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Impacts of the river water pollution control on the health of aquatic animals in downstream

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ABSTRACT
Water pollution is one of the most significant environmental issues and problems. Surface water, running water, and rivers are always the most polluted, due to passing through numerous areas. The objective of this study is to investigate the water quality of Euphrates River in central Iraq in terms of aquaculture, as well as how to control the concentrations of pollutants. About 60-km length of Euphrates River was modeled using artificial neural networks (ANN) using qualitative data. The standard range of polluting substances for aquaculture was evaluated, and the effect of implementing the scenario of controlling point sources of pollution and preventing the flow from coming into contact with waste piles and animal excrement were studied. Statistical criteria, including NSE, RMSE, and MAE, were used to evaluate the model performance in the training and testing phases. According to the results, implementing the desired scenario has reduced the concentrations of all pollutants to an acceptable level for aquaculture. The most significant decrease occurred in the regions closest to the industries and factories (0-10 km), while the slightest change occurred in the farthest reaches of the study area (50-60 km). The findings of this study can be used to implement water quality controls at the optimal time and location to influence the Euphrates River general state.

Keywords: Pollution, Artificial neural networks, Aquatic animals, Euphrates River.
Article type: Research Article.

INTRODUCTION
Human health has always been concerned with water pollution (Molajou *et al.* 2021). Pollutants enter aquatic ecosystems, causing surface and subsurface water pollution and ecosystem disruption (Brontowiyono *et al.* 2022). Assessing the quality of water resources has become one of the most pressing issues in recent years due to the growing water demand, the depletion of natural water reserves, environmental pollution, and the increase in the water requirements of human activities (Dutta *et al.* 2020; Israa Ibrahim *et al.* 2021; Abdouni *et al.* 2021; Melnik *et al.* 2021; Talib Jawad *et al.* 2022; Alewi *et al.* 2022). In this situation, monitoring and controlling the water quality at regular intervals appears necessary. This issue is more pronounced in arid and semi-arid regions where precipitation is irregular, intermittent, and accompanied by high evaporation rates (Rajmohan *et al.* 2019). The expansion of industries, the resulting release of wastewater, and the widespread use of chemical fertilizers and pesticides in agriculture have prompted grave concerns regarding water quality (Singh & Chandra 2019; Ustaoğlu & Tepe 2019). Generally, deteriorating water quality threatens human health, aquatic life, economic growth, and

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social welfare (Molajou *et al.* 2021). Given the limited amount of potable water and the growing demand for water resources, it is now more critical to monitor available water quality (Mishra *et al.* 2019). When the pollution load exceeds the absorption capacity of the receiving environment, the quality of the river water exceeds the standard quality level, and various damages are caused to the ecosystem's functions for the exploitation of drinking water, the production of agricultural products, and the health of the river ecosystem (Prata *et al.* 2021; Saravanan *et al.* 2021). Water quality models with simple and accurate simulations to improve the solutions can be utilized as a tool in the water quality management. In recent years, using water quality models has become widespread (Kulisz & Kujawska 2021). In one-dimensional models, the transmission and diffusion processes are assumed to occur in the main flow direction. Some dynamic models are more intricate than their one-dimensional counterparts. Complex two-dimensional and three-dimensional models are not easily constructed (Alias *et al.* 2021). They require a vast array of field data and the modification of parameters and coefficients of transport-reaction equations in different dimensions (Chowdhary *et al.* 2020). Due to the limited availability of simulation-required data, one-dimensional hydraulics and water quality models have gained widespread acceptance. In recent years, artificial neural networks (ANN) have been used to model the complex processes underlying river pollution (Elkiran *et al.* 2019). Several studies have been conducted using this model in water quality simulation and impact analysis of river water quality improvement scenarios (Nasir *et al.* 2022). Therefore, determining the water quality in various regions, including arid and semi-arid regions, is essential (Okereafor *et al.* 2020). In tropical arid and semi-arid regions, rivers are the only source of water for various uses (drinking, industry, agriculture, etc.). The downstream water quality will be negatively affected when a hazardous chemical or organic pollutant is introduced into a river by residential, industrial, or agricultural units (Ustaoğlu *et al.* 2020). Consequently, the qualitative investigation of the river and its polluting sources is of utmost importance (Maurya *et al.* 2019). Given that Euphrates River is one of the two major rivers of Mesopotamia, its pollution has a negative impact not only on the environment of the region and the aquatic life of the river, but also on agricultural lands irrigated with this water and on the widespread consumption of contaminated agricultural products. It is essential to check the water quality of this river by examining its water. In light of the significance of Euphrates River as one of the most important sources of drinking water supply and agriculture in the region, as well as the presence of numerous factories and sewage around it, choosing the water quality of this river and identifying the most critical polluting sources for wastewater planning and control is essential, to reduce the concentration of pollutants to the standard level. This study investigates the water quality of a portion of Euphrates River and the impact of the proposed aquaculture pollution control method. In addition to temporal and spatial field monitoring of hydraulic parameters and water quality, modeling of non-point pollutant sources and return flows from agricultural lands have been discussed in this study. The novelty of the present study is its multidimensional and exhaustive analysis of the proposed method for combating pollution.

