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Assessment and Modelling of Water Quality along Al-Gharraf River (Iraq)

[1]Basim Sh. Abed, [2]Mariam H. Daham, [3]Hayder A. Al-Thamiry

[1]Assistant Professor, Department of Water Resources Engineering, University of Baghdad, Iraq.
E-mail: bassim.shabaa@coeng.uobaghdad.edu.iq
[2]M.Sc. in Water Resources Engineering, University of Baghdad, Iraq
E-mail: maryam.hadi95@gmail.com
[3]Assistant Professor, Department of Water Resources Engineering, University of Baghdad, Iraq.
E-mail: hy_hyder@coeng.uobaghdad.edu.iq

Abstract

Al- Gharraf River is one of the Tigris River branches, it is flowing within Wasit and Dhi Qar Governorates. The river's total length is 230 *km*. It is the main source of water for the cities along it extends. So, the quality of the river needs to be monitored continuously. Accordingly, a water quality model was developed by implementing HEC-RAS software to predict the values of some water quality parameters along Al-Gharraf River during different seasons. The water quality model was calibrated and validated using collected data from previous studies.In the first 58 km of the river and during high flow or wet season, the Carbonaceous Biochemical Oxygen Demand is bounded between 8 to 10 *mg/l* which was considered acceptable, but these values were increased during the low flow or dry season to 11 and 15 *mg/l* and it was not within the standard. While the values of Carbonaceous Biochemical Oxygen Demand for the lower part of the river (from 58 to 230)*km* ranged between 11 to 24 mg/l during the wet season and 15 to 27 *mg/l* during the low discharge season or dry season, for both seasons the Carbonaceous Biochemical Oxygen Demand levels in the lower part of the river were not within the suitable range. The values of Dissolved Oxygen ranged from 7 to 8.2 *mg/l* during the high flow season and 7 to 6 *mg/l* in low flow season. While the values of Nitrate are 4.1 to 4.78 *mg/l* during the high flow period and 5.1 to 7.5 *mg/l* during the low flow period. Moreover,

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the values of Phosphate are ranged from 0.13 to 0.62 *mg/l* during the high flow period and 0.2 to 0.72 *mg/l* during the low flow period. In general, the values of Dissolved Oxygen, Nitrate, and Phosphate were within the allowable limits in all seasons.

Keywords: HEC-RAS Simulation, Water quality, Gharraf River, CBOD, DO, NO_3, PO_4.

1 Introduction

Monitoring and managing the water quality in the rivers is considered a growing challenge nowadays due to the great numbers of the used chemicals daily in our lives. The water quality assessment requires an investigation of the pollution indicators in the stream and management of it by testing the gathered samples from different locations of the river in the laboratory to measure the concentration of parameters and comparing the values of the results with the typical standards to estimate whether the river in these locations is polluted or not. There are different approaches to assess the quality of water in rivers like water quality modeling, which occurs by implementing a model using software, the water quality model predicts the location and the value of pollutants by using mathematical methods like the finite difference method. Taralgatti et al., 2020, developed a Water Quality Model in Bhima River located in India by implementing HEC-RAS software. The length of the study reach was 800 *km* divided into five stations, the samples were gathered at these stations during 2017. The results of WQM showed the water quality of the river was within the acceptable limits**.** (Daham and Abed, 2020) developed a one-dimensional sediment transport model by implementing HEC-RAS software version 5.0.4 for the upper reach of Al-Gharraf River that extended from Kut to Hay City. 13 stations were distributed equally to collect the sediment samples for a period extended from February 2019 to July 2019. First, The hydraulic model was calibrated and the value of Manning roughness in steady-state for the river was 0.026, then the sediment model was calibrated during different periods, after that, the model was simulated to predict the sediment capacity values during different periods for both assumed and real values of flowrates.(Daham and Abed, 2020) developed one and two-dimensional unsteady-state hydraulic models by implementing HEC-RAS software version 5.0.4 in the selected reach of Al- Gharraf River that lies between Kut and Hay City. The hydraulic models were calibrated and validated to estimate the Manning roughness value for the unsteady state in the river, and it was equal to 0.025. (Al-Husseini and Alsalman, 2020) assess the water quality in Al- Gharraf River in Dhi Qar Governorate, the length of the study reach was 59 *km* located between Qalat sukar and Shatrah Town that divided into five stations, the samples were gathered monthly from March 2018 to March 2019. The concentrations of the analyzed samples showed that Al- Gharraf River was polluted in the selected region of the river. (Ewaid *et al*., 2020) assess the water quality index for the Tigris River and its branches using principal component analysis (PCA) and the information of 27 parameters. The WQI was classified as good for Diyala, poor for Al- Gharraf River, and bad for Shatt Al-Arab. (Butler and Ford, 2019) assess the water quality in a mining-influenced watershed in Colorado. 14 stations were distributed along the site to evaluate the TDS and TSS concentrations values, also to develop relationships between total dissolved solids and total suspended solids. (Mohammed, 2018) simulated the one-dimensional hydraulic model by implementing HEC-RAS software version 5.0.3 in the upper reach of Al-Gharraf River. The estimated values of Manning roughness for steady-state were ranged between 0.025 and 0.027 while for unsteady-state were ranged from 0.024 to 0.026.(Mirza and Nashaat, 2018) assess the water quality of Al- Gharraf River in Wasit province, the reach length was 50 *km* divided into five stations with a distance interval equal to 10 *km*, and the water quality samples were collected monthly during 2016.The results of laboratory tests showed that water quality in the river was poor. (Al-dabbas *et al.*, 2018) evaluated Al- Gharraf River Water's ability for different Uses.Seven stations were selected to collect samples along the river near the important cities for both the wet and dry seasons of 2017. The laboratory results showed the high concentrations of hardness due to the sewage discharge into Al-Gharraf River in these seven stations. (Ewaid and Abed, 2017)evaluated the water quality index for Al- Gharraf River by collecting 11 parameters from the selected five-station that distributed along the river during 2015. Overall the WQI for Al- Gharraf River was classified as poor (Ewaid, 2017) assess the water quality of Al- Gharraf River by gathering samples at 10 stations distributed along the river during the year 2015. The CBOD annual values for the first three stations located between Kut and Hay City were within the standard, while these values for the last seven stations were not within the criteria values during both seasons. The DO values, PO4, and NO3 values were within the accepted limits of Iraqi standards for river health. (Ewaid, 2016) evaluated the WQI for Al- Gharraf River using data of 17 parameters gathered from the selected five stations spread along the river during 2013-2014. The water of Al- Gharraf River was poor for drinking and aquatic life and fair for irrigation. (Maatooq *et al.*,2016) developed an empirical formula for estimating sediment rate using the SPSS program in Al-Gharraf River for the reach located between Al-Nasar City and Badaa Regulator. The length of the study reach was 14 *km* that divided into 13 stations, at each station the required information was gathered. (Hubert and Wolkersdorfer, 2015) evaluated the water quality of mine waters in South African. The conversion factor was established between electrical conductivity and total dissolved solids by using the data of 45 water quality samples collected from 2000 to 2013[1-14].

