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Hydrodynamic and pollutant distribution in the Euphrates River under the impact of extreme flow conditions using numerical analysis and parameter calibration

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ABSTRACT

This research is used to study the quality of water of the Kufa River, a branch of the Euphrates River, which flows through the Najaf city in Iraq. The Kufa River receives several point sources of pollution along the river. In order to protect the river from the pollution that leads to destroying the environment of the river, it is necessary to model the quality of the Kufa River's water for studying the variations of the water quality parameters and understanding the transport of pollution within the river. The created model is used to manage the flow operation in minimum and maximum conditions, especially for the current time, with the decline in the water resources. To develop the water quality model, MIKE 11 was used to simulate the water quality parameters such as biochemical oxygen demand (BOD), dissolved oxygen (DO), total dissolved solids (TDS), and phosphate (PO_4). The developed model was calibrated for 2023 and validated for 2024, using observed water levels and measured water quality collected for this study. The developed hydrodynamic and water-quality model shows a good match between observed and simulated water-quality parameters, with a correlation coefficient exceeding 80%. Using the calibrated model, three proposed scenarios were introduced to study the flow operation and manage the Kufa River. The two-way ANOVA results indicate a significant difference among the flow operation scenarios and the t-test results show a significant difference between the sites in the scenarios, especially for TDS and PO_4.

Keywords: ANOVA, Euphrates River, Kufa River, hydrodynamic of river flow, MIKE 11 ECO Lab, pollution dispersion.

INTRODUCTION

Two of Iraq's most urgent environmental issues are river pollution and water scarcity, particularly in southern Iraq, where water supplies are running low and water quality is rapidly declining. One of the main sources of freshwater in southern Iraq is the Kufa River, a branch of the Euphrates River that passes through the Najaf Directorate (Al Sharifi et al., 2024). It is used for industrial, agricultural, and drinking water purposes. However, as demand for freshwater resources rises to accommodate a growing population, the Kufa River has deteriorated over the past few decades due to reduced water supply and increased pollution from human activities (Al-Ansari et al., 2014).

The water resources of the Euphrates River are declining due to dams being built upstream in Turkey, poor irrigation systems, population growth, and the effects of global warming (Al-saadi, 2021). All this effect lead to big change in the amount of water in the rivers (UN-ESCWA and BGR, 2013). The average discharge of the Euphrates River from 1933 to 1972 was 30.26 billion m3, while the average discharge from 1973 to 1989 was 23.59 billion m^3. It has dropped by 44.1% in recent years, to an average of 16.90 billion m3 (from 1990 to 2014) (JICA, 2016). Al-Ansari (2013) shows that water demand is predicted to range from 66.8 to 77 billion cubic meters (BCM), while supply is estimated at 43 BCM in 2015 and 17.61 BCM in 2025 (Al-Ansari, 2013). In addition to this problem of scarcity, the Kufa

River is becoming increasingly polluted due to the direct discharge of untreated municipal wastewater, agricultural runoff, and industrial effluents along its banks (Kashkool and Obead, 2025). These sources cause a high level of heavy metals, such as cadmium, to enter the Kufa River, leading to deterioration in its water quality (Kamel et al., 2022). Inadequate wastewater treatment facilities also play a significant role in the decline of water quality in most Iraqi cities. Regrettably, almost all the drains collect substantial amounts of untreated residential wastewater and discharge it directly into the Kufa River, negatively impacting its water quality (Silva and Hatoum, 2005). For these two challenges, quantity and quality of the Kufa River, there is an urgent need for an integrated model of water quality management using MIKE11, developed by the Danish Hydraulic Institute (DHI). Mike 11 EcoLab is a one-dimensional hydrodynamic and water-quality modelling software used to simulate river flow, pollutant transport, and interactions between waterways. MIKE 11 has a lot of simulation models. The hydrodynamic model, the advection-dispersion model, and the EcoLab model were selected for this study (DHI, 2014).

The water quality of the Kufa River has been assessed in previous studies, which compared its water quality characteristics with corresponding standards (Abdulmuttaleb, 2012; Hussein et al., 2020). Prior research indicates that the water quality of the Kufa River has deteriorated, with numerous studies revealing that the examined parameters exceed their respective standards. These studies utilised data from only two stations, which were either located adjacent to or downstream from the study reach. In contrast to this study, seven sites were sampled and their chemical characteristics were analysed. The parameters investigated are used to build Mike 11 EcoLab.

Another study evaluated water quality using various water quality indices (Al Sharifi et al., 2024; Alanbari et al., 2017; Kamel et al., 2022; Kareem et al., 2021; Kashkool and Obead, 2025). Kareem et al. (2021) conducted an extensive assessment of the quality of water in a branch of the Euphrates, the Kufa River, by using three water quality indices. The results revealed phosphate as a primary parameter affecting index performance, showing significant changes in water quality classification based on its inclusion in the analysis, and indicating poor water quality.

Water quality models are often used to predict and manage the water quality of the Euphrates River (Abidalla and Abed, 2025; Al-Dalimy and Al-Zubaidi, 2023; AL-Thamiry and Haider, 2013). Abidalla and Abed (2025) applied the QUAL2KW model to simulate the quality of water for a study reach from the Euphrates River, west of Iraq, and used it to predict water quality parameters at any point along the River (Abidalla and Abed, 2025). In 2013, HEC-RAS Software was used to simulate the salinity of the Euphrates River in another study that reached Ashshinnafiyah and Assamawa cities. Several scenarios were simulated in the developed model to reduce salinity in the River (AL-Thamiry and Haider, 2013). Previous studies were conducted in another part of the Euphrates River, but not in the Kufa River.

