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RETRACTED: Modeling Spatial Distribution of Some Contamination within the Lower Reaches of Diyala River Using IDW Interpolation

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Abstract: The aim of this research was to simulate the water quality along the lower course of the Diyala River using Geographic Information Systems (GIS) techniques. For this purpose, the samples were taken at 24 sites along the study area. The parameters: total dissolved solids (T.D.S), total suspended solids (T.S.S), iron (Fe), copper (Cu), chromium (Cr), and manganese (Mn) were considered. Water samples were collected on a monthly basis for a duration of five years. The adopted analyzing approach was tested by calculating the mean absolute error (MAE) and the correlation coefficient (R) between observed water samples and predicted results. The result showed a percentage error less than 10% and significant correlation at $R > 89\%$ for all pollutant indicators. It was concluded that the accuracy of the applied model to simulate the river pollutants can decrease the number of monitoring station to 50%. Additionally, a distribution map for the concentrations' results indicated that many of the major pollution indicators did not satisfy the river water quality standards.

Keywords: ArcGIS; river pollution indices; monitoring points; interpolation; sustainability

1. Introduction

Water resources, such as lakes, rivers, and groundwater, are one of the fundamentals for sustainable development in the world. The availability of water in quantity and quality is not only necessary for agriculture, industry, and tourism purposes, but also essential for daily life use. Population and economic growth lead to an increase in the demand for water, on the one hand, and increased pollution of water, on the other, which constitutes a threat to all water resources and sustainable development.

Water quality is the “overall process of evaluation of the physical, chemical, and biological nature of water in relation to natural quality, human effects and intended uses, particularly uses which may affect human health and the health of the aquatic system itself” [1]. The physical parameters usually include: temperature, turbidity, color, salinity, suspended solids, and dissolved solids. The chemical and biological parameters often contain the following: pH, dissolved oxygen, biological oxygen demand, nutrients, organic and inorganic compounds, for the former, and bacteria and algae, for the latter.

Monitoring the quality of water requires understanding of the transport of pollutants and knowledge of their fate in rivers until they reach the seas or groundwater aquifers. Traditional monitoring of water quality requires in situ sampling, which is time-consuming and costly laboratory work and can only

be done for small areas that do not cover the entire water body. Therefore, these limitations make it difficult for overall and successive water quality forecasting [2]. Many modern models are used to monitor the pollutants such as hydrology transport model [3]. One of these models are Geographic Information Systems (GIS) and remote sensing data for hydrological investigations. GIS technology provides suitable information in the spatial and temporal domain and intricate databases, which are more important for natural resources management [4]. Ref. [5] uses the spatial interpolation technique through inverse distance weighted (IDW) approach of GIS in the Ganga River for predicting the average values of the major parameters including transparency, dissolved oxygen (DO), biological oxygen demand (BOD), total suspended solids (TSS), and total dissolved solids (TDS). The results indicate that many of the major parameters do not satisfy the drinking water quality standards. Ref. [6] uses geo-statistical analysis and the GIS method to estimate water pollution changeability of major water pollutants at 67 monitoring sites and recognizes the potential polluted risky zones in the Honghe River. The results indicate that 83.27% of the watershed in total is polluted by complete pollutants at medium, heavy, and important polluted levels. Ref. [7] uses the GIS system and an extensive environmental agency monitoring database to map regional water quality of the Humber catchment. This study demonstrates the importance of the application of GIS mapping techniques to diagnosis the major factors affecting the general characteristics of water quality. Ref. [8] discusses the application of remote sensing and GIS in monitoring water quality parameters, such as suspended matter, phytoplankton, turbidity, and dissolved organic matter. In conclusion, remote sensing and GIS tools, coupled with computer modeling, are valuable tools in providing a solution for future water resources planning and management, especially to control plans related to water quality. Ref. [9] investigates the spatiotemporal variation and searches for the basic socioeconomic and environmental factors causing the water pollution of heavy metal in China's major cities using GIS techniques and statistical methods. This study concludes that economic progress and urbanization play main roles in monitoring water pollution problems.

The decrease in water bodies in the world, and in Iraq particularly, is the most important problem to be faced. The domestic sewage, factory effluents, and agriculture waste can lead to a decrease in river water quality. Thus, a monitoring program is required in order to avoid threats of contamination of water resources. In situ, sampling site monitoring for preceding laboratory analyses is used to evaluate water quality. These measurements are correct for a point in time and space, but they do not give the spatial or temporal view of water quality in widespread space. The importance of this research is to simulate and monitor some of the physic-chemical variables that affect the quality of water across the lower part of Diyala River near Baghdad City using the GIS technique. By using this technique, a digital map for pollution indicators covering large areas in a short time, with less effort and minimum cost can be obtained. Additionally, two standard specifications for river pollution are used to assess the upstream Tigris River's and Diyala River's water characteristics.

2. Study Area

The Diyala River is one of the main tributaries of the Tigris River in Iraq; it contributes to about 11% of the Tigris's total water income. It drains an area of about 32,600 km², of which 20% lies in Iran, and the remainder in Iraq (Figure 1). The total length of the river is about 445 km. The Diyala River has three main tributaries: Sirwan, Tanjeru, and Wand Rivers. Two dams were constructed across the river: Derbendikhan and Hemrin (360 and 188 km upstream the confluence with the Tigris River, south of Baghdad, respectively). In addition, Diyala weir was constructed across the river (11 km downstream from Hemrin Dam) which controls floods and irrigates the area northeast of Baghdad [10–12]. The climatic conditions vary so much in the river catchments during the rainy season from November to April, with an annual amount of precipitation that varies from 800 mm near the northern parts to 250 mm near the southern limits of the basin. The annual evaporation rate may reach as high as 2000 mm/year. The mean daily discharge of the river is about 182 m³/s. These conditions have clear effects on the variation of river water quality [13,14]. The river catchments

can be divided into four parts: Derbendikhan, Upper Diyala, Middle Diyala, and Lower Diyala. In this work, the Lower Diyala River was investigated. It is about 17 km, starting from 2 km upstream from Rustimiyah's third expansion plant (R3) at $33^{\circ}18'34.2''\text{N}$, $44^{\circ}32'13.8''\text{E}$ and extends to the confluence of the Tigris-Diyala Rivers at $33^{\circ}13'14.49''\text{N}$ $44^{\circ}30'21.81''\text{E}$, Zone 38 North, according to the datum WG84. It is located within the Southeast of the capital city of Baghdad, Iraq (Figure 2).

