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GEOGRAPHICAL INFORMATION SYSTEM AND REMOTE SENSING FOR WATER RESOURCES MANAGEMENT CASE STUDY: THE DIYALA RIVER, IRAQ

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ABSTRACT

Utilizing Geographical Information System (GIS) in the management of water resources, especially, in the quality of surface water, constitutes a worthwhile attempt made in the improvement and control the levels of pollution in the water. In this paper, GIS technology was used in conjunction with Water Quality Index (WQI) to assess the suitability for consumption of water in the southern part of the Diyala River within Baghdad City for human needs based on the set of monthly measurements during the period from January to December 2016. The variables measured in seven monitoring stations along the studied reach of the river were: Total Dissolved Solids (T.D.S), Total Hardness (T.H), Sulphate ion ($SO_4^{=}$), Dissolved Oxygen (DO), and Biochemical Oxygen Demand (BOD_5). The results showed that the variables values higher than the permissible limits specified by Iraqi and WHO regulations for the dry and wet seasons. The digital pollution maps showed that the pollution moved from extremely polluted zones near the outfalls of wastewater to low polluted zones near the confluence of the Diyala and Tigris Rivers. Also, it is concluded that GIS techniques are among the most effective methods to display the seasonal variability on water quality, which can be used by the decision makers.

Keywords: Water Quality Index, Seasonal Spatial Variation, Geographical Information System, River Pollution Indices.

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1. INTRODUCTION

It has been estimated that water covers 71% of the earth's surface [1]. Water is essential to sustain life where a satisfactory (adequate, safe and accessible) supply must be available. Surface water is represented to be the primary source for a variety of needs such as “water supply, industries, and power plants….etc”. Surface waters periodically receive organic and inorganic contaminants which are as the result of man-made activities (i.e., municipal sewage, industrial wastewater and agriculture runoff), or pollution that is produced from natural sources on the quality of the water [2].

Water quality can be evaluated based on its chemical, physical and biological characteristics where these measured characteristics are specified as required to determine the suitability of the water for human consumption [3]. Surface water quality in developing countries now, is considered as a critical issue in recent years, due to the expected reduction in the quantum of fresh water that will be available in the future. A water can be monitored for different uses (e.g., preservation of aquatic life, drinking water use, and contact recreation). Evaluation of water quality depends on large number of samples and is very difficult due to the number of chemical, physical and biological ingredients. Mathematical modeling of river water quality is probable but needs more hydraulics and hydrodynamics data and it is require wide validation [4]. WQI in conjunction with (GIS) can be used to overcome most of the above mentioned problems and can specify the status of the water (i.e. excellent, good, bad, etc.). This will serve as an efficient tool for decision maker to identify its suitability for public uses [5]. This index will reflect the overall water quality at a certain location and time. It will also be fruitful in conducting a comparison between different water resources [6]. Several studies [7 - 11] used (one-dimensional finite difference technique, QUAL2K model, CCM-WQI model, CWQI model) to assess the water quality in the southren part of the Diyala river in Iraq. The outputs of these studies signified that the water quality of the Diyala River is not suitable for aquatic life, and Rustimiyah wastewater treatment plant has been found to be the main source of the pollution.

Geographic Information System (GIS) represents a powerful tool for collection, storage, management, retrieval of a multitude of spatial and non-spatial data, and spatial analysis and integration of the data to derive useful outputs [12]. Many researchers used the GIS technique to find solutions to water resources, such as those outlined in [13]. This study provided the means to summarize the overall conditions of water quality in a manner that can be clearly connected to policymakers by analyzing physicochemical water samples collected from different locations on the Mahi River (India) using GIS and WQI. The 96 water samples were collected from the Tigris River (Iraq) and these were used for evaluation the river water quality by spatial analysis with GIS [14]. Researcher [15] Evaluated the synthetically Eco environmental quality of Hunan Province by combining (GIS) with analytic hierarchy process (AHP).They showed that their method could be very interesting Policy makers and to help administrators resolve some problems about the eco-environmental. [16] Used geostatistical analysis for spatial interpolation of environmental data for the assessment of bathing waters quality. Other studies have proven that Inverse Distance Weighted (IDW) has irreplaceable advantages for data estimation in rivers because of its high level of accuracy, and it is widely used by earth scientists especially in river pollution modeling [17–20].