Several researchers have developed a water quality model by using MIKE 11 (Assar et al., 2020; Girbaciu et al., 2016; Holguin-Gonzalez et al., 2013; Huang et al., 2024; Karaer et al., 2018; Khwairakpam et al., 2019; Liang et al., 2015; Minh et al., 2022; Yi et al., 2017). MIKE 11 has never been used to simulate the Kufa River; however, there are limited studies that have utilised it to simulate the Euphrates River in another study reach (Kamel, 2008; Saad & Khayyun, 2024). Another study used MIKE 11 to simulate the impact of low discharge on the water quality of the Shatt Al-Arab River (Al-Fartusi, 2021; Lafta et al., 2013). Most studies have only assessed the water quality characteristics of the Kufa River, and there are no studies that have investigated its water quality model and management. Therefore, the novelty of the research is in developing an accurate management model for the Kufa River, considering future risks associated with bridge construction in Turkey, increasing pollution, and the demand for freshwater. The present research aims to analyse the river hydrodynamics and pollutant dispersion under the influence of extreme operating scenarios (flood and dry state) obtained from frequency analysis of the Kufa River flow data for the period from 2004 to 2024, based on calibration models of flow parameters and pollutant dispersion from their real sources on the river reach to evaluate the river condition.

METHODOLOGY

Study Area

The Kufa River is one of two branches that flow through the Al-Najaf Governorate. The study reach extends 42.5 km from the downstream of the Kufa dam to the upstream of the Aboskhir regulator, as shown in Figure 1. It gets a significant amount of untreated domestic sewage, which contributes to the decline of the river's water quality. The study area includes six pollution sources, one of which is the Barakiya wastewater treatment plant (S5), the Alboshkair domestic pipe (S4), and five drains: Al-Kufa Northern drain (S2), Albohedary drain (S3), Al-Kufa Southern drain (S6), and Albakriya drain (S7). The Albarakiya treatment plant receives 100,000 m³/day of domestic sewage, and approximately 65,000 m³/day is discharged directly into the Kufa River without prior treatment. One reason for considering this part of the Kufa River is the study area's characteristics, which are influenced by various sources of pollution along the study reach. The Kufa River is primarily used for drinking purposes, with water intake stations located within the study area for some towns. The methodology chart for the hydrodynamic and water quality model development process, along with the two enhancements for the Kufa River using the calibrated model, is shown in Figure 2.

Research data

The data used in this research were obtained from several sources, such as the Ministry of Water Resources (Water Resources Directorate in Najaf) and the Ministry of Environment (General Directorate of Environment in Najaf). Daily observed discharges were recorded at the Kufa regulator as upstream boundary conditions. Daily observed water levels were measured at Abosakhir Regulator as downstream boundary conditions. The daily water surface profile levels from two stations, Kufa and Manathera, were used for calibration and verification in 2023 and 2024, respectively. Water quality records, including TDS, BOD, DO, and PO_4, were collected at seven stations in March 2023 and August 2024 for calibration and validation, respectively. In this study, seven sampling sites along the Kufa River were investigated to examine the model of the effects of point-source pollution discharging directly into it. Twenty-two water samples were collected at the same point source, before and after the point, to make a better idea of the river's state (Kashkool and Obead, 2025). These samples were obtained in the winter and summer of 2024, specifically at two-month intervals. Clean bottles were used to collect samples, which were then transported to the lab to measure the water quality parameters. This study used total dissolved solids (TDS), biochemical oxygen demand (BOD), dissolved oxygen (DO), and phosphate (PO_4) as the main water quality indicators that were simulated and modelled.

Hydrodynamic and pollutant distribution models

MIKE is a software tool developed by the Danish Hydraulic Institute (DHI) that includes numerous models for practical study, modelling, and simulation of rivers, lakes, estuaries, and coastal systems. It is used here to simulate the integrated modelling of flow and pollution dispersion in the Kufa River. It comprises three models: hydrodynamic (HD), advection dispersion (AD), and ecological (EcoLab) models. The HD is a one-dimensional, unstable, non-uniform flow simulation model that can simulate water surface levels, discharge, and wastewater effluent. The EcoLab module (WQ module), on the other hand, shows how pollutants move and spread over time in streams or channels. The hydrodynamic model solves the Saint-Venant equations using the finite differences approach, which incorporates fluid continuity and momentum conservation, as demonstrated in Equations 1 and 2. It uses the Abbott-Ionescu six-point implicit difference method to find the water surface level (h) and the flow rates (Q) that go with it. (Danish Hydraulic Institute, 2014).

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial \left(\alpha \frac{Q^2}{A}\right)}{\partial x} + gA\frac{\partial h}{\partial x} + \\ + \frac{n^2 gQ|Q|}{AR^{2/3}} = 0 \tag{2}$$

where: Q represents the discharge (m³/s), A is the cross-sectional area of the flow (m²), and x represents the distance in the flow direction (m). In contrast, t denotes the time, q represents the lateral flow discharge (m/s), h means the river water level, g is the gravitational acceleration (m²/s), n Manning resistance coefficient ($m^{1/3}$/s), R is the hydraulic radius (m), and α is the momentum correction coefficient.