MATERIALS AND METHODS

This study necessitates three categories of data including meteorological, the river hydraulic and hydrological, along with the river water quality. The data recorded by the synoptic station was used to provide meteorological information. In order to simulate the hydraulics of the river, information was extracted from the ecological status determination plan maps of the river's different longitudinal sections. After transferring these sections to the HEC-RAS model, charge-discharge and stage-discharge curves were extracted. Inputs to the water quality model included discharge-Echelon and discharge-river velocity curves. In the low- and high- water seasons, the coefficient of water returned to the river, based on basin-wide studies and field observations, was estimated to be 13% and 32%, respectively. According to the field visits conducted during the fall season, water harvesting from the river has not occurred during this season. However, water harvesting occurs along the river during the spring and summer. Based on the mass conservation equation and the difference in flow rate between the beginning and the end of the studied area, the amount of return flows to the river, and the flow rate of point polluting sources, the amounts of water harvested during these seasons were calculated. Examining the long-term discharge data of the hydrometric stations in the river reveals that April and May are the river wet seasons and that from June until the end of the water year, the flow intensity decreases, making late summer and early autumn the dry season.

Study area

The Euphrates is 2800 kilometers long and flows through three countries. The catchment area of the Euphrates is approximately 500 thousand square kilometers in size. This river's average flow rate is 356 cubic meters per second. The significance of the Euphrates is that the first civilizations arose in this region, and the fertility of the Iraqi soil due to the Euphrates' passage through the country's center and west has attracted people to the Mesopotamia plain, which lies between the Euphrates and Tigris rivers. In recent years, a great deal of pollution has been associated with the Euphrates River due to the activities of industries, agriculture, etc. In May, September, and December of 2021, sampling operations and field trips were conducted on the Euphrates River. Due to the location of polluting sources in the river, the extensive length of the study period, and financial and time constraints, water quality parameters were collected at eight points along the river. In these courses, 12 water quality variables were recorded and measured in situ and the laboratory. During the field visits, it was discovered that the river receives wastewater from industries and factories, water treatment plants, urban and rural wastewater, and effluent from agricultural activities. Examining the spatial variations of the measured variables during May and September reveals that these polluting sources have had a significant impact on the downstream water quality of the river and that the water quality degrades significantly after passing through these locations.

ANN Model

Artificial Neural Networks (ANN) are a simple approximation of the human brain. In recent decades, ANN, as one of the AI techniques, has been used to simulate the quality of water (Yu *et al.* 2021). Using physical mapping methods, the neural network model links inputs with outputs (Molajou *et al.* 2021). Since the beginning of the 1990s, artificial intelligence has been used as a statistical information technique. The primary benefits of ANNs in this application are their ability to simulate the watershed system with just a few data, to provide far more flexibility in simulation with nonlinear mapping, and to compensate for the lack of hydrological expertise. In several publications, ANN is integrated with wavelet-processed data, capturing data seasonality and boosting single-layer ANN implementation (Parvan *et al.* 2019). An ANN is a nonlinear mathematical structure capable of illustrating the nonlinear communication process between the inputs and outputs of any system (Chen *et al.* 2020). This network is trained to predict the future using current data as part of its learning process. Weights link neurons from one layer to the next. Fig. 1 depicts a diagram of the ANN model.