Water quality modeling is one of the important applications of (GIS) in water resources management. Thus, the main objectives of this research are:

- Using the (GIS) and (WQI) to assess the water quality within the Diyala River running through Baghdad City between upstream 3 Km from the Rustimiyah plant and the confluence of the Tigris-Diyala Rivers;

- Predicting the influence of the Diyala River on the water quality of the Tigris River; and
- Building digital pollution maps with the aid of GIS for the studied reach of Diyala River as case study.

2. MATERIALS AND METHODS

2.1. Study Area

The southern part of the Diyala River was chosen for the case study because it is considered to be one of the main water resources in Iraq. Its confluence with the Tigris river is south of Baghdad City, which is the capital of Iraq (Figure 1).

The population for this city may exceed 7.5 million persons, and the Diyala River represents the chief source for domestic, industrial, and irrigation water demands in this region [21].

The catchment of the Diyala River is comprised of two main regions located in Iran and Iraq. Along the total length of 574 km, this river has a drainage area of 33,240 km^2 of which 25% is located in Iran and the remainder in Iraq [22]. The reach selected for this study is approximately equal to 18 Km and it start 3 Km upstream of Rustimiyah's third expansion plant (R3B) (geographical coordinates 33°18' 34.2"N, 44°32' 13.8"E) and extended to the point of confluence with the Tigris-DiyalaRivers (33°13' 14.3"N 44°30' 21.14"E) (Figure 1).

The climatic conditions are characterized by a very hot summer and a short cold winter within the selected catchment. The period from November to April is considered as a wet season because 90% of the annual rainfall can occurred in this period with an annual precipitation of 420 mm [23]. Annual evaporation rate may reach 2000 mm/year [24]. Climate changes such as high temperature, low rainfall, and generation of dust storm have significant effects on the quality of river water.

There are five outfalls distributed along the reach of the river under consideration and these outfalls may be considered to be continuous sources of pollution that discharged wastewater to the DiyalaRiver and, consequently, to the Tigris river (Figure 1). The five sources of pollution are: (R3A), (R3B),(RO1),(RO2), besides the Army canal's outfall. The sources of pollution are located 16km before the confluence of Tigris River south of Baghdad City and they are considered as the chief components of Rustimiyah wastewater treatment plant. The disposal of wastewater from these sources can cause a serious deterioration for the quality of water in Diyala and Tigris rivers.