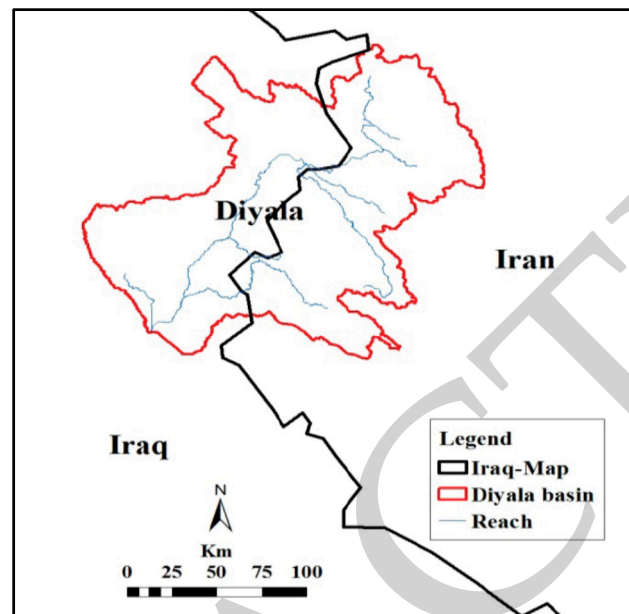


Figure 1. The Diyala River catchment area.

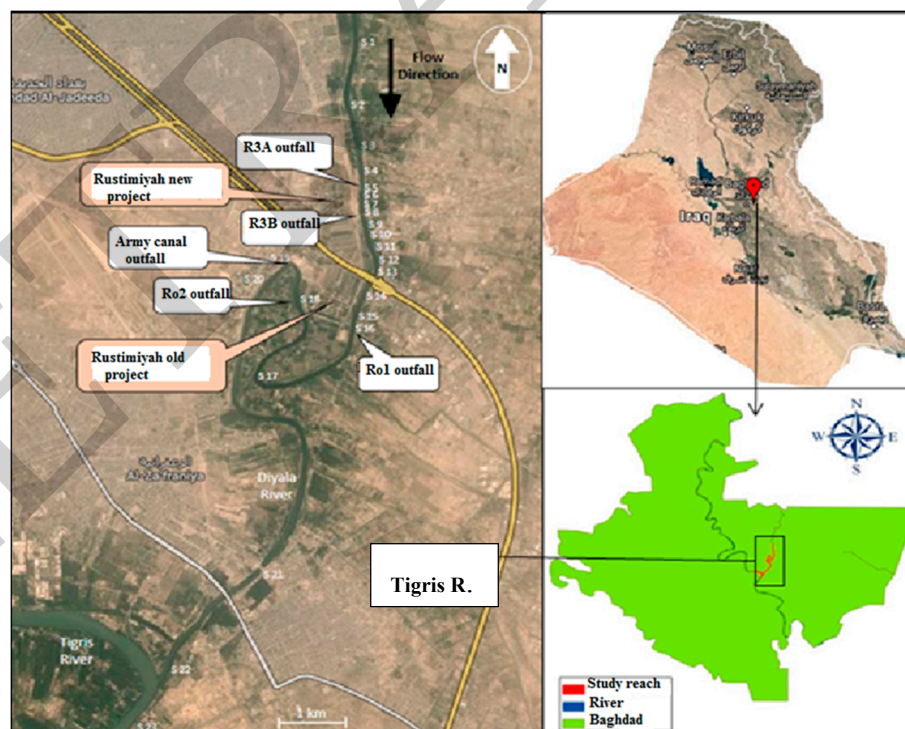


Figure 2. General layouts of the study reach.

3. Source of Pollution

Sources of pollution in the study area (lower Diyala River) can be summarized as follows:

- (1) Five outfalls were recorded as main multi-point sources of pollutants, which disposed the untreated wastewater continuously to the Diyala River and, thus, into the Tigris River. These outfalls were located at different positions along the lower reach of the Diyala River (Figure 1). The Rustimiyah wastewater treatment plant (WWTP) is the oldest project and located on the right bank of Diyala River; 14 km prior to the confluence of the Tigris River, south of Baghdad City. It consists of an old project, and other extensions: the first extension (Ro1), second extension (Ro2), and third extension (R3A); and a new project, dubbed the third expansion (R3B). This project was close to what was known as Army canal outfall. These outfalls caused physical, chemical, and biological pollution, leading to the downstream part of the river.
- (2) An unacceptable decrease of water flows of the river in the Baghdad area during dry months due to the construction of two large storage reservoirs in the upper reach of the river.
- (3) Returned irrigation water from agricultural areas within the Diyala basin.
- (4) Discharge of untreated wastewater from houses, factories, and various institutions directly into the river.
- (5) Leakage from sewer pipes and the drinking water distribution network. The efficiency of the water distribution network is about 32% of the production of wastewater [15].
- (6) The river was exposed to non-point sources of pollution from agricultural activities and rain that cannot be easily determined