Contamination transportation is simulated using the AD model, which employs the one-dimensional

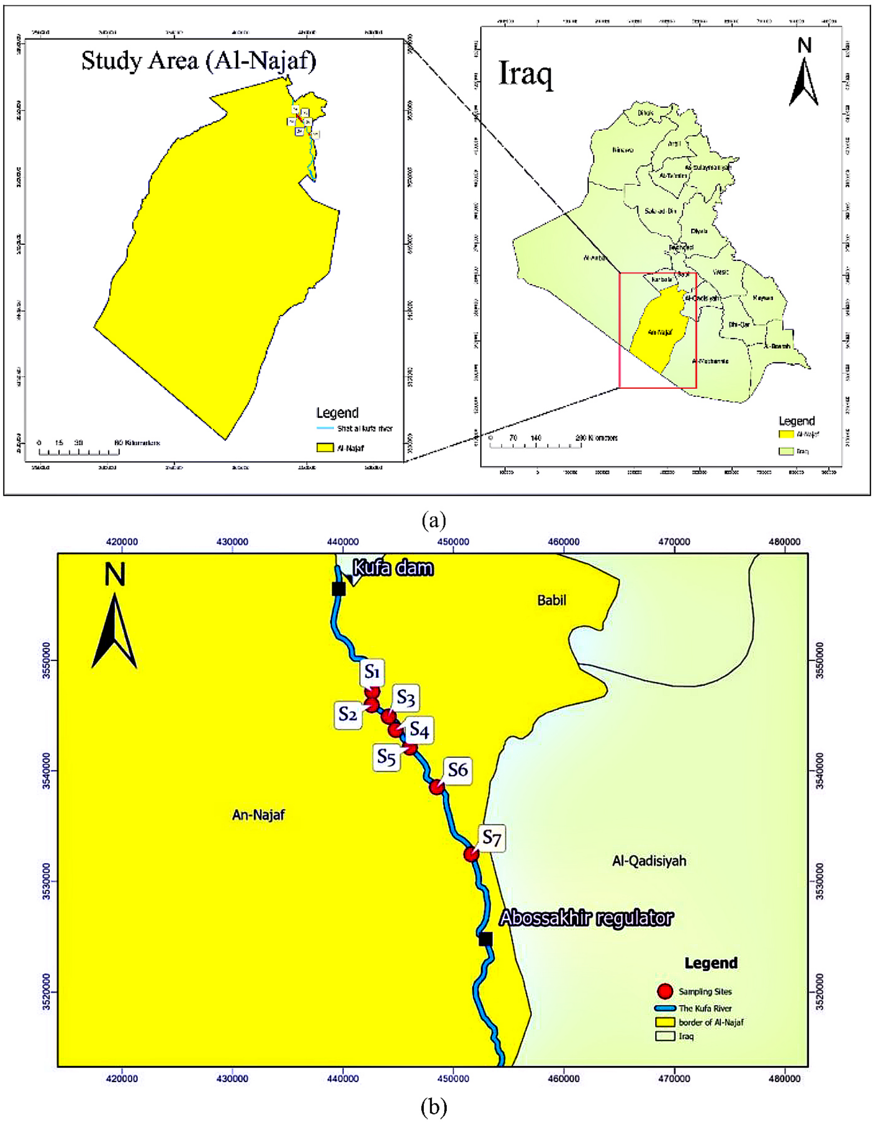


Figure 1. (a) Map of Iraq and the Najaf province; (b) the Kufa River with its upstream, downstream boundaries, and the sampling sites (Kashkool and Obead, 2025)

mass-conservative equation for dissolved and suspended materials as expressed in Equation 3. The AD module requires the results of the HD module, including discharge and water (DHI, 2014).

$$\frac{\partial AC}{\partial t} + \frac{\partial QC}{\partial x} - \frac{\partial}{\partial x}\left(AD\frac{\partial A}{\partial x}\right) = = -AKC + C_2 q \quad (3)$$

where: C is the concentration of the water quality parameters (mg/l), D is the coefficient of dispersion (m^2/s), A is the section area of the flow, K represents the coefficients of linear decay, $C2$ is the source or sink concentration, x is the spatial coordinates, and t is the time coordinates.

The EcoLab model is integrated with the AD model. Pollutant change in the river is the focus of EcoLab models, whereas the AD model simulates the transit process. The water level and discharge were simulated using the hydraulic model. Total dissolved solids (TDS) are modelled in the advection-dispersion model, while the biochemical oxygen demand (BOD) and dissolved oxygen (DO) are simulated in the AD and EcoLab models. Table 1 shows the details of using MIKE 11 in the development of the hydrodynamic and water quality model.

Model development

The surface water quality of the Kufa River was simulated using MIKE 11, which integrates hydrodynamic (HD), advection-dispersion (AD), and EcoLab models. The input files for the