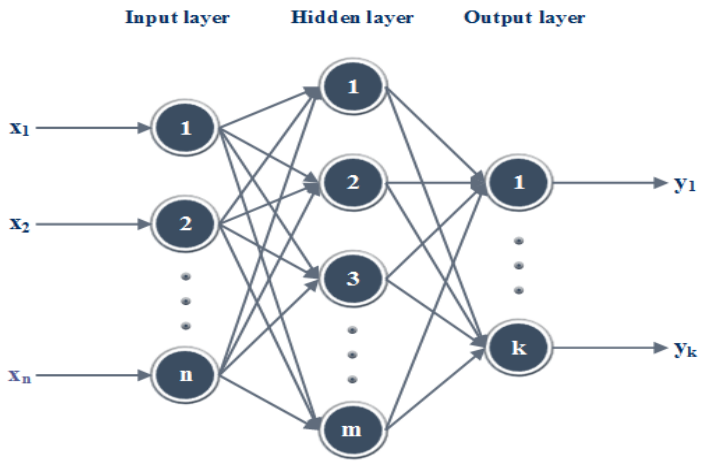

Fig. 1. Schematic figure of ANN model.

In addition to the model's main assumptions, the river has been simulated quantitatively, qualitatively, and with the stimulation functions of each season in permanent conditions. It is assumed that all harvests occur at the beginning of each interval. The incoming agricultural pollutants are evaluated uniformly for the duration of the interval. This study assumed the thickness of the sediment layer and the porosity of the sediment grains were 14 cm and 0.3, respectively. In addition, the modeling included:

- Information regarding the amount of sediment oxygen demand (SOD),
- The qualitative condition of the hypothetical area, and
- The thickness and flow of this area.

Due to the absence of anaerobic conditions in Euphrates River, it was determined that the denitrification rate was equal to zero. For a more accurate evaluation, the desired 60-km length of the river was divided into smaller sections. The methods of Euler and Newton-Raphson were used to solve mass transfer equations and pH simulation, respectively. Given the presence of vegetation on the bed and its definition in the model, the minimum simulation time required to reach the permanent state should be greater than two times the passage time. The passage time of the desired flow was calculated based on the flow characteristics and the path length of the studied interval. Consequently, the duration of the model execution in this study was assumed to be seven days. The September and May data from 2021 were used to calibrate the dry and wet season models. The validation period was also formulated and evaluated based on meteorological, hydraulic, and hydrological data and water quality parameters collected in December 2021.

Statistical criteria

In order to determine the error between the observed and simulated data in the calibration and validation stage, statistical criteria have been used. The following three statistical criteria were used to evaluate the models: Nash–Sutcliffe efficiency (NSE), root mean squared error (RMSE), and mean absolute error (MAE).

$$NSE = 1 - \frac{\sum_{i=1}^{N} [(Q_0)_i - (Q_c)_i]^2}{\sum_{i=1}^{N} [(Q_0)_i - \bar{Q}_0]^2}, \quad (1)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N} [(Q_0)_i - (Q_c)_i]^2}, \quad (2)$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N} |(Q_0)_i - (Q_c)_i|, \quad (3)$$

where, N is the number of data points and Q_0, Qc, and $\bar{Q}_0$ denote the observed, simulated, and mean observed values respectively.

Assessing the qualitative health of the river

The concentrations of river water quality variables were extracted and compared to the recommended values for aquatic organisms using credible scientific references to evaluate the health of river water quality. The recommended standard ranges of water quality variables for aquatic life used in this study are presented in Table 1.

Table 1. Standard range of water quality variables for aquatic life

Variable	Standard range
pH	6-9
TEMP (°C)	<30
EC (mm cm^{-1})	<5
BOD (mg L^{-1})	<6
DO (mg L^{-1})	>6
NO_3 (mg N L^{-1})	<10.161
NH_4 (mg N L^{-1})	<0.77
NH_3 (mg N L^{-1})	<0.024
TN (mg N L^{-1})	<5
TP (mg P L^{-1})	<0.5

RESULTS AND DISCUSSION

Training results

In the training phase, the model parameters for two wet and dry seasons are depicted in Table 2 exhibiting the calibration results for a particular parameter difference between the wet and dry seasons. This difference is due to differences in the river hydraulic characteristics and flow rate, river vegetation status, water temperature, nature of materials, as well as the type and number of microorganisms during the wet and dry seasons. The results of the training phase of hydraulic models and water quality of Euphrates River revealed that the water quality in the river's lower reaches is degraded due to the introduction of point and diffuse sources of pollution. The presence of animal excrement and garbage on the riverbank (riverside villages) is one of the primary causes of water pollution during the wet and dry seasons. Its most significant effect is an elevated concentrations of nutrients (phosphorus and nitrogen types) in the river. Table 3 displays the evaluation statistics for the model training stage for both seasons. Comparing the results with the acceptable error values reported in previous studies demonstrates that the constructed models have sufficient accuracy for simulating the river water quality during the training phase.