The present research aims at assessing the water quality in Al- Gharraf River by calculating the values of CBOD, DO, PO_4, and NO_3 during different periods, which occurs by comparing these values with measured values for the accuracy of the implemented HEC-RAS model.

2 Study Area

Al- Gharraf River is one of the greatest branches of Tigris River, it extends from Wasit province to Dhi Qar Governorate with a total length equal to 230 km, the width and the depth of the river ranged from (50 to 200) *m* and (3 to 7) *m* respectively. Al- Gharraf River is an essential source of water for the cities located in the south of Iraq, the operation flowrate varied from 300 m^3/s at Gharraf Head Regulator to 45 m^3/s at Badaa Regulator. The length of the study reach begins upstream of the river near Kut City and ends downstream of the river near Gharraf City, the total length of Al-Gharraf River was divided into ten stations distributed at the important cities, Figure1 shows the layout of the river. The first three stations are located in the upper reach between Al Kut and Hay Cities, the fourth to sixth stations are located near Al-Fajr City, Qalat sukar City, and Rifai City respectively. The seventh to the tenth stations are located near Al Naser City, Badaa Head Regulator, Shatrah City, and Gharraf Town, respectively.

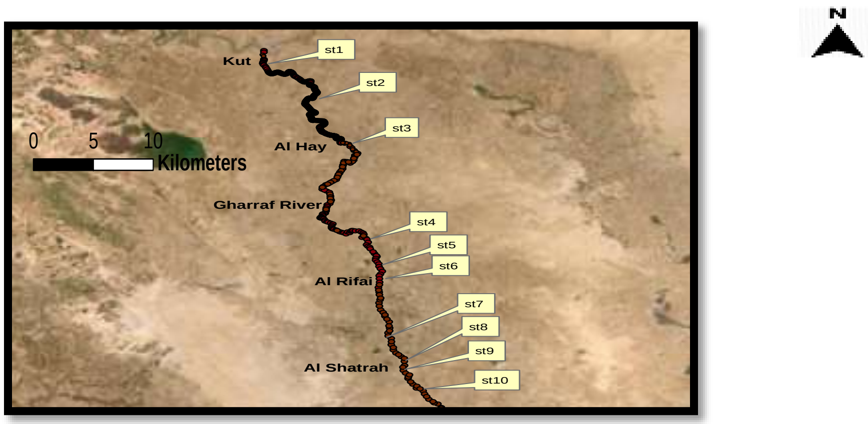


Figure 1 Selected Stations Along With Al- Gharraf River using Arcmap (10.2)

3 Water Quality Model

The water quality model (WQM) development requires information on geometry data, hydraulic data, and water quality data. In this study, the WQM was simulated by implementing HEC-RAS software version 5.0.4. The Hydrologic Engineering Center's /River Analysis System, HEC-RAS, was developed to serve the United States Army Corps of Engineers, and it was upgraded in 2016 to simulate One and Two-dimensional flow calculations. This section will describe the material data and used methods to develop WQM[15].