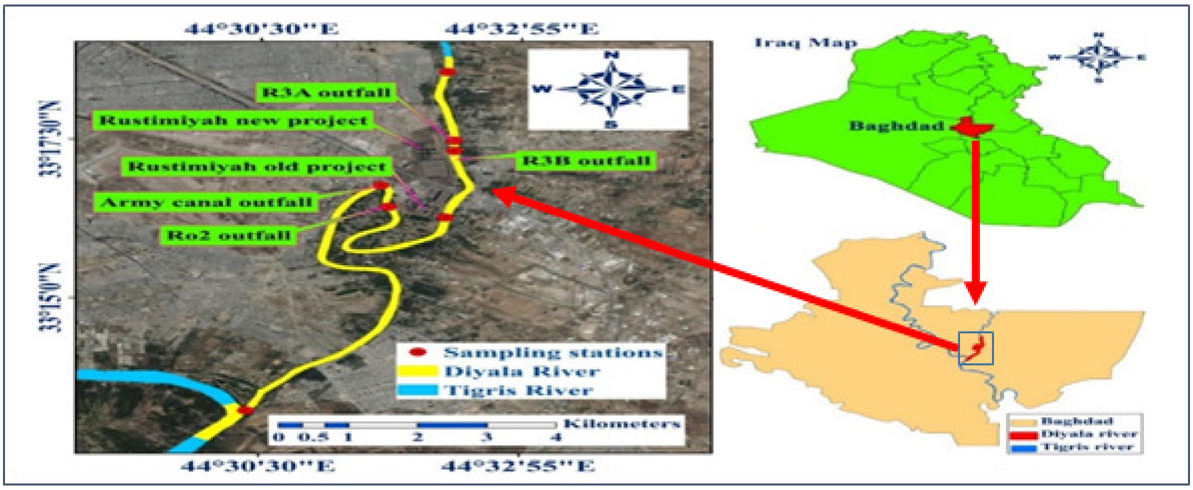


Figure 1 General layouts of the Diyala River reach

2.2. Sampling and Analysis

Seven sampling stations were selected to represent all the selected **river reaches** described previously within the study area. The coordinates and locations of these stations are summarized in Table 1 and Figure 2. The sampling station (St-1) is located upstream of the river can be considered as a reference station for other stations because it is far from the outfall of wastewater as shown in Figure 1.

Table 1 Coordinates of the sampling stations selected in the present study.

Station	Name	Altitude (m)		Geographic coordinates	
St-1	upstream	456915.4	3685695	33°18'34.2"N	44°32'13.8"E
St-2	R3A outfall	457007.4	3683689	33°17'29.1"N	44°32'17.7"E
St-3	R3B outfall	457008.7	3683391	33°17'19.4"N	44°32'17.8"E
St-4	Ro1 outfall	456875.9	3681445	33°16'16.2"N	44°32'13.0"E
St-5	Ro2 outfall	456052.1	3681756	33°16'26.2"N	44°31'41.1"E
St-6	Army canal	456052.1	3681756	33°16'46.9"N	44°31'36.9"E
St-7	Confluence with the Tigris river	453952	3675847	33°13'14.3"N	44°30'21.14.3"E

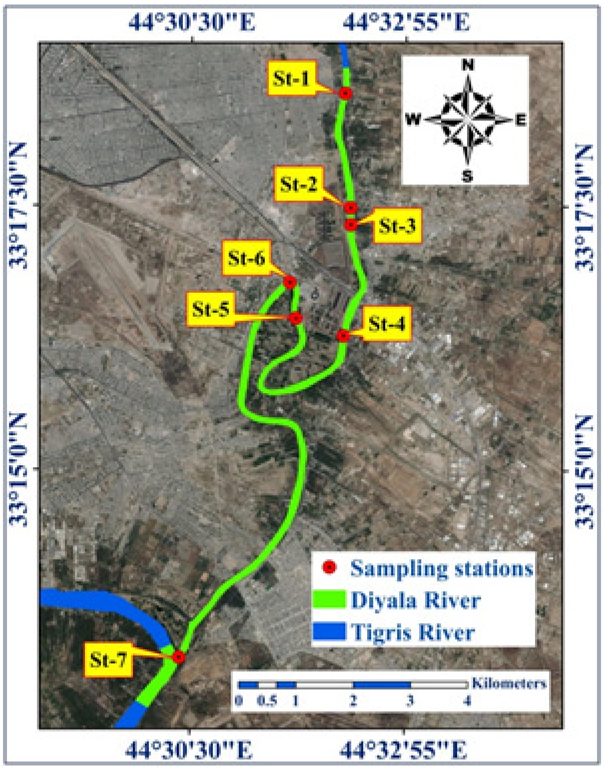


Figure 2 Locations ofthe sampling stations selected in the present study.

The sampling period commenced in 2016 and continued for one year where monthly samples were taken periodically from the stations described previously. Samples were taken from the middle region of the river at distance approximately equal to 35 m from the right or left bank of the river and at 50 cm under surface of the water. . The water samples were collected in high-density polyethylene bottles (1-liter capacity) under sterile conditions. Sample stabilization and analysis were achieved within 24 h to avoid the possible changes due to degradation or otherwise, taking into account all recommendations of the standard methods for analysis [25]. Total Dissolved Solids (TDS), Total Hardness (TH), Sulfate (SO_4), Dissolved Oxygen (DO), and Biological Oxygen Demand (BOD) were analyzed according to the methods described in Table 2, and these parameters can be used in the evaluation of water quality through WQI.