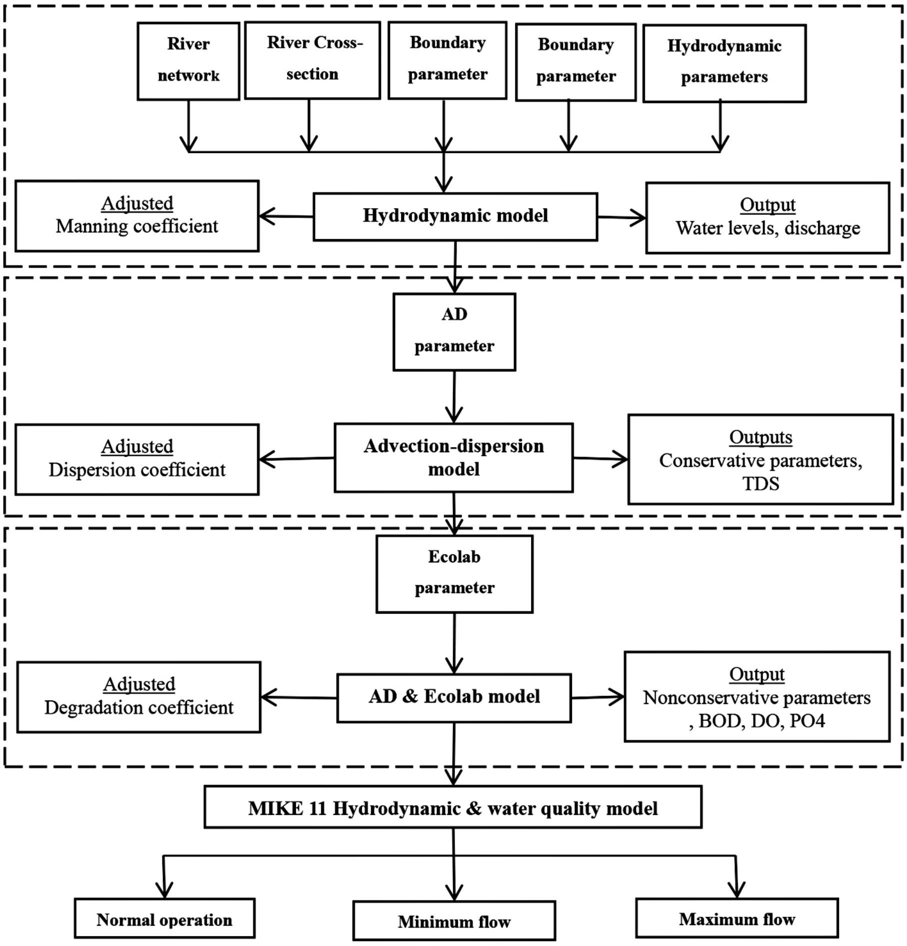


Figure 2. Flowchart of the hydrodynamic and water quality model and research methodology

Table 1. Type of model, boundary data, adjusted coefficients, and output

Model's type	Input data	Adjusted coefficient	Output
Hydrodynamic	Discharge at upstream BC and Water levels at the downstream BC	Manning coefficient	Water velocity, discharge, and water levels
AD	TDS	Dispersion coefficient	Simulated TDS
EcoLab	BOD, DO, PO_4	Degradation: first-order decay rate at 20 °C	Simulated BOD, DO, and PO_4

hydrodynamic model primarily consist of the river network, river cross-sections, boundary condition data, hydrodynamic parameters, and simulation files. Since the hydrodynamic model served as the basis for the EcoLab model, the files containing the advection-dispersion parameters and the EcoLab parameters must be adjusted to the hydrodynamic model for this study. The cross-section of the Kufa River was measured at thirty locations, which were used as input in the MIKE 11 EcoLab to simulate the river topography, as shown in Figure 3.

This research modelled the 42.5 km length of the Kufa River, incorporating two structures: the Kufa Dam and the Abosakhir regulator, as well as three bridges along the river reach. To ensure numerical computation stability and maintain the Courant number within the intended range of the model, the simulation time step was chosen to be 5 seconds (DHI, 2014). The purpose of the constructed water quality model was to model DO, BOD, TDS, and PO_4. The EcoLab model's integrated solution employed the Euler integration method (DHI, 2014).

Calibration and validation processes

The Kufa River HD model was calibrated using March 2023 water level data and validated using

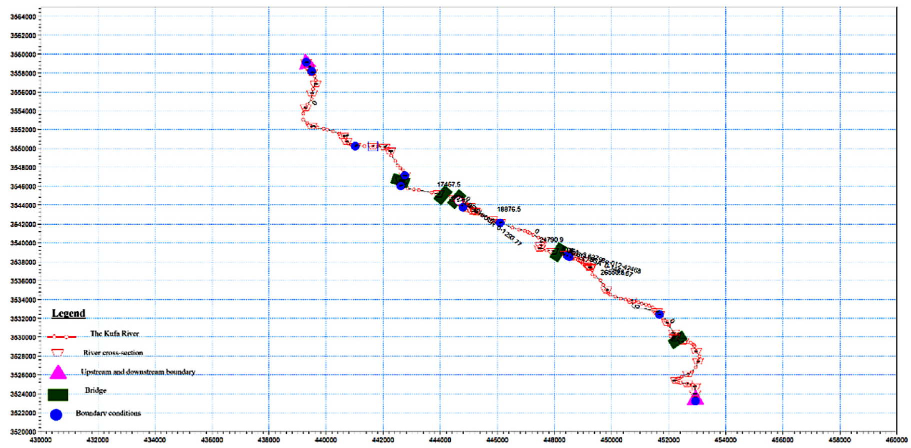


Figure 3. Network of the Kufa River used in the hydrodynamic and water quality model

August 2024 data at Kufa and Manathera stations. Model calibration and validation were conducted by adjusting parameters such as the coefficient of dispersion (D) for the AD module and Manning's roughness coefficient (n) for the Hydrodynamic module. Additionally, EcoLab parameters like the degradation coefficient were adjusted using a trial-and-error procedure to match the observed data. Model performance was evaluated using the correlation coefficient (R^2), Root Mean Square Error (RMSE), and RMSE-observation standard deviation ratio (RSR). After calibrating the HD MIKE 11 model, it was coupled with AD and EcoLab modules, which were further calibrated and validated for better performance according to efficiency criteria (R, RMSE) as recommended by (Moriasi et al., 2007; Khalilzadeh Poshtegal and Mirbagheri, 2023; Khwairakpam et al., 2018; Liu et al., 2022)

Extreme flow conditions

Three main scenarios were adopted to simulate different river conditions:

Normal river flow

This scenario reflects the current state of the Kufa River. The water quality for the given status was assessed along the Kufa River. The simulated water quality parameters of the Kufa River, including TDS, BOD, DO, and PO_4 for the periods March 2023 and August 2024, represent the main parameters in the normal operation flow.