4. River Sampling and Analysis

Twenty-four sites along the lower part of the Diyala River were used as observation stations to collect the river samples (Figure 3). Water samples were taken starting from Station S1 (2 km) upstream of Rustimiyah, at the third expansion plant (R3A) to Station S24 (17 km) at the confluence of the Tigris and Diyala rivers. Four heavy metals were chosen in the analysis; iron (Fe), copper (Cu), chromium (Cr), and manganese (Mn). Two physical behavior determinants were also chosen for the analysis: total dissolved solids (T.D.S), and total suspended solids (T.S.S). These determinants were selected to represent a wide range of physico-chemical pollutant sources in river water as toxic metals and very important for the evaluation of water quality. The effect of the seasons was assumed to be negligible. The drawing samples of water at various depths of Diyala River was achieved by using simple handmade device consisting of a plastic bottle with a small stone that was arranged and tied with two ropes. After collecting monthly water samples, they were sent to the sanitary laboratory of Al-Mustansiriya University–College of Engineering to be analyzed for all heavy and physical determinants. Standard methods were used to conduct these tests. T.D.S was measured using “filtration followed by evaporation then oven drying”, while T.S.S was measured using the “evaporation method” at 103–105 °C. The heavy metals concentrations of Fe, Cu, Cr, and Mn were determined using an atomic absorption spectrophotometer (AAS) (novAA 300) [16].

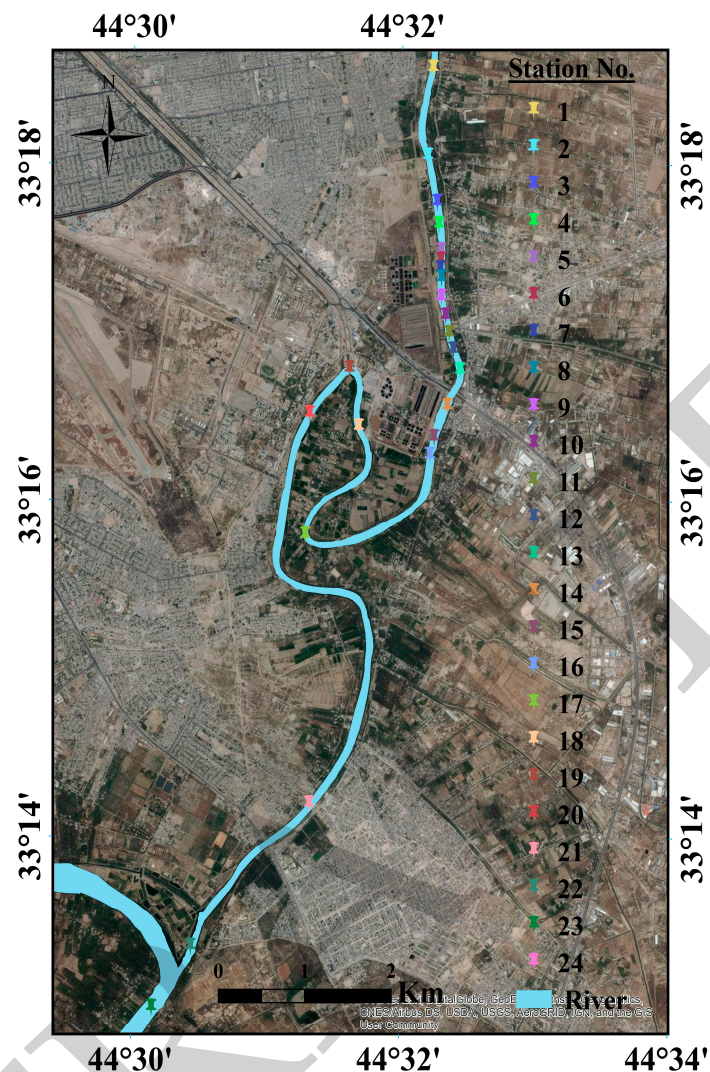


Figure 3. Sampling stations along the lower part of the Diyala River.

5. Methodology

The application of (GIS) and statistical methods were used to examine the impacts of outfalls on river pollution. One major advantage of the GIS observations over traditional water quality monitoring measurements is that they provides both spatial and temporal information of surface water characteristics [17]. The path of river pollution was modeled using (GIS) ArcView 10.4 (Esri, Redlands, CA, USA), spatial analysis tools, and interpolating a raster surface from points using an inverse distance weighted (IDW) technique. Previous studies have proven that (IDW) has irreplaceable advantages for data estimation in rivers because of its high accuracy, and it is widely used by some authors in pollution modeling [18–20].

Twelve monitoring stations, distributed in the river (Figure 4), were selected as input pollution data to GIS model. The predicted water pollution data of the rest of the stations from a total of 24 stations were extracted from the GIS model as predicted values and validated by comparing them to the observed values using a correlation coefficient (R) and mean absolute error (MAE). The optimal estimation from the data set for each variable was identified based upon the results of (R-value > 0.05) and smallest (MAE). The resulting data was analyzed in Excel and ArcGIS version 10.4 (Esri, Redlands, CA, USA) (e.g., Buffer, Clip, Extract, Overlay, Proximity, Convert, Reclassify, and Map Algebra, etc.). The predicted asset values of each variable were grouped into nine categories.