.**Table 2** Standard methods for measurement of parameters adopted in the present study.

Parameter	Units	Technique used
T.D.S	mg/L	Evaporation and calculation methods [26]
SO_4	mg/L	$AgNO_3$ titration
T.H	mg/L	Titration by standard EDTA
DO	mg/L	standard method 4500 in the field ,DO meter (HACH, 6)
BOD	mg/L	Winkler's method, incubation for 5 days at 20°C

2.3. Geographic Information System (GIS) Analysis

GIS is a very efficient and economical choice for planners to develop an instrument that is spatially area-wide with inbuilt water quality protection programs. The application of this technique allows the user to overlay coverages, analyze and determine pollutant load rates and provide both spatial and temporal information of surface water characteristics [27].

The pollution path in the Diyala River was formulated using Excel and GIS ArcView 10.4 (Esri, Redlands, CA, USA) (i.e. Buffer, Clip, Extract, Overlay, Proximity, Convert, Reclassify, and Map Algebra, etc.). Global references and coordinates for each location were recorded by mobile GPS (Etrax). Google Earth was used as support tool to provide the required input data for adopted chemical parameters in the stations described above for operating the GIS model.

The sampling locations were integrated with the water data to generate the spatial distribution maps. Spatial analysis tools, and interpolating a raster surface were used along with the Inverse Distance Weighted (IDW) technique for spatial interpolation of water parameters. IDW is a type of deterministic method for multivariate interpolation with a known scattered set of points. It is assigned cell values using a linear-weighted combination set of sample points. The assigned weight is a function of the distance of an input point from the output cell location and the greater the distance, the less influence the cell has on the output value [28].

2.4. Water Quality Index calculations

The degree of water quality suitability for a particular use can be specified by WQI. Mathematically, this index is represented by an arithmetic-weighted term that is used to transform the large numbers of water quality data into a single value [29]. WQI was calculated based on the procedure developed by [30] using five parameters (Table 3) in combination international WHO standards [31] with Iraqi [32] as follows:

$$WQI = \Sigma\, qi\, Wi / \Sigma\, Wi \qquad (1)$$

Where Wi is the weighting factor computed by,

$$Wi = K/Si \qquad (2)$$

Where Si is the standard value for selected parameter using Iraqi and international WHO standards (Table 3) and K is proportionality constant calculated by,

$$K = 1/(\sum_{i=0}^{n} \frac{1}{Sn}) \qquad (3)$$

The quality rating (qi) for the nth water quality parameter is determined as follows:

qi = 100 (Vi – V10) / (Si – V10) (4)

Where Vi is the estimated value of the nth parameters at certain station, V10 is the ideal value of the nth parameter of the pure water. All the ideal values are assumed zero for the drinking water except DO equal to 14.6 mg/L.

The WQI values were calculated for all parameters in the selected stations and the water was identified as excellent, good, poor, very poor and unsuitable for human consumption (Table 4) [33].

Table 3 Drinking Water Standards according to international (WHO) and Iraqi Standards [31-32] (All values in mg/L).

No.	Symbol	Standards	Recommended agency	Unit Weight(Wi)
1.	T.D.S	1500	Iraqi and international standards	0.00067
2.	T.H	300	Iraqi and international standards	.0033
3.	SO_4	250	Iraqi and international standard	0.004
4.	DO	5	Iraqi and international standard	0.2
5.	BOD	6	Iraqi and international standard	0.167

Table 4 Classification of water according to the WQI [33].

Water Quality Index (WQI)	Water quality status
0-25	Excellent
26- 50	Good
51-75	Poor
76-100	Very poor
Above 100	Unsuitable for drinking

3. RESULTS AND DISCUSSION

3.1. Hydrochemistry Seasonal Variation of the River

Several sources were used to formulate the necessary map layers within the GIS. The first source was digital maps (shapefile). The individual shapefile maps for the Diyala River were set using the internal reports of the Iraqi Ministry of Education [34]. The second source converted the available maps into the digital maps using the appropriate information checked by analyzing satellite images of the Baghdad Governorate [35]. The third source was the experimental data from the laboratory analysis for the indicators of concentrations of pollutants. Table 5 shows the statistical summary of mean and standard deviations for concentrations of T.D.S, T.H, SO_4, DO, and BOD_5 for the selected stations in the wet and dry seasons.