Minimum river flow

The minimum river flow in the Kufa River is found to follow a three-parameter Weibull distribution. It represents the second scenario used in the developed water quality model.

The PDF(x) for this distribution is expressed by Equation 4:

$$PDF(x) = \left(\frac{37.057}{1.725}\right)\left(\frac{x - 28.706}{1.725}\right)^{(36.057)} exp\left[-\left(\frac{x - 28.706}{1.725}\right)^{37.057}\right] \quad (4)$$

where: x is the minimum discharge event (m^3/sec).

The findings of frequency analysis for various return periods (T) are given in Table 2 for the minimum river flow. Therefore, the minimum discharge for a return period of 50 years is 30.495 m^3/s.

Maximum river flow

The maximum river flow of the Kufa River follows the two-parameter Weibull distribution, which characterises the probabilistic behaviour of extreme values and estimates the probability of exceeding them. The probability density function (PDF) illustrates the relative likelihood of the occurrence of maximum events (as river discharge). It is shown in Equation 5:

$$PDF(x) = \left(\frac{3.894}{171.301}\right)\left(\frac{x}{171.301}\right)^{(3.894-1)} exp\left[-\left(\frac{x}{171.301}\right)^{3.894}\right] \quad (5)$$

where: x is the maximum discharge event (m^3/sec).

Table 3 presents the findings of frequency analysis utilising the Weibull (2) distribution for various return periods (T). So, the maximum discharge of the Kufa River for a return period of 50 years is 243.159 m^3/s. It represents the third

Table 2. Outline of the frequency findings derived from the Weibull (3) distribution

Return period T (years)	Discharge, x_T (m^3/s)	Exceedance probability $P(X>x_T)$
2	30.414	0.50
5	30.453	0.20
10	30.470	0.10
15	30.478	0.067
25	30.486	0.040
50	30.495	0.020

scenario applied to the developed model for managing the water quality of the Kufa River.

Contaminants with high concentrations posing environmental risks, including TDS, BOD, and PO_4^{3-}, were selected and calibrated in the MIKE 11 model to assess organic, agricultural, and sewage pollution at stations such as S3 and S5. The study evaluated normal, minimum, and maximum operation scenarios using ANOVA and paired t-tests to determine the statistical significance of changes in water quality parameters and to identify the stations along the river reach most affected by different management scenarios. Analysis was performed using Excel.

Table 3. Outline of frequency analysis findings derived from the Weibull (2) distribution

Return period T (years)	Discharge, x_T (m^3/s)	Exceedance probability $P(X>x_T)$
2	155.913	0.50
5	193.568	0.20
10	212.216	0.10
15	221.242	0.067
25	231.281	0.04
50	243.159	0.02

RESULTS

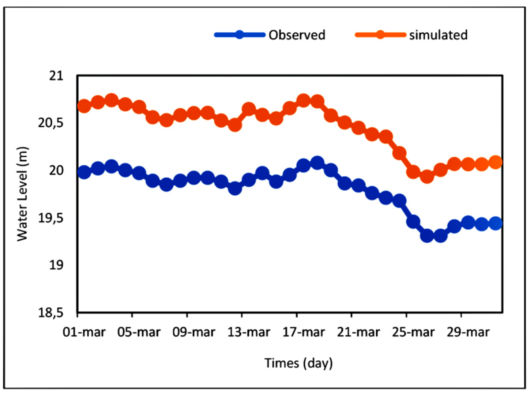
Hydrodynamic model calibration and validation results

In the calibration and validation process, Manning's roughness coefficient (n) for the Kufa River was determined to be 0.0245 $m^{1/3}/s$. The Hydrograph of the simulated and observed water levels is shown in Figure 4. Table 4 displays the accuracy of the hydrodynamic model. The results indicate that the model performs well. Additionally, Figure 5 shows that the simulated results closely match the observed results at the calibration points. The 2023 calibration performance is better than the 2024 validation.

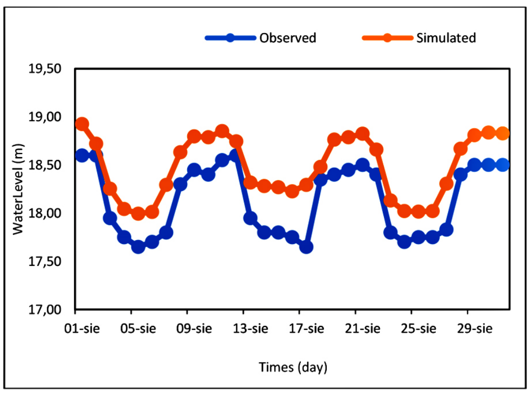
Figure 5 illustrates the high degree of agreement between the two stations' simulated and actual water levels. The results suggest that the created hydrodynamic module performs well and can be used for further simulation activities and management scenarios.