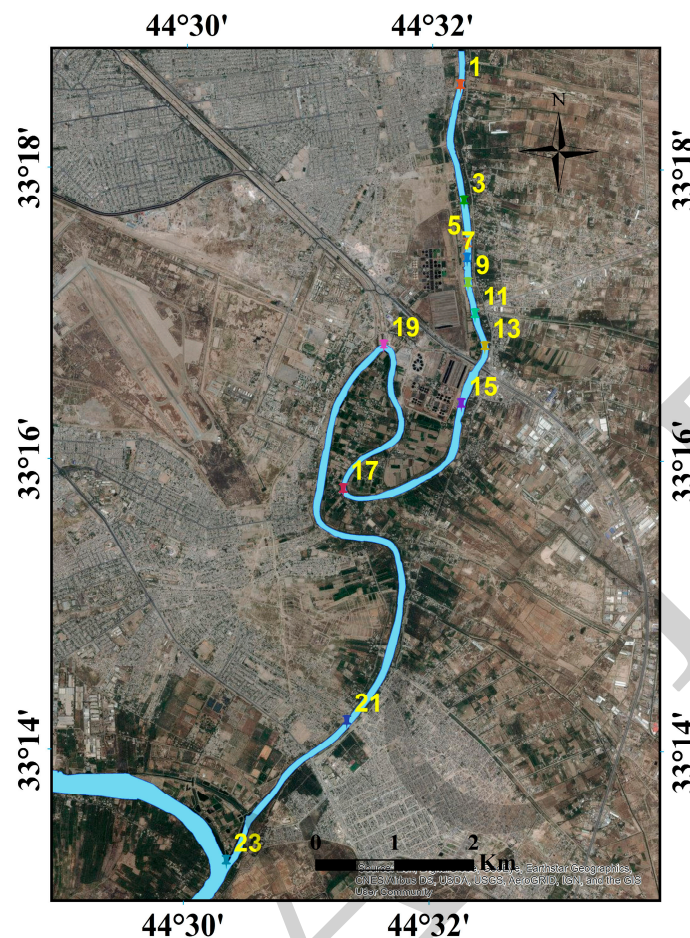


Figure 4. The stations that were used as input data in GIS along the lower part of the Diyala River.

Concept of Inverse Distance Weighted (IDW) Interpolation Method

(IDW) is one of the deterministic spatial interpolation procedures in geostatistical information. This method determines cell values using a linearly-weighted combination of a set of sample points [21]. The IDW formula is used to estimate the unknown of the monitoring station value $Z^*(S_0)$ in location S_0 , where n is the number of monitoring stations, given the observed $Z(S_i)$ values at the sampled locations S_i as shown in Equation (1):

$$Z^*(S_0) = \sum_{i=1}^n W_i Z(S_i) \quad (1)$$

W_i is the weight defined as:

$$W_i = doi^{-\alpha} / \sum_{i=1}^n doi^{-\alpha} \quad (2)$$

with:

$$\sum_{i=1}^n W_i = 1 \quad (3)$$

Each measurement is multiplied by the inverse of the distance $doi \geq 0$ from the station o to the station i with the exponent α . Then each product is divided by the sum of the terms $1/doi^{-\alpha}$ over all the stations i so that the sum of all W_i 's for an unsampled station will be unity (Equation (3)). The power α of the distance has to be chosen appropriately depending on the interpolated variable [22].

6. Results and Discussion

The prediction of the distribution of contaminants was useful in the evaluation, management, and operation of water resources engineering projects. Maps of the concentration of contaminants played an important role in the evaluation of water quality. Several sources were used to formulate the

necessary map layers within the GIS for the current study. The first source were digital maps (shapefile). The individual shape file maps for the Diyala River were set accordingly using the internal reports of the Iraqi Ministry of Education [23]. The second source changed the available maps into digital maps using the appropriate information in the map checked by analyzing satellite images of the Baghdad Governorate from 2011 [24]. The third source was the experimental data from the laboratory analysis from 24 stations for the indicators of pollutant concentrations, as shown in Table 1. This showed the statistical summary of monthly concentrations and standard deviations for each determinant and each observed station for the period from December 2012 to November 2016. The statistical results, the mean and standard deviation (SD), were computed using Microsoft Excel 2010 in order to study the water measurement and its deviation with distance for the 24 samples.

Table 1. The statistical summary (mean $\pm$ SD) of monthly concentrations for stations from 2012–2016.