Table 5 Mean± standard devotion concentration (mg/L) of the selected environmental parameters during the study period from January to December in 2016.

Station No.	T.D.S		T.H		SO_4		DO		BOD_5	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
St-1	1412.8 ± 301	1502 ± 221	746.6 ± 160	748.16 ± 20.4	545 ± 137	740 ± 202	7.6 ± 3.1	8.5 ± 0.92	746.6 ± 0.22	748.1 ± 0.72
St-2	1418.5 ± 649	1301 ± 52.8	752.3 ± 102	816.83 ± 104	777.3 ± 447	790 ± 65	3.656 ± 1.7	6.335 ± 3.47	752.3 ± 49	816.8 ± 34
St-3	1728.5 ± 100	1699 ± 289	840.5 ± 117	775.83 ± 78	776.8 ± 50	474.6 ± 99	7.041 ± 3.3	4.633 ± 1.7	840.5 ± 55	775.8 ± 70
St-4	1729.1 ± 245	1807 ± 150	668.3 ± 290	815.66 ± 127	504.6 ± 121	604.6 ± 177	4.001 ± 2	6.811 ± 3.85	668.3 ± 70	815.6 ± 23.7
St-5	1258.8 ± 62	1663 ± 337	787.5 ± 37	813.5 ± 116	514.5 ± 174	815.6 ± 76	3.495 ± 1.6	6.955 ± 3.1	787.5 ± 58	813.5 ± 30.7
St-6	1430.5 ± 265	1276 ± 112	778 ± 46	823 ± 127	633.3 ± 166	606 ± 77	4.306 ± 0.94	6.755 ± 3.2	778 ± 74	823 ± 30.45
St-7	1405.5 ± 283	1820 ± 196	773 ± 42.8	818.83 ± 126	670.5 ± 160	785 ± 73	5.626 ± 1.16	6.045 ± 2.98	773 ± 67.5	818.8 ± 31.9

The experimental results for the seven stations were imported into GIS as features and, then, these data were converted into a shapefile using the “export data” feature to produce the shapefile map for adopted parameters. The extension tool “IDW” within GIS was used to generate the digital map of the pollutants concentrations and, finally, the digital map was produced for the dryseason (Figure 3) and the wet season (Figure 4). The maximum concentration of the T.D.S was equal to 1820 mg/L in the wet season, while this value decreased in the dry season to 1729 mg/L and this may be due to large quantities of sediment transported throughout the rainy seasons as well as the cutting of Wand river coming from the Iranian regions since 2008 [22]. It can be seen that these values have exceeded the allowable limits according to the Iraqi and international standards for water quality which equals to 1500 mg/L for T.D.S, however, this result is consistent with the findings of many studies such in [7] and [9]. The concentration of T.H was observed to be very high, and its values were equal to 840 and 822 mg/L for dry and wet seasons, respectively, in comparison with the acceptable limit which equals to 300 mg/L. The high values of this indictor can be recognized in the St-3, and this may be the result from the disposal of industrial and municipal sewage which is characterized by the presence of a large quantity of alkaline ions. This result is in agreement with the study in [10]. The highest value of $SO_4^{=}$ was measured in the wet season and reached 815 mg/L; however, the presence of this ion can be the result from the wastewater of fertilizer manufacturing industries and agriculture areas located around the river. The values of $SO_4^{=}$ in the stations distributed along the Diyala River exceeded the permissible limit specified by both the Iraqi standards for water quality and WHO standards for drinking water. Similar results were obtained by the study in [10].The values of BOD_5 ranged from 129.8 to 75.8 mg/L and these values are identical to those of the dry and wet seasons, respectively. The concentration of the BOD_5 decreased in the wet season, and this may be because of the dilution as a consequence of surface run-off produced from heavy rainfall. The values of BOD_5 were greater than the acceptable limit (i.e. 6 mg/L) and this result is similar to the results noticed by [8 -10] and [36].The measurements of DO indicated that its value ranged from 7.65 in the dry season, and it has increased to 8.51 mg/L in the wet season. This increase is very logical, because the presence of rainfall will play a significant role in increasing aeration, as well as the decrease in temperature through the winter season which will enhance the solubility of oxygen. The values of DO for the wet season are greater than the permissible limit which has a minimum value of 5 mg/L, and this is a positive indictor about the status of water quality in comparison with results of other parameters described in previous points. For the dry season, the values of DO changed from “acceptable” at St-1, St-2, and St-7 to “not acceptable” for the remaining station, and this can be attributed to the increase in temperature and, consequently, the decrease of flow rate in the river. This result is in agreement with the findings of [10] and [36-39]. All the values mentioned above about the seasonal variation (Max., Min., and Standard) of water quality for the Dry and Wet seasons are summarized as shown in (Figure 5). All the results also supported by observations of earlier workers [7-11], [22], [36].