Table 2. Value of parameters for river water quality modeling in training stage.

Parameter	Value			
	Min	Max	Wet season	Dry season
Fast CBOD oxidation rate (/d)	0	5	3.681	2.734
Slow CBOD oxidation rate (/d)	0	0.5	0.249	0.262
Slow CBOD hydrolysis rate (/d)	0	5	0.417	3.273
Basal respiration rate (/d)	0	0.3	0.011	0.034
Death rate (/d)	0	05	0.019	0.057
Excretion rate (/d)	0	0.5	0.008	0.66
Organic P hydrolysis (/d)	0	5	0.029	1.114
Organic N hydrolysis (/d)	0	5	0.006	0.431
Ammonium nitrification (/d)	0	10	0.752	0.973
Detritus dissolution rate (/d)	0	5	2.806	4.135
Detritus settling velocity (m/d)	0	5	3.164	2.655
Organic N settling velocity (m/d)	0	2	0.042	0.362
Organic P settling velocity (m/d)	0	2	0.009	0.135
Inorganic P settling velocity (m/d)	0	2	0.043	1.247

Table 3. The values of statistical criteria in the training stage of the modeling.

Parameter	Wet season			Dry season		
	NSE	RMSE	MAE	NSE	RMSE	MAE
pH	0.81	0.31	0.75	0.74	0.53	1.27
EC (μm cm^{-1})	0.52	8.43	0.93	0.46	12.07	1.49
BOD (mg L^{-1})	0.67	1.67	12.08	0.72	1.36	11.23
DO (mg L^{-1})	0.78	0.34	0.71	0.68	0.59	0.86
NO_3 (mg N L^{-1})	0.86	0.28	2.56	0.78	0.42	2.73
NH_4 (mg N L^{-1})	0.93	0.06	1.82	0.91	0.11	1.67
NH_3 (mg N L^{-1})	0.72	0.67	2.19	0.87	0.23	1.58
TN (mg N L^{-1})	0.64	0.79	3.87	0.56	0.62	2.73
TP (mg P L^{-1})	0.88	0.17	2.35	0.86	0.26	3.28

The high flow velocity and depth values in May compared to September are influenced by the river's upper discharge in the early spring months, while its decline in September due to upstream harvests to meet regional consumption needs. The error values presented in Table 3 illustrate the collection of a comprehensive set of qualitative data at 12 monitoring points along Euphrates River, as well as the evaluation of statistics of these qualitative parameters during the training phase used to evaluate the condition of the river.

Testing results

After training the river water quality model for the wet and dry seasons, sampling and field visits in December 2021 were used to test the model for the dry season. Examining the values of the statistical criteria between the observed and simulated data for various variables and comparing them to the acceptable limits reported in previous studies verifies the accuracy of the models. Table 4 displays the values of statistical criteria at the testing stage.

Table 4. The values of statistical criteria in the testing stage of the modeling.

Parameter	NSE	RMSE	MAE
pH	0.76	0.39	0.92
EC (μm cm^{-1})	0.38	12.49	8.56
BOD (mg L^{-1})	0.64	1.87	12.61
DO (mg L^{-1})	0.71	0.62	1.53
NO_3 (mg N L^{-1})	0.75	0.41	3.17
NH_4 (mg N L^{-1})	0.92	0.08	3.46
NH_3 (mg N L^{-1})	0.67	1.28	4.35
TN (mg N L^{-1})	0.48	3.72	11.40
TP (mg P L^{-1})	0.72	1.17	4.79

In the test phase, the model results for the nitrogen and phosphorus pollutants are significantly off. Investigations revealed that the variation in discharge and concentrations of polluting sources during the testing period could not improve these models. Flow rate changes can impact hydrolysis, sedimentation, and organic matter suspension rates. Given that the flow rate during the test period is not significantly different from the flow rate during the training period, the cause of this error cannot be attributed to flow characteristics. This error can be caused by introducing pollutants whose location and quantity cannot be precisely predicted. Examining the spatial variations in the concentration of water quality variables in the November month reveals that after introducing wastewater from industries and factories, the concentration of biochemical oxygen demand has increased, resulting in degraded water quality in downstream of the desired location.