St. No.	Distance (km)	T.D.S (mg/L)	T.S.S (mg/L)	Fe (mg/L)	Cu (mg/L)	Cr (mg/L)	Mn (mg/L)
1	0.0	2265 $\pm$ 640	93 $\pm$ 47	0.022 $\pm$ 0.58	0.076 $\pm$ 0.42	0.033 $\pm$ 0.16	0.54 $\pm$ 0.48
2	1	2249 $\pm$ 657	95 $\pm$ 49	0.02 $\pm$ 0.48	0.037 $\pm$ 0.49	0.034 $\pm$ 0.12	0.57 $\pm$ 0.42
3	1.5	2270 $\pm$ 669	96 $\pm$ 45	0.023 $\pm$ 0.34	0.082 $\pm$ 0.38	0.031 $\pm$ 0.18	0.57 $\pm$ 0.4
4	1.75	2188 $\pm$ 537	86 $\pm$ 43	0.026 $\pm$ 0.51	0.075 $\pm$ 0.26	0.031 $\pm$ 0.19	0.55 $\pm$ 0.44
5	2	3705 $\pm$ 690	231 $\pm$ 20	2.013 $\pm$ 0.45	1.41 $\pm$ 0.19	0.329 $\pm$ 0.15	2.09 $\pm$ 0.41
6	2.1	3453 $\pm$ 636	205 $\pm$ 43	1.742 $\pm$ 0.23	1.381 $\pm$ 0.28	0.3 $\pm$ 0.19	1.88 $\pm$ 0.42
7	2.2	3371 $\pm$ 603	212 $\pm$ 41	1.659 $\pm$ 0.33	1.221 $\pm$ 0.38	0.259 $\pm$ 0.12	1.7 $\pm$ 0.48
8	2.3	3518 $\pm$ 639	202 $\pm$ 48	1.734 $\pm$ 0.35	1.261 $\pm$ 0.29	0.232 $\pm$ 0.12	1.6 $\pm$ 0.31
9	2.5	3183 $\pm$ 608	163 $\pm$ 49	0.914 $\pm$ 0.38	0.745 $\pm$ 0.49	0.147 $\pm$ 0.17	1.1 $\pm$ 0.29
10	2.7	2641 $\pm$ 589	127 $\pm$ 43	0.403 $\pm$ 0.18	0.332 $\pm$ 0.46	0.086 $\pm$ 0.13	0.81 $\pm$ 0.36
11	2.9	2539 $\pm$ 522	112 $\pm$ 48	0.348 $\pm$.29	0.31 $\pm$ 0.29	0.079 $\pm$ 0.16	0.82 $\pm$ 0.48
12	3.1	2451 $\pm$ 591	110 $\pm$ 42	0.308 $\pm$.39	0.293 $\pm$ 0.36	0.07 $\pm$ 0.19	0.74 $\pm$ 0.41
13	3.3	2526 $\pm$ 593	105 $\pm$ 39	0.314 $\pm$ 0.26	0.288 $\pm$ 0.19	0.075 $\pm$ 0.19	0.75 $\pm$ 0.4
14	3.7	2467 $\pm$ 501	129 $\pm$ 42	0.3 $\pm$ 0.29	0.303 $\pm$ 0.38	0.076 $\pm$ 0.14	0.73 $\pm$ 0.32
15	4.1	2446 $\pm$ 493	113 $\pm$ 35	0.291 $\pm$ 0.19	0.266 $\pm$ 0.41	0.071 $\pm$ 0.17	0.7 $\pm$ 0.25
16	4.3	2760 $\pm$ 496	110 $\pm$ 20	0.454 $\pm$ 0.28	0.392 $\pm$ 0.22	0.085 $\pm$ 0.16	0.84 $\pm$ 0.28
17	6	2547 $\pm$ 499	105 $\pm$ 48	0.335 $\pm$ 0.37	0.301 $\pm$ 0.32	0.07 $\pm$ 0.08	0.79 $\pm$ 0.27
18	7.5	2813 $\pm$ 477	129 $\pm$ 28	0.427 $\pm$ 0.46	0.397 $\pm$ 0.25	0.09 $\pm$ 0.02	0.91 $\pm$ 0.21
19	8.2	2725 $\pm$ 434	117 $\pm$ 23	0.409 $\pm$ 0.51	0.375 $\pm$ 0.16	0.08 $\pm$ 0.06	0.83 $\pm$ 0.19
20	8.8	2571 $\pm$ 482	113 $\pm$ 40	0.351 $\pm$ 0.26	0.344 $\pm$ 0.24	0.08 $\pm$ 0.02	0.79 $\pm$ 0.15
21	13.5	2572 $\pm$ 423	115 $\pm$ 35	0.349 $\pm$ 0.34	0.337 $\pm$ 0.31	0.08 $\pm$ 0.04	0.788 $\pm$ 0.2
22	15.3	2454 $\pm$ 553	108 $\pm$ 29	0.342 $\pm$ 0.26	0.32 $\pm$ 0.22	0.07 $\pm$ 0.02	0.756 $\pm$ 0.2
23	16	896 $\pm$ 491	46 $\pm$ 20	0.192 $\pm$ 0.23	0.076 $\pm$ 0.14	0.01 $\pm$ 0.04	0.161 $\pm$ 0.18
24	17	560 $\pm$ 412	33 $\pm$ 21	0.11 $\pm$ 0.24	0.023 $\pm$ 0.12	0	0.02 $\pm$ 0.2

The experimental results from the laboratory analysis from 12 Stations (Figure 4) were only imported into GIS as features; then these data were converted into a shapefile using the “export data” feature to produce the shapefile map for heavy metals contaminants (Cr, Cu, Fe, Mn) and physical contaminants (T.D.S, T.T.S). The extension tool “IDW” within GIS was used to generate an interpolation (predicted value) for the lower part of the Diyala River.

Finally, the digital map of the concentration of pollutants was produced for the heavy metals group, as shown in Figure 5, and for the physical group in Figure 6.

The maximum and minimum concentrations and their locations are tabulated in Table 2. It can be noticed that the maximum concentrations are all distributed in Station 5, while the minimum concentrations are mainly in Station 24. Figures 5 and 6 indicate that the water of the Diyala River became polluted when reaching Station 5. This was because, at Station No. 5, the first pollutant source was located at the river (R3A outfall). As a result, the average concentration of all pollution indicators increased, which considered that as a large pollutant source. The situation remained relatively as it was downstream at Stations 6–8 due to the effect of the waste water treatment plants within the vicinity of the R3A outfall and the R3B outfall. Downstream of Station 8, the concentration of the studied variables relatively decreased at Stations 9 to 15 (Figures 5 and 6) until the water reaches the R01 wastewater plant outfall at Station 16. Further downstream, the concentrations started to increase at

Station 18 where the RO2 wastewater outfall discharged the wastewater into the river. Downstream of Station 23 was the confluence of the Tigris and Diyala Rivers. The effect of increasing the flow when the two rivers merge together was well noticed by the decrease of the concentrations of all variables at Station 24 due to dilution.