Advection-dispersion model results

The Mike 11 AD model simulates the transport of conservative components, such as TDS, which is selected for modelling during the calibration periods (the wet season in March 2023 and the dry season in August 2024). Figure 6 (a) shows the observed and simulated TDS profiles during the two seasons at the considered stations. In the calibration process, the dispersion coefficient was



(a)



(b)

Figure 4. Comparison of observed and simulated water levels at two stations for the period (a) March 2023 for calibration and (b) August 2024 for validation

Table 4. Evaluation criteria for the daily observed and simulated surface water levels of the Kufa and Manathera stations along the Kufa River

Statistics	Kufa station	Manathera station
	March 2023	August 2024
R^2	0.965	0.920
RMSE	0.655	0.354
RSR	2.772	0.976

shown to range from 50 and 100. Figure 6 (a) illustrates the TDS concentration. The coefficient of correlation ranges from 0.8 to 0.89 for TDS, while root mean square error (RMSE) varies from 27.5 to 120.1 mg/l.

Water quality model results

Ecolab was calibrated with March 2023 data and validated with August 2024 data to ensure agreement between observed and simulated WQ parameters, and the degradation coefficient is found to be 1.0 per day. Statistical analysis was performed at S1, S2, S5, and S6 along the 42.5 km Kufa River reach. The calibration results indicated satisfactory accuracy for simulating water quality. Figure 6 shows the observed versus simulated TDS, BOD, DO, and PO_4 values for 2023. Table 5 presents a statistical evaluation of the Kufa River's water quality parameters during the calibration period in the wet season, including TDS, BOD, DO, and PO_4. The assessment of BOD is shown in Table 5. R^2 ranges from 0.82 to 0.92. At the same time, RMSE varies from 0.799 to 1.071.

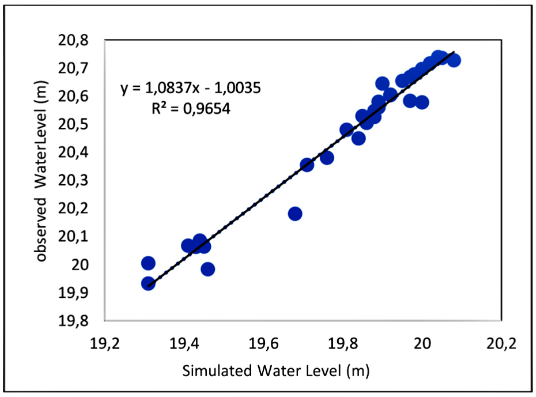
In the same way, the statistical measures for DO are explained in Table 5, with R^2 ranging from 0.82 to 0.100 and RMSE ranging from 1.0910 to 2.549. The evaluation of PO_4 ranges from 0.76 to 0.99, and RMSE varies from 1.35 to 3.51. Higher values indicate greater accuracy of the model and less modelling error.

Extreme flow conditions results

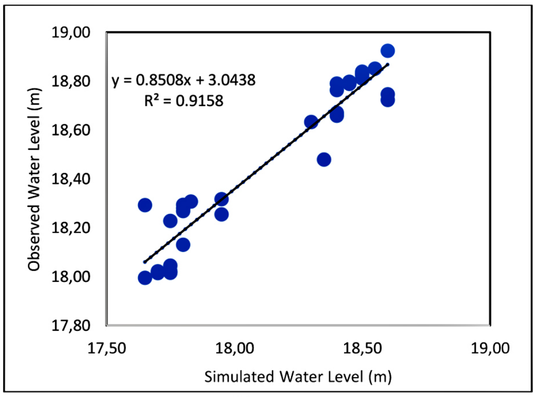
Three management scenarios (Figure 2) were applied, using the calibrated Kufa River model. Four water quality parameters, including TDS, BOD, DO, and PO_4, were used as management key indicators. The results of the scenarios application are presented in Figure 7. In the minimum flow operation scenarios, the decline in water amount of the Kufa River has significantly impacted its water quality, as illustrated in Figure 7. The TDS concentrations increased with the decline in the amount of the Kufa River, as shown in Figure 7 (a). The BOD findings of the Kufa River substantially increased due to the decline in the freshwater quantity (Figure 7 (b)). The DO levels significantly decreased with decreases in freshwater quantity, as shown in Figure 7 (c). When the flow of the Kufa River is decreased in the minimum flow operation, the concentration of the PO_4 increased as declared in Figure 7(d). On the other hand, when the amount of water is increased in the maximum flow operation scenario, the quality of water is improved as indicated by the reduction of TDS concentrations (Figure 7(a)), decreased BOD levels, increased BOD concentrations, and PO_4 concentrations.

Interpretation of the ANOVA test

A two-factor analysis of variance (ANOVA) is conducted on the mean matrix for the 22 river



(a)



(b)

Figure 5. Correlation plots between the observed and simulated water levels for the periods (a) March 2023, (b) August 2024