3.1 Geometry Data

The simulation of the one-dimensional hydraulic model needs the geometric data of Al-Gharraf River within the study area. The data include the coordinate data of the river and the data of the available cross-sections, in this study 46 cross-sections were distributed along the river with distance interval of 1 to 5 *km*, the survey data of cross-sections were measured by [16] and [13]**.** Figure 2 shows the one-dimensional river scheme in the geometry window of HEC-RAS software.

3.2 The Steady Flow Data

The flow profile is generated by selecting the type of flow regime and the suitable value of Manning coefficient for the river, also it requires the hydrological data which includes the information of discharge and water levels. The flow regime type in Al-Gharraf River is subcritical flow and the Manning coefficient value for steady-state is equal to 0.026[2]**.** The discharge and water levels data in this study were measured by[16] and [13].

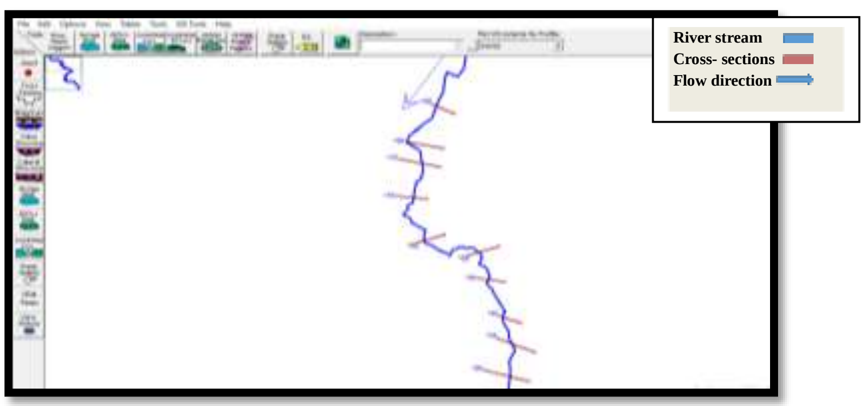


Figure 2 The one-dimensional river scheme in HEC-RAS geometry window

3.3 Water Quality Data

The WQM requires the time-series of the temperature data of the river, chemical nutrient concentration such as CBOD, DO, NO_3, and PO_4, also meteorological data such as (atmospheric pressure, Air Temp., Humidity, Cloudiness, and Wind Speed). In the present study, ten stations were selected and separated along the river and the water quality data of the chemical nutrient concentration and temperature of the river at these were collected from previous studies [10][11]. The meteorolowere taken from **[17].**

3.4 Method Used

A one-dimensional water quality model was developed by implementing HEC-RAS software which solves the dispersion equations using the numerical method (explicit method). The following equation is the advection-dispersion equation in one direction: (Brunner, 2016):

$$\frac{\partial}{\partial t}(V\Phi) = -\frac{\partial}{\partial t}\,(Q\Phi)\Delta x + \frac{\partial}{\partial x}\left(\Gamma A\frac{\partial \Phi}{\partial x}\right)\Delta x \;\pm S \qquad (1)$$

Where: V= The cell volume, *m3*.Φ= concentration of chemical nutrient such as NO_3, PO4, CBOD and DO, *kg/m*^{3}. Q= Flowrate, m3*/s*. Γ= dispersion coefficient, m2*/s*. A= Area, m2. S = discharge of chemical Nutrient (Sources or sinks), *kg /s*.

The second equation is the Water Temperature (Heat) transport in source and sinks terms: (Brunner, 2016):

$$\text{Heat,} \frac{source}{sink} = \frac{q\;net \times As}{\rho w \times cpw \times V} \qquad (2)$$

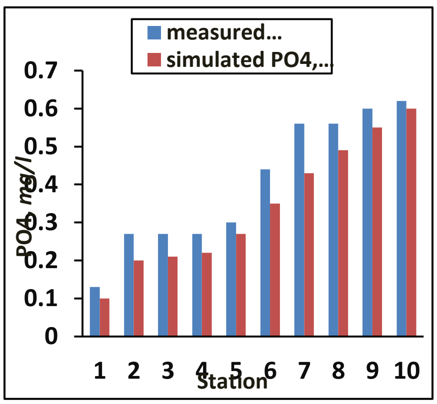
Where: $q\;net$= the net heat flux located in the air-water interface, *W/ m*^{2}. ρw = water density, *kg /m*^{3}. cpw = Specific heat of water, *J/ kg ℃.* As = surface area of cell, *m2*.V = The cell .The WQM contains constants that represent the chemical and physical reactions between the represented components and it is called parameters, there is a parameter for each simulated chemical nutrient and the values of these parameters were obtained from [18]. There are previous studies related to WQM by implementing QUAL2K software which also estimated the parameters' values of chemical nutrients such as [18-23] . Table 1 Illustrate the used parameters in the WQM in the present study.