River pollution control

The action of controlling pollutant sources at the point of origin (wastewater of industries and factories) and preventing the flow from coming into contact with waste piles and animal excreta is investigated in this study based on the obtained conditions and results. Notably, the pollutant concentrations in the headstream exceeds the standard maximum amount and that the control of pollutant sources in downstream will not contribute significantly to lower their concentrations. Following issue is an evaluation about the effect of implementing the scenario presented on the changes in concentrations of various parameters that exceeded the allowable limit for aquatic life. Table 5 displays the results for various distances within the studied range.

Table 5. Concentration of pollutants for different intervals of the studied range

Parameter	Desired distances (km)					
	0-10	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**
pH	8.13	7.86	7.61	7.12	7.26	7.19
EC (μm cm^{-1})	3.81	3.16	3.02	2.46	2.27	1.83
BOD (mg L^{-1})	2.37	2.26	2.68	1.74	1.49	1.04
DO (mg L^{-1})	8.43	8.62	9.12	9.35	9.64	9.87
NO_3 (mg N L^{-1})	6.57	6.32	6.11	5.73	5.43	5.16
NH_4 (mg N L^{-1})	0.26	0.23	0.18	0.15	0.14	0.09
NH_3 (mg N L^{-1})	0.02	0.02	0.01	0.01	0.01	0.01
TN (mg N L^{-1})	3.76	3.82	4.36	3.17	3.34	3.29
TP (mg P L^{-1})	0.41	0.42	0.44	0.34	0.36	0.37

Based on the values of each pollutant in Table 5 and a comparison with the standard values in Table 1, it is possible to conclude that the concentrations of all pollutants are within the acceptable range for aquaculture. Therefore, implementing the scenario described has significantly reduced the number of pollutants in Euphrates River. Noteworthy, various authors have always investigated and controlled the pollutants in rivers, with some results consistent with the present findings (Shi *et al*. 2018; Ahmed *et al.* 2019; Kadam *et al.* 2019) while others inconsistent (Rajaee *et al.* 2020). Most studies have not exhaustively examined polluting sources, focusing on the effects of industries and factories, garbage, as well as human and animal waste (Grbčić *et al*. 2022; Li *et al.* 2019). One of the benefits of this study is the exhaustive and multidimensional examination of polluting sources and the provision of suitable solutions. The investigation of a 60-km section of Euphrates River and using a single numerical model to conduct investigations are among the limitations of this study. In addition, the water quality standards presented in this study are general and not species-specific.

CONCLUSION

Due to their proximity to human activities, rivers, one of the natural resources, are subject to high pollution. In this study, the entire process of river water quality management was conducted to identify and control river pollution in 2021 to ensure the Euphrates River water quality for aquatic life. Due to its ecological significance, diversity of aquatic life, the urban and rural water supply, contribution to agricultural and industrial water consumption, the excessive discharge of pollutants, and poor water quality, the lower Euphrates was selected as the study area. Maintaining the quantity and quality of water flow in the river downstream stations positively affects the river-fed wetland ecosystems, protecting the diverse aquatic animal species in the region. This study revealed that the pollution of nutrients and organic carbon materials resulted in unfavorable water quality conditions for aquatic species during certain seasons and in some river regions. During various times of the year, the amount of pollution (types of nutrients) entering the river from wastes and garbage accumulated on the riverbanks accounts for a significant portion. By implementing control measures from the defined source at different times of the year, it is possible to provide favorable water quality conditions for aquatic life without requiring any structural or hydrology- and morphology-related alterations to the river. The findings of this study can be used to implement water quality controls at the optimal time and location to influence the Euphrates River general state. For future research, it is suggested that the requirements of different habitats for the indicator species of the river at its various distances be investigated, in addition to the evaluation of measures to provide suitable habitats for aquatic animals. It is suggested that the dam reservoirs effects on the river water quality be evaluated and modeled using different models and the results compared together.

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