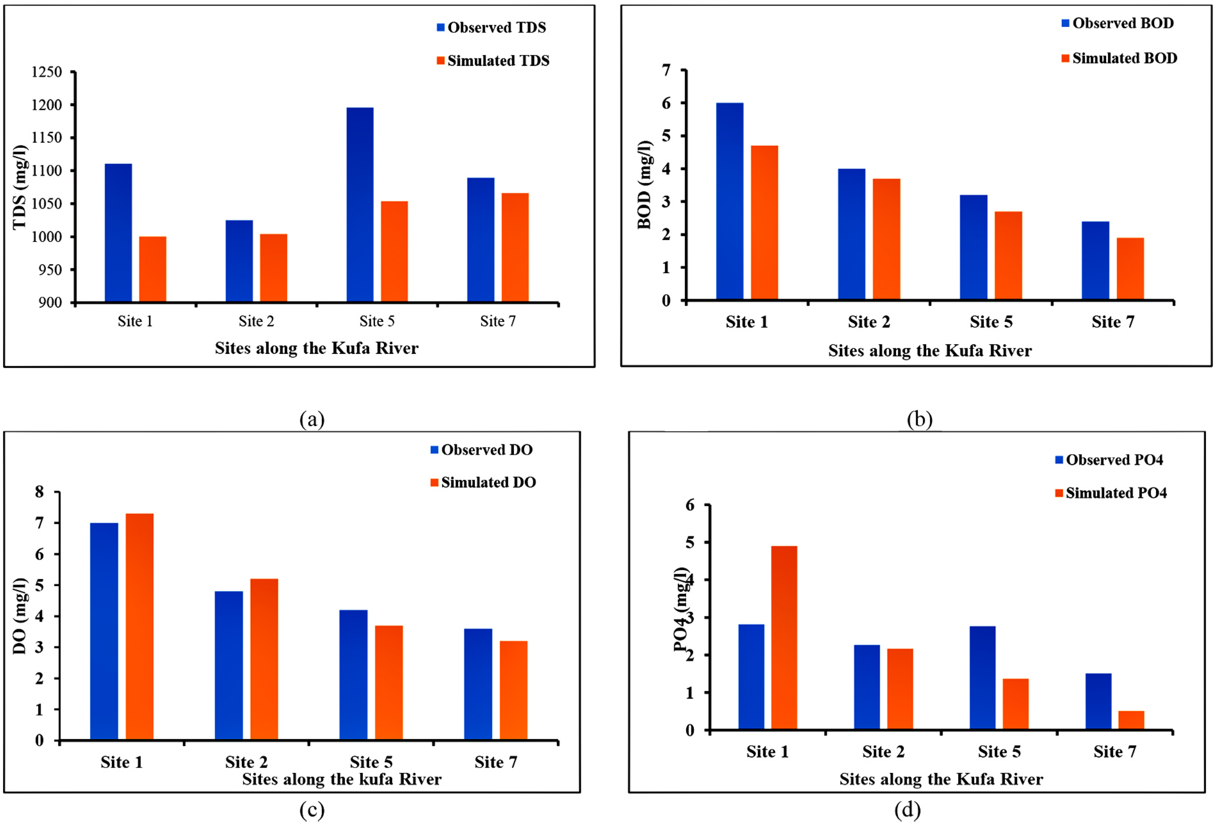
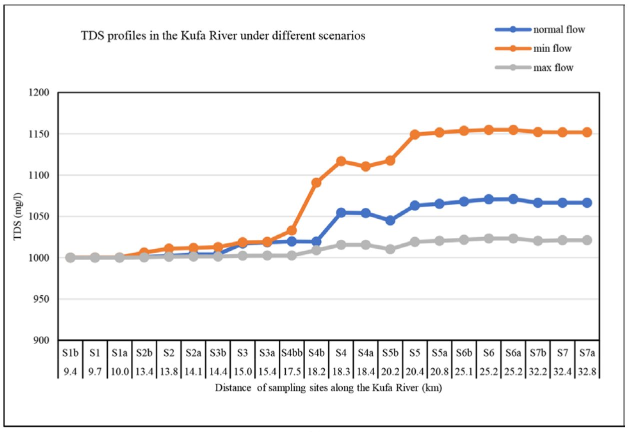


Figure 6. Calibration results of water quality parameters at the four sites within the study reach for the period March 2023 of (a)TDS; (b)BOD; (c)DO; (d) PO_4

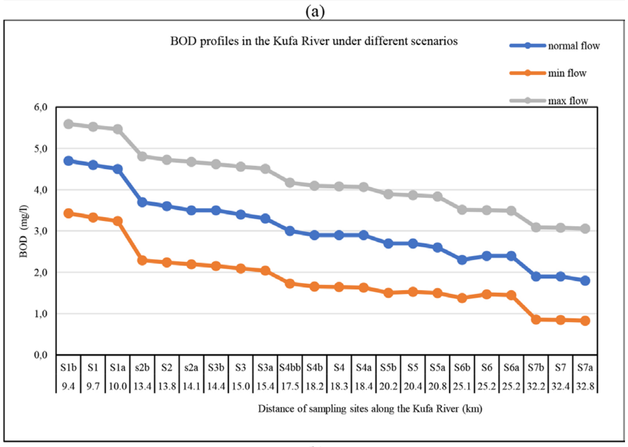
Table 5. Statistical analysis of the calibrated model for the water quality parameters for the Kufa River during the calibrated period

Sites	Statistics	TDS	BOD	DO	PO_4
S1	R^2	0.84	0.83	0.96	0.82
	RMSE	112.2	1.036	2.217	3.51
	RSR	2.088	1.050	2.663	4.20
S2	R^2	0.80	0.83	0.94	0.76
	RMSE	133.4	0.779	2.549	1.35
	RSR	1.651	0.789	2.549	13.21
S5	R^2	0.89	0.92	0.82	0.99
	RMSE	120.085	0.804	1.910	1.36
	RSR	2.296	0.966	4.633	2.61
S7	R^2	0.84	0.82	0.100	0.70
	RMSE	27.504	1.071	1.974	1.89
	RSR	0.640	1.325	1.924	2.56

sites across three operating scenarios (Normal, Maximum, and Minimum) to explain variation in water quality parameters among stations. The analysis revealed a significant spatial effect between sites ($F(21, 42) = 4.38$, $p = 2.32 \times 10^{-5}$) and a strong effect of scenarios on TDS concentrations ($F(2, 42) = 31.81$, $p = 3.89 \times 10^{-9}$), with MS_Error = 754.86 and MS_Error = 754.86. While for the DO parameters test, the analysis revealed significant spatial differences between sites ($F(21,42) = 10.21$, $p = 1.6 \times 10^{-10}$) and a strong effect of scenarios on DO concentrations ($F(2,42) = 146.5$, $p = 1.16 \times 10^{-19}$. As well as in the test of BOD parametrs, the analysis revealed a