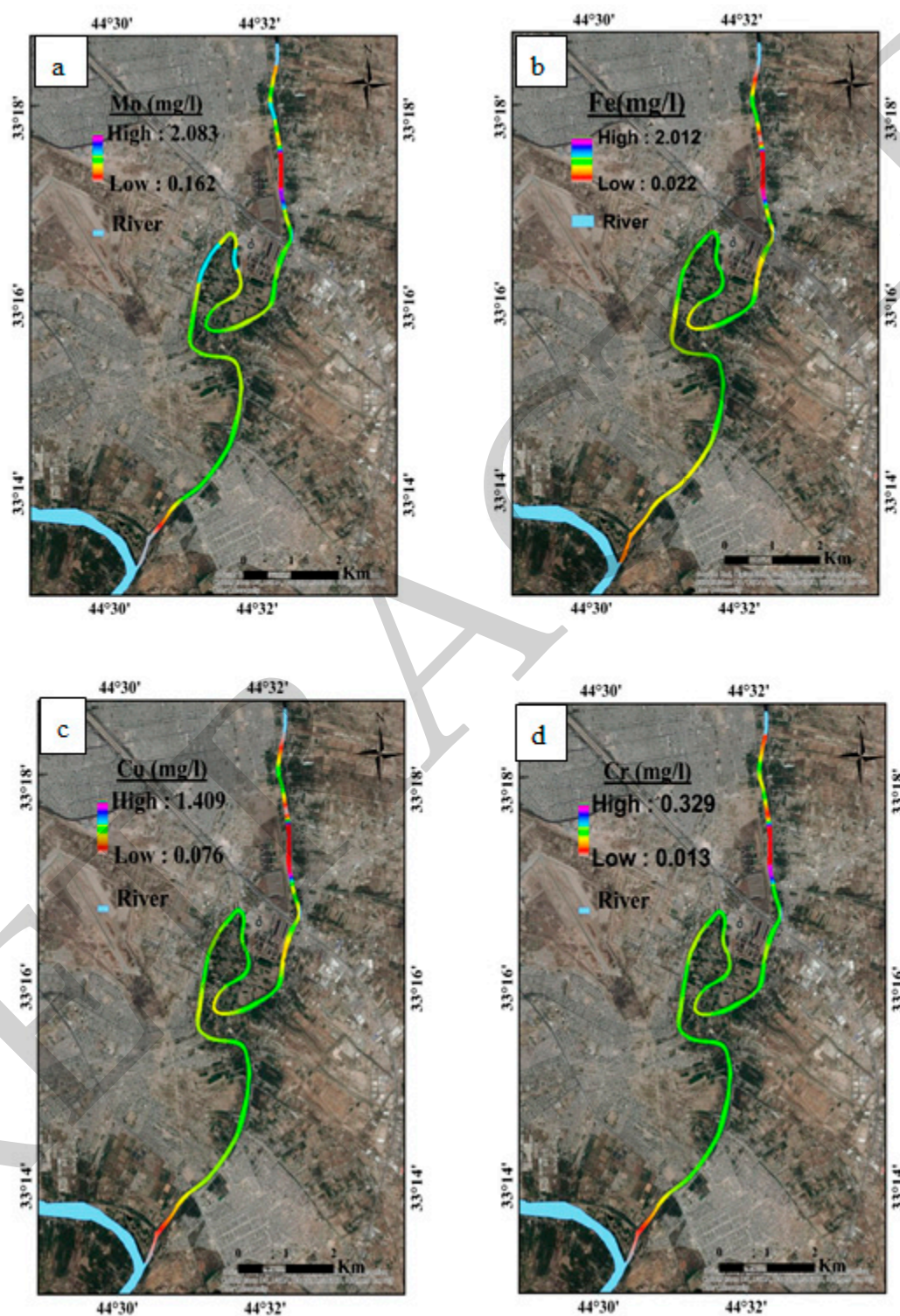


Figure 5. Maps of the spatial distribution of concentrations for (a) manganese (Mn); (b) iron (Fe); (c) copper (Cu); and (d) chromium (Cr).

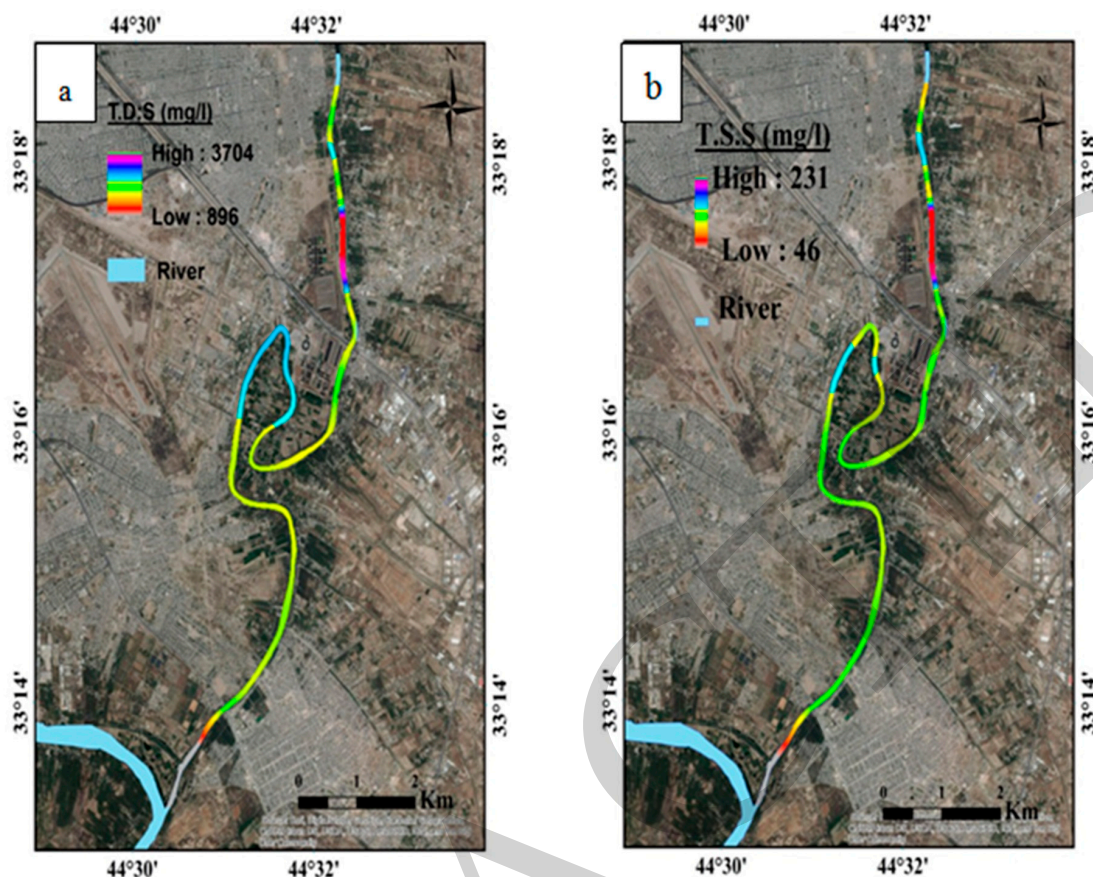


Figure 6. Maps of the spatial distribution of concentrations for (a) T.D.S and (b) T.S.S.

