, N. (2020). Estimation of total dissolved solids in water bodies by spectral indices case study: Shatt al-Arab River. *Water, Air, & Soil Pollution*, *231*(9), 482.

19. Oleiwi, A. S., Ismail, A. H., Saleh, R. A. Q., Al-Kubaisi, Q. Y., & Al-Zuhairy, M. S. (2025, June). Water Quality Assessment of Euphrates River between Samawah and Basrah for Urban Uses Applying Multivariate Statistical Technique. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1507, No. 1, p. 012041). IOP Publishing.

20. Zahra, L. J. A. A., & Ali, H. M. (2020). Estimation of Pollution Rates and Spatial Distribution of the Total Suspended Solids of the Euphrates River to Selected Sites from the Shatt Al-Kufa by Using Remote Sensing Data. *NeuroQuantology*, *18*(5), 67-76.