Table 1 The used parameters in the WQM of HEC-RAS software

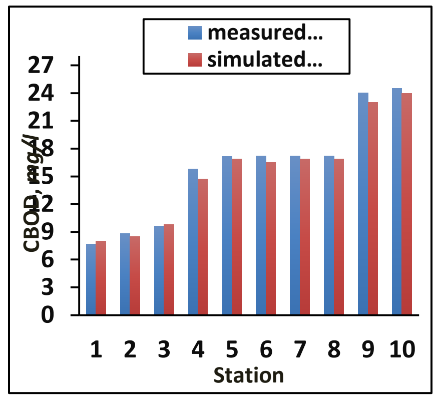
Symbol of parameter	Definition of parameter	Units	Value	Calibrated Values	Temperature Correction Coefficient(θ)
K_1 *	Deoxygenationrate (CBOD)	day $^{-1}$	0.02	0.02	1.047
K_2*	Reaeration rate (DO)	day $^{-1}$	0	0	1.024
K_3 *	(Settling rate)CBOD	day $^{-1}$	0	0	1.024
β_1*	Rate constant (NO_3)	day $^{-1}$	0.20	0.20	1.047
β_4*	Rate constant (PO_4)	day $^{-1}$	0.01-0.70	0.01	1.047

4 Model Validation

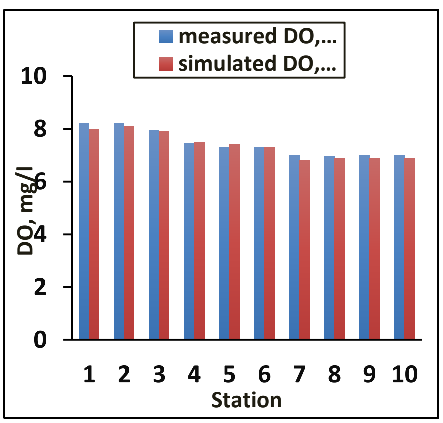
The WQM was calibrated using collected data of nutrients (NO_3, PO_4, CBOD and DO) from previous studies in the selected ten stations distributed along the river [10,11]. The calibration process was conducted by simulating the model during different conditions for the accuracy of the developed model during the period extended from February to May 2015 using the measured values of flowrates along the river which varied from 230 m^3/s at the first station to 40 m^3/s at station number ten, then the simulated values of NO_3, PO_4, CBOD, and DO were compared with the measured data to estimate the values statistical indicators.Figure 3 shows the calibration of the WQM.



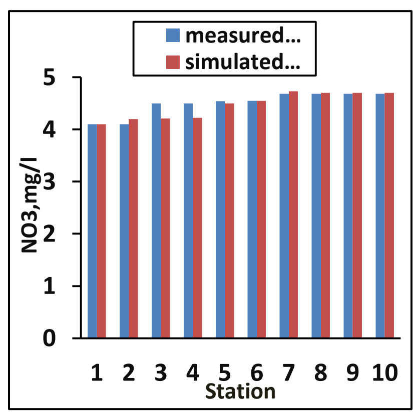
A: PO_4 values at the rivers stations



B: CBOD values at the rivers stations



C: DO values at the rivers stations

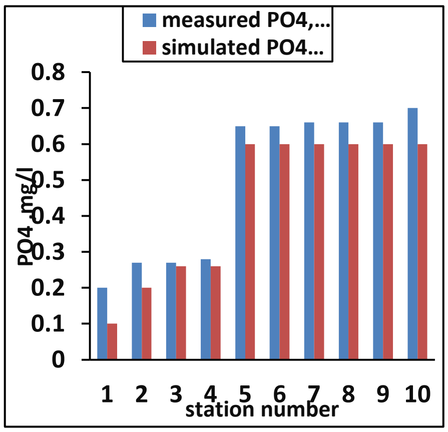


D: NO_3 values at the rivers stations

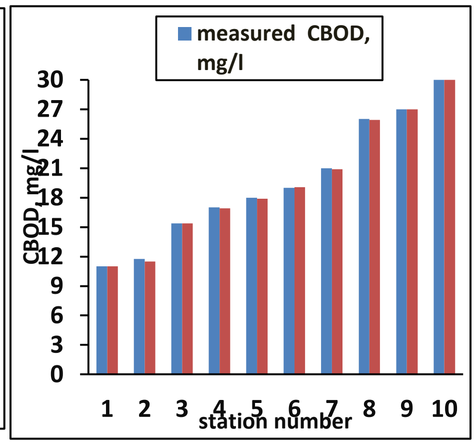
Figure 3 The calibration of the water quality model for the period from February to May 2015.

The calibration results of WQM showed that the determination coefficient value and RMSE value for PO_4 and NO_3 were 0.95 and 0.2 *mg/l* respectively while the values of RMSE and R^2 for CBOD were 0.5 *mg/l* and 0.94 respectively, also the values of RMSE and R^2 for DO were 0.1 *mg/l* and 0.96 respectively. The model was validated by simulating the WQM from

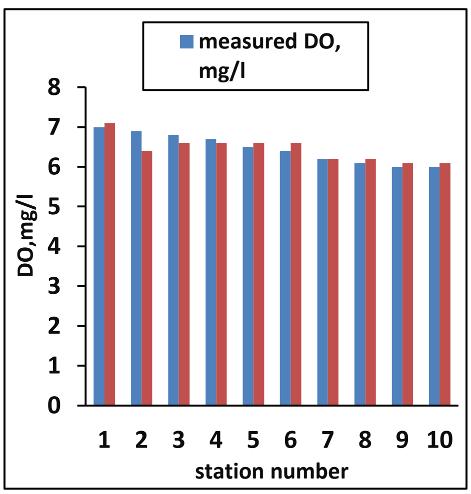
Jun to October 2015, and the values of the measured flowrate were 190 m^3/s at the first station to 34 m^3/s at the last station The validation of WQM is shown in figure (4).