Table 2. Maximum and minimum concentrations of the studied variables and their location in the studied area.

Variable	Max. Concentration (mg/L)	Location	Min. Concentration (mg/L)	Location
Cr	0.329	Station 5	0.013	Station 24
Fe	2.012	Station 5	0.022	Station 24
Cu	1.409	Station 5	0.076	Station 24
Mn	2.083	Station 5	0.162	Station 24
T.D.S	3704	Station 5	896	Station 24
T.S.S	231	Station 5	46	Station 24

According to simulation results by GIS, it can be noticed that the concentration of the studied variables within the lower reach of Diyala River at Stations No. 6 to 22 remained above the desired limits according to Iraqi standard specification and the World Health Organization standards (Table 3) [25,26]. Furthermore, at Stations S23 and S24 upstream of the Tigris River, some pollutants, such as Mn and T.S.S, were still above the allowable limits. This occurred because of the sources of toxic chemical fertilizers which are widely used in the agricultural areas adjacent to the downstream of the Diyala River that transported in one way or another to the Tigris River, causing pollution of many toxic compounds. This implied that the water quality parameters of the Tigris River, though upstream, were well-matched with the Iraqi and WHO standards, except the Mn and T.S.S, which showed increasing levels than the maximum allowable levels. As a result, this means that Diyala River was one of the polluting sources of the Tigris River.

Allowable limits of water quality variables in river water are according to Iraqi standards [25,26].

Table 3. Allowable limits of water quality variables in river water according to Iraqi and WHO standards [25,26].

Variable	Symbol	Upper Limit IRAQI (mg/L)	Upper Limit WHO (mg/L)
Total Dissolved Solids	T.D.S	1500	1200
Total Suspended Solids	T.S.S	25	30
Copper	Cu	0.1	1.0
Chromium	Cr	0.05	0.05
Manganese	Mn	0.05	0.05
Iron	Fe	0.3	0.3

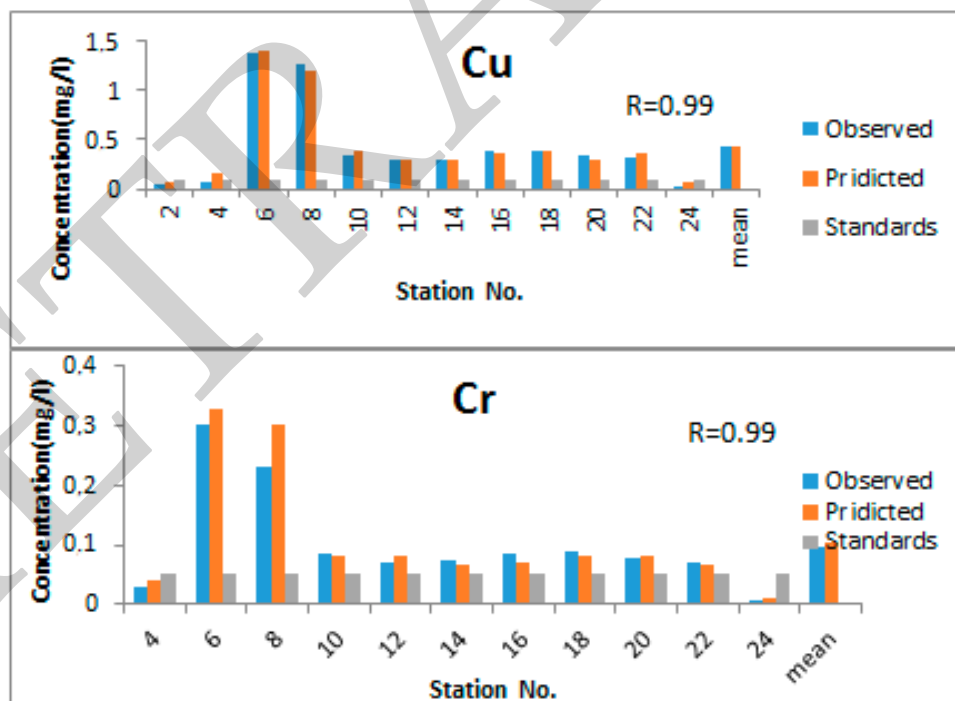
7. Evaluation of the Performance of the Model

The success with the GIS model depends upon the availability of accurate laboratory and field data. Statistical criteria, the mean absolute error (MAE) and correlation coefficient (R), are applied to evaluate the accuracy of results for all water quality parameters TDS, TSS, Fe, Cu, Cr, and Mn concentrations (Figures 7 and 8). The R and MAE are defined by Equations (4) and (5) [27,28]:

$$\frac{1}{n} \sum_{i=1}^n |O - P| \times 100(\%) \quad (4)$$

$$R\% = \frac{\sum_{i=1}^n (O - Oavg)(P - Pavg)}{2\sqrt{\sum_{i=1}^n (O - Oavg)^2 (P - Pavg)^2}} \quad (5)$$

where n is the number of observation and prediction stations; O is the value of the observed station; P is the value of the predicted station; $Oavg$ and $Pavg$ are the observed and predicted mean stations, respectively.