(a)



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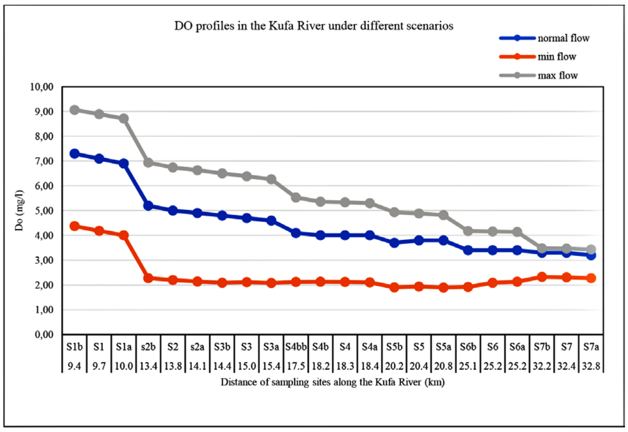
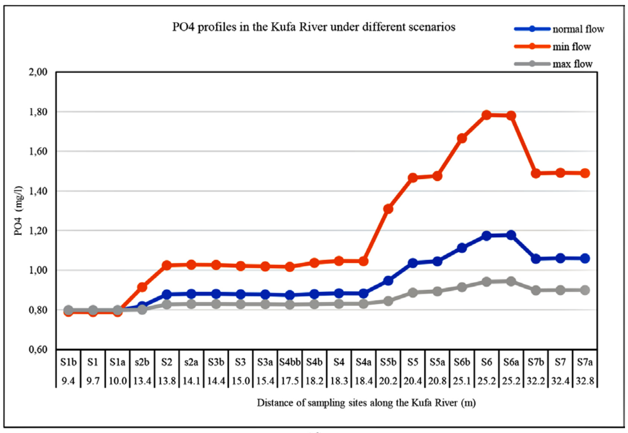


(c)



(d)

Figure 7. Water quality Profiles in the polluted river reach for different scenarios in terms of (a) TDS; (b) BOD; (c) DO; and (d) PO_4

significant spatial effect between sites ($F(21, 42) = 10.21$, $p = 1.6\times 10^{-10}$) and a substantial impact of scenarios on TDS concentrations ($F(2, 42) = 146.49$, $p = 1.16\times 10^{-9}$), with MS_Error = 754.86 and MS_Error = 754.86. In contrast to the phosphate parameters, the analysis revealed significant spatial differences between sites ($F(21,42) = 4.37$, $p = 2.38\times 10^{-5}$) and a strong effect of scenarios on PO_4 concentrations ($F(2,42) = 43.17$, $p = 6.49 \times 10^{-11}$). These results indicate that both site and flow scenarios contribute significantly to TDS, BOD, DO, and PO_4 fluctuations across the river reach, with a general trend of Minimum < Normal < Maximum.

Interpretation of the paired t-test

A paired t-test is applied to the results of the three scenarios. The results of the t-test on the TDS parameter indicate that the change of the scenario from normal river flow to minimum river flow has a significant difference on the S1 with a p-value of 0.95. In contrast, for Maximum river flow, S3 has a significant difference with a p-value of 0.29. When the t-test is applied to the BOD findings, the results indicate that there is no significant difference on the site for the three scenarios. The three scenarios' final results are subjected to a paired t-test. With a p-value of 0.01, the t-test findings on the DO parameter show that the scenario change from normal river flow to maximum river flow has a substantial impact on the S1. In contrast to the minimum river flow, there is no difference in scenarios at the sampling sites. Finally, the PO_4 findings for the three scenarios indicate that the T-test results show a significant difference for all the sites.

CONCLUSIONS

The Kufa River serves as the main source of the freshwater that is used for drinking water and irrigation purposes in the neighboring region as the river passes. The Kufa River is affected by two pollution, considered the wastewater treatment plants and irrigation drainage discharged directly into the Kufa River. These factors lead to deterioration of the water quality. So the main objective is to develop the management framework for the water quality. Mike 11 software is used to develop the Hydrodynamic and water quality model as the main analytical tool. The resulting developed model was calibrated and validated. The results show a good match with the correlation coefficients for the calibration of the hydrodynamic model during March 2023 was 96.5%, while the correlation coefficient of the validation during August 2024 was 92%. The calibration of the water quality model has a good match with a correlation coefficient above 80%. The development model used for the water quality management scenarios of the Kufa River for the current state of the river, minimum flow operation, and maximum flow operation. The finding shows that the minimum flow operation scenario led to a decrease in DO levels; at the same time, TDS, BOD, and PO_4 concentrations increased, leading to more worsen of the Kufa River due to the decline in the flow and water levels of the river. The findings of the flow operation scenarios, using the ANOVA test and t-test, show a significant spatial difference between the sampling sites, as well as both the sampling sites and the flow operation scenarios affect the water quality parameters. So the treatment of the wastewater from the point source pollution is necessary to protect the ecosystem of the Kufa River from deterioration. Furthermore, the future recommendations for monitoring the important water quality parameters along the river at the monitoring site.

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