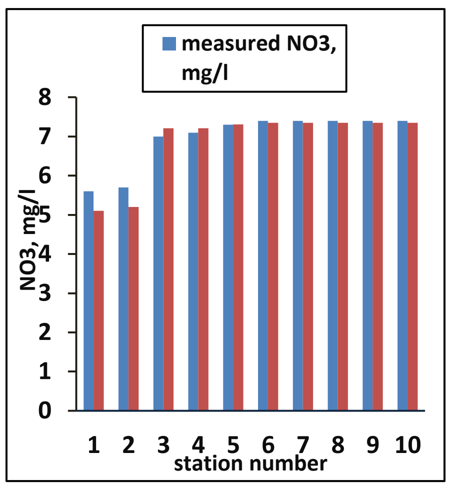
A: PO_4 values at the rivers stations stations



B: BOD values at the rivers



C: DO values at the rivers stations



D: NO_3 values at the rivers stations

Figure 4 The validation of WQM for the period from Jun to October 2015

The validation results of WQM showed that the determination coefficient (R^2)value and RMSE value for PO_4 and CBOD were 0.98 and 0.1 *mg/l* respectively. Also, R^2 and RMSE for DO were 0.97 and 0.2 *mg/l* respectively, for NO_3 the value of RMSE was 0.2 *mg/l* and the value of R^2 was 0.96.

5 Model Simulation with Different Operational Cases

The process of river assessment requires representing the river during different possible operational flowrate for different periods. In this study, the WQM was simulated during the dry and wet season using the measured flowrate values for Al-Gharraf River. For the wet season, the value of flowrate upstream of the river was 250 m^3/s, and downstream of the river was 45 m^3/s. While for the dry season the used values of flowrate at the upstream and the downstream of the river were 190 m^3/s and 34 m^3/s respectively**.**Figures 5, 6, 7, and 8 show the concentration of CBOD, DO, NO_3, and PO_4 respectively in Al- Gharraf River during the wet and dry seasons.

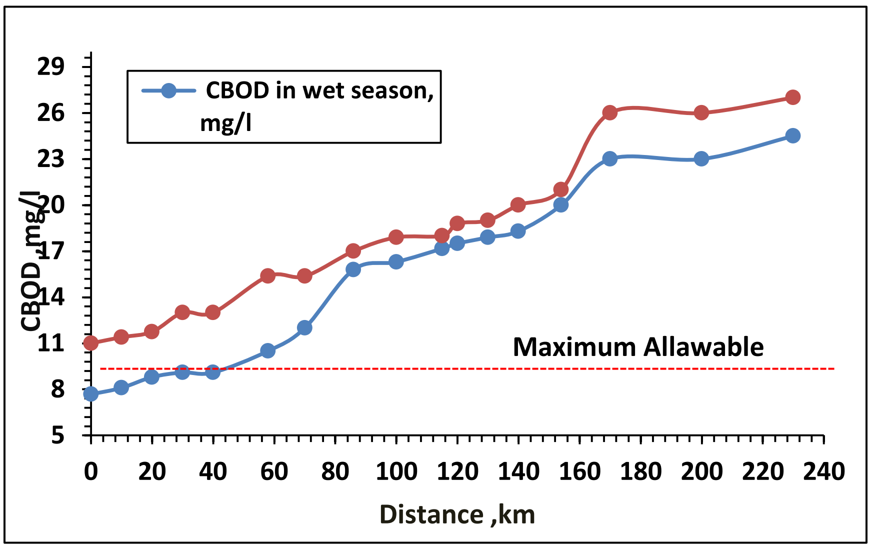


Figure 5 The values of CBOD in Al-Gharraf River during the high and low flow periods (seasons).

The CBOD for the first three stations located between Kut and Hay Cities (for a distance between 0 to 58 *km*) were ranged between 8 to 10 *mg/l* for the wet season which considered within the allowable limits of CBOD in the river according to [25] while for the dry season, the CBOD values at the first three stations ranged from 11 to 15 *mg/l*, which were not within the typical values of CBOD in the river(the CBOD value must be less than 10 *mg/l*). The CBOD values for the downstream part of the river located within Dhi Qar Governorate (for a distance located between 58 to 230 *km*) ranged between 11 to 24 *mg/l* in the high flow season and 15 to 27 *mg/l* in low flow season, for both periods the CBOD in the last part of the river were not out the suitable range. Therefore Al-Gharraf River within Dhi Qar Governorate is considered as polluted in all periods or seasons.