**Figure 7.** Cont.

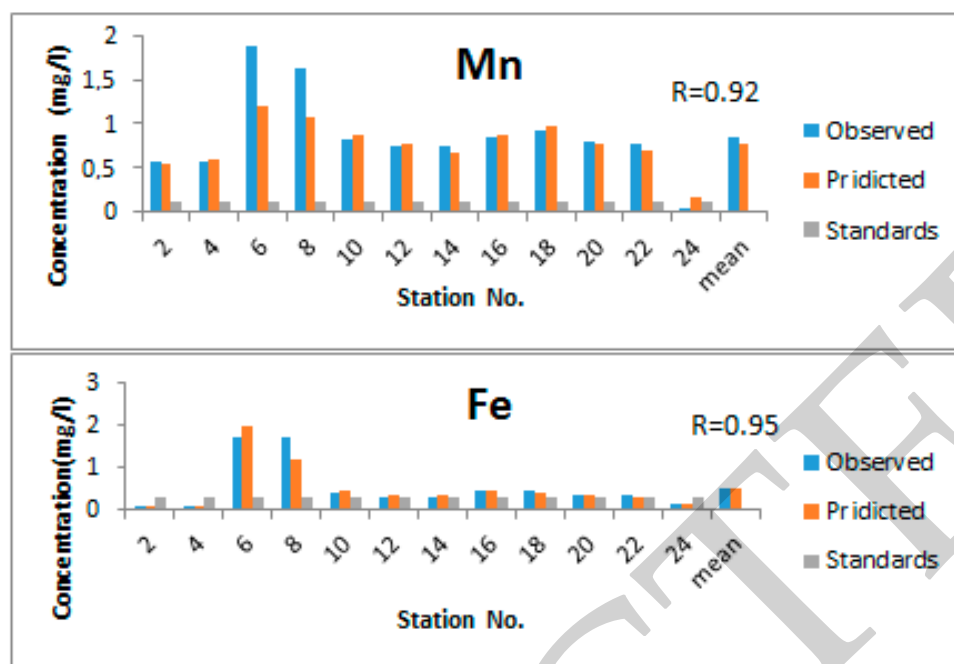


Figure 7. Comparison between observed and predicted concentrations of heavy metals along the study reach for copper (Cu), chromium (Cr), manganese (Mn), and iron (Fe).

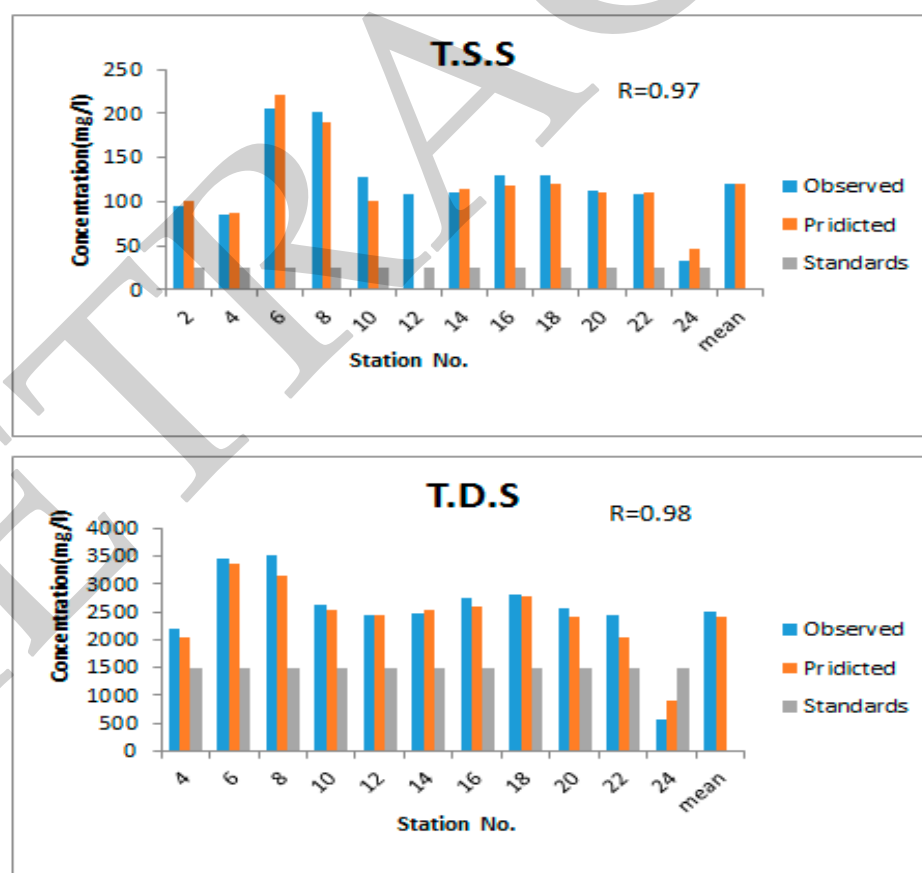


Figure 8. Comparison between observed and predicted concentrations of physical contaminants along the study reach for total suspended solids (T.S.S) and total dissolved solids (T.D.S).

The result showed that the value of the correlation coefficient (R) between the observed values derived from laboratory tests and the predicted values derived from the (IDW) interpolations were larger than 0.05 (0.87–0.99), as shown in Figures 7 and 8. This indicated that the model performance was reliable and that there were no differences between observed and predicted values. These values demonstrated a good agreement and adoption of the results from the derivation with a percentage error less than 10%. This implied that the simulation results obtained by the GIS can be used for extracting water quality maps and reducing the number of observation stations from 24 to 12 stations. This would reduce the number of water samples analyzed by 50%.

8. Conclusions

A GIS model was applied on the lower reach of the Diyala River to study the spatial distribution of some water quality variables. The results obtained from the simulating the pollutant transport can be summarized as follows:

- (1) The concentration levels of all pollution indicators, T.D.S, T.S.S, Fe, Cu, Cr, and Mn, were within the allowable limits. Then, the concentrations exceeded the allowable limits when wastewater was discharged into the river.
- (2) Diyala River's water affected the quality of the water of the Tigris River where concentrations of some variables exceeded the allowable limits.
- (3) Army Canal and Rustimiyah wastewater treatment plant outfall were the greatest significant point sources of contamination that badly affected the water quality of the river. This indicated that the water of the Diyala River within the study reach was not fit for potable water supply and the protection of aquaculture life.
- (4) The GIS model can be used as an effective tool to predicting and monitoring water quality. It can reduce the number of monitoring stations by 50%, thus decreasing the effort, and the financial and material costs.

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Conflicts of Interest: The authors declare no conflict of interest.

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