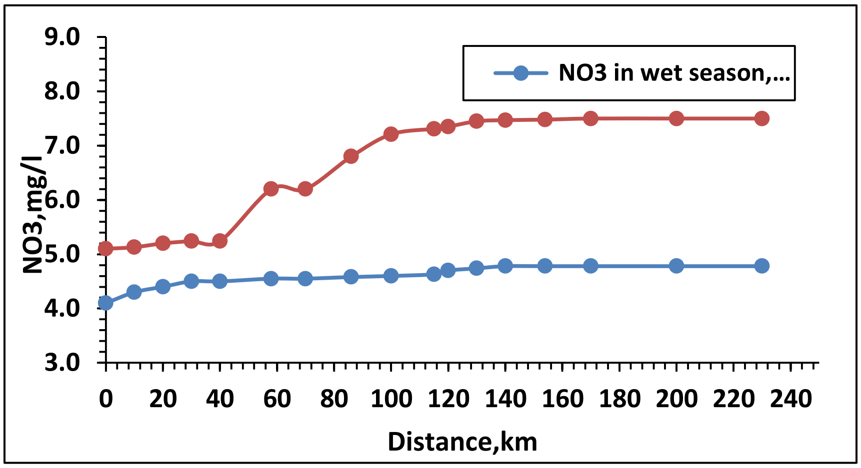
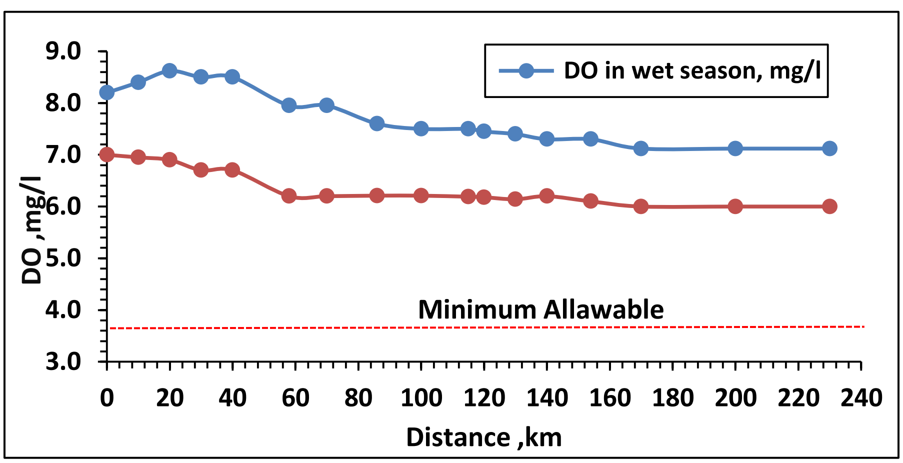


Figure 6 The values of DO in Al- Gharraf River during the wet and dry season

From figure 6 the values of DO during the wet season ranged between 8.2 *mg/l*, upstream of Al- Gharraf River to 7 *mg/l*, downstream of the river. While during the dry season the values of DO ranged from 7 *mg/l* upstream of the river to 6 *mg/l* downstream of the river. The values of DO continue to decrease towards the lower part of Al- Gharraf River. However, the values of DO for both seasons were within the acceptable values according to [25] [the values of dissolved oxygen must be greater than 4 *mg/l*].



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igure 7 The values of NO_3 in Al- Gharraf River during the wet and dry season

Nitrate is considered a source for living creatures, also for plants, which take nitrogen as the main supplement [26].Figure 7 showed the values of NO_3 for the wet season varied from 4.1 *mg/l*, upstream of the river, to 4.78 *mg/l* downstream of the river, and for the dry season, the values were raised to 5.1 *mg/l* upstream of the river and 7.5 *mg/l* downstream of the river. The values of NO_3 were within the standard for both seasons, according to [27] the values of nitrate must be less than 10 *mg/l*, and also according to both World Health Organization [28][29] Iraqi quality standards, the values of NO_3 must be less than 50 *mg/l*.

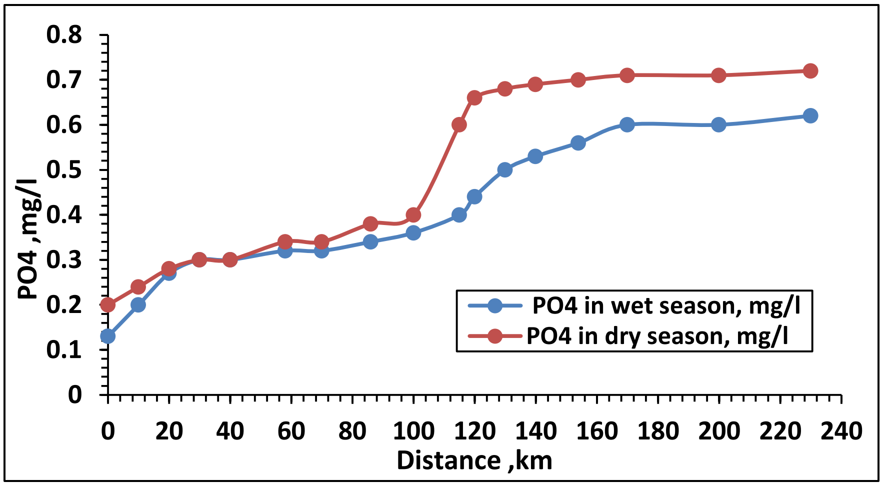


Figure 8 The values of PO_4 in Al- Gharraf River during the wet and dry season

Phosphate is considered a source for creatures and plant's growth but only within the permissible limits because the high concentration of it can increase Eutrophication. Domestic Sewage, cleaners- detergent, and fertilizers are the main sources of Phosphate [30].From figure 8, the values of PO_4 in Al-Gharraf River during the wet season were ranged from 0.13 *mg/l*, upstream of the river to 0.62 *mg/l* downstream of the river and these values increased during the dry season and it ranged from 0.2 *mg/l* to 0.72 *mg/l*.The concentration values for PO_4 in Al- Gharraf River for all seasons were within the accepted range according to (IQS, 2009), the values of PO_4 must be less than 3 *mg/l*.

6 Conclusions

The following conclusions were extracted from the present study:

- The WQM was calibrated for the period from February to May 2015 and the values of the determination coefficient and RMSE for PO_4 and NO_3were 0.95 and 0.2 *mg/l* respectively. While the determination coefficient and RMSE for CBOD were 0.94 and 0.5 *mg/l* respectively, also these values for DO were 0.96 and 0.1 *mg/l* respectively.
- The validation of the WQM period was from Jun to October 2015. The determination coefficient value and RMSE value for PO_4 and CBOD were

0.98 and 0.1 *mg/l* respectively, while R^2 and RMSE for DO were 0.97 and 0.2 *mg/l* respectively, for NO_3 the value of RMSE was 0.2 *mg/l* and the value of R^2 was 0.96. The WQM gives a good prediction for the values of chemical nutrients based on values of statistical indicators.

- The CBOD values in Al -Garraf River between Kut and Hay Cities were predicted between 8 to 10 *mg/l* in high flow season and between 11 to 15 *mg/l* during low flow season. This values affects the water quality in Al-Gharraf River at the upper reach during the low flow periods.
- The CBOD for the last 172 *km* which is located within Dhi Qar Governorate, for a distance located between (58 to 230)*km*, ranged between 11 to 24 *mg/l* in high flow season and 15 to 27 *mg/l* in the low flow season. For both seasons the CBOD levels were out the suitable range. Therefore Al-Gharraf River within Dhi Qar Governorate is considered polluted in all seasons.
- The DO values during the wet season ranged from 8.2 upstream of the river to 7 *mg/l*, downstream of Al- Gharraf River. While the values of DO during the dry season ranged from 7 upstream of the river to 6 *mg/l* at its downstream. Overall values of DO were within the standard range.
- The values of NO_3 during the wet season varied from 4.1 *mg/l*, at the upstream of the river, to 4.78 *mg/l*, at the downstream, and for the dry season, the values were ranged from 5.1 *mg/l* at the upstream to 7.5 *mg/l* at the downstream of the river. The values of NO_3 were within the standard for both seasons.
- The predicted PO_4 in Al-Gharraf River are within the permissible limits in all seasons. Its values during the low and high flow seasons were 0.2 to 0.72 *mg/l* and 0.13 *mg/l* to 0.62 *mg/l*, respectively.

7 Recommendations

This section will highlight the recommendations suggested in the present study:

- The lower part of Al-Gharraf River located within Dhi Qar Governorate is considered more polluted than the upper reach of the river which lies between Kut and Hay Cities during all seasons according to the observed and evaluated chemical concentration values of (CBOD, DO, NO_3, and PO_4). Due to the accumulation of sewage discharge along the river towards the downstream, therefore maintenance and purification of the river are required to refine the water quality of the river in the polluted sites.
- The CBOD values increased above the accepted range during the dry season for the upper reach of Al-Gharraf River, and it makes this part of the river polluted in this season since the flowrate value is decreasing and decreases the aeration process. To solve this problem the flowrate upstream of Al-Gharraf River must more than 230 m^3/s as MIF value.

References

[1] Taralgatti, P., Pawar, R., Pawar, G., Nomaan, M., and Limkar, C. "Water Quality Modeling of Bhima River by using HEC-RAS Software", International Journal of Engineering and advanced Advanced Technology, Vol.9, No.3, pp. 2886-2889,2020.

[2] Daham, M., and Abed, B. "Simulation of Sediment Transport in the Upper Reach of Al-Gharraf River", Materials Science and Engineering, Vol.901, No.1, pp.1-11,2020.

[3] Daham, M., and Abed, B. "One and Two-Dimensional Hydraulic Simulation of a Reach in Al-Gharraf River".Journal of Engineering, Vol. 7, No. 26, pp.28-44,2020.

[4] Al-Husseini, K., and Alsalman, I. "Quarterly variation and their impact on phytoplankton dynamics in the Gharraf River environment in southern Iraq", Plant Archives, Vol. 20, No.1, pp.1354-1360, 2020.

[5] Ewaid, S., Abed, S., Al-Ansari, N., and Salih, R. "Development and Evaluation of a Water Quality Index for the Iraqi Rivers", Hydrology,Vol. 7,No.67,pp.1-14.,2020

[6] Butler BA, and Ford RG. "Evaluating relationships between total Dissolved solids (TDS) and total suspended solids (TSS) in a mining-influenced watershed", Mine Water and the Environment, Vol. 37, No.1, pp.18-30, 2019.

[7] Mohammed, A.Y., Arrar A. N., and Abed, A.A. "Roughness characteristics of Kut-Hay reach of Al- Gharraf River and its impact on the Hay regulator", Association of Arab Universities Journal of Engineering Sciences, Vol.25, No.5, 2018.

[8] Mirza, N., and Nashaat, M. "An ecological assessment for interactionsbetween the physico-chemical of Gharaf river characteristics, Southern Iraq".Journal of Research in Ecology, Vol. 6, No. 2, pp.2244-2263,2018.

[9] Al-dabbas, M., Al-Shamma'a, A., and Al-Mutawki, K. "Evaluationof Gharraf River Water for different Uses, South Iraq", Iraqi Journal of Science, Vol. 59, No.3, pp.1697-1709, 2018.

[10]Ewaid, S., and Abed, S. "Water quality index for Al-Gharraf River, southern Iraq".,Egyptian Journal of Aquatic Research, Vol. 43, No 2, pp.117-122,2017.

[11]Ewaid, S. "Water quality evaluation of Al-Gharraf river by two water quality indices". Appl.Water Sci., Vol.7, No.7, pp.3759-3765, 2017.

[12]Ewaid, S. "Water Quality Assessment of Al-Gharraf River, South of Iraq by the Canadian Water Quality Index (CCME WQI)". Iraqi Journal of Science, Vol.57, No.2, pp.878-885,2016.

[13]Maatooq, J., Omran, H., and Aliwe, H. "Empirical Formula for Estimation the Sediment Load inShat AL-Gharaf River",Basrah Journal for Engineering Sciences, Vol.16, No1, pp.38-41, 2016.

[14]Hubert, E., and Wolkersdorfer, Ch. "Establishing a conversion factorBetween electrical conductivity and total dissolved solids in South African mine waters", Water SA, Vol. 41, No.4, pp. 490-500,2015.

[15]Ministry of Water Resources, MoWR, The General Authority for Surveying of the Ministry of Water Resources, Data on the cross-sections and coordinates of Al-Gharraf River,2012.

[16]Ministry of Water Resources MoWR. Data on the water levels and hydraulic information of Al-Gharraf River, 2015-2019.

[17]Weather-atlas,2015-2020. Meteorological data of Iraq. Available Online:https://weather-and-climate.com/average-monthly-Wind-speed,Bagdad,Iraq

[18]Brunner, G.. "HEC-RAS River Analysis System 1D and 2D Modeling User Manual", US Army Corps of Engineers Hydrologic Engineering Center, 2016. Available online: http://www.hec.usace.army.mil/

[19]Mustafa, A., Sulaiman, S., and Shahooth, S. "Application of QUAL2K for Water Quality Modeling and Management in the lower reach of the Diyala river", Iraqi Journal of Civil Engineering, Vol.11, No2, pp. 66-80, 2016.

[20]Brown, L.C., and Barnwell, T.O.Jr. "The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User Manual", USEPA, Environmental Research Laboratory, 1987.

[21]O'Connor, D., and Dobbins W.. "Mechanisms of aeration in Natural streams". J. Sanitary Eng. Div. ASLE, Vol.83, No.6, pp.1–30, 1958.

[22]Al-Dulaimi, A. G. "Evaluation of BOD and DO for Diyala River by Using Stream Water Quality Model", International Journal of Environmental Science and Development, Vol.8, No.8, pp.543-548, 2017.

[23]Ismail, A., and Abed, G. "BOD and DO modeling for Tigris River at Baghdad city portion using QUAL2K model", Journal of Kerbala University (Scientific), Vol.11, No.3, pp.257 – 273,2013.

[24]USEPA.The typical scale of CBOD results,2016. Available online: http://maineenvironmentallaboratory.com

[25]USEPA. Rates, constants, and kinetics formulations in surface water quality second edition, U.S. Environmental Protection Agency, 2006. Available at:http://www.ecy.wa.gov/.

[26]Ell, MJ. "Total suspended solids (TSS)", NDDO Health (ed), North Dakota, USA, 2008.

[27]Edet, AE., and Offiong, OE. "Evaluation of water quality Pollution indices for heavy metal contamination monitoring. A study case from Akpabuyo-Odukpani area, Lower Cross River Basin (Southeastern Nigeria)". Geo J, vol.57,pp.295–304, 2002.

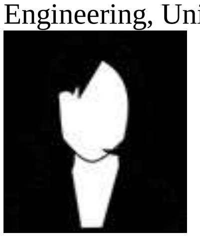
[28]World Health Organization (WHO). Guidelines for drinking water Quality, 4th edn, 2011. http://www.who.int/water.

[29]IQS. Iraqi Quality Standards. Ministry of Planning, Central Agency for Standardization and Quality Control, Standard No, (417) 2nd modification, drinking water, 2009.

[30]Viessman, W., and Hammer, MJ. Water supply and pollution control, 7th edn. The University of Michigan, Pearson Prentice Hall, USA, 2005.

Biographies

Basim Sh. Abed, Assistant Professor, Department of Water Resources Engineering, University of Baghdad, Iraq.



Mariam H. Daham, Water Resources Engineering, University of Baghdad, Iraq.

Hayder A. Al-Thamiry ,Assistant Professor, Department of Water Resources Engineering, University of Baghdad, Iraq.