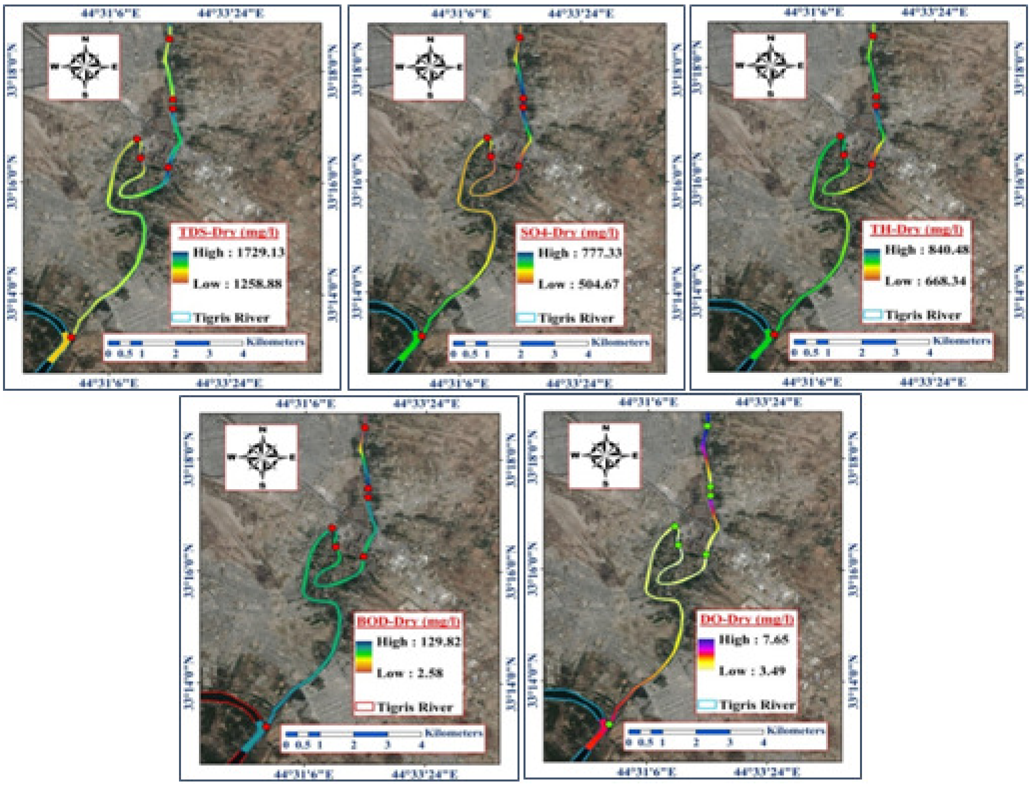


Figure 3 Maps of the spatial distribution of concentrations for dry season (**a**) T.D.S; (**b**) $SO_4^{=}$ (**c**) T.H (**d**) BOD_5 (**e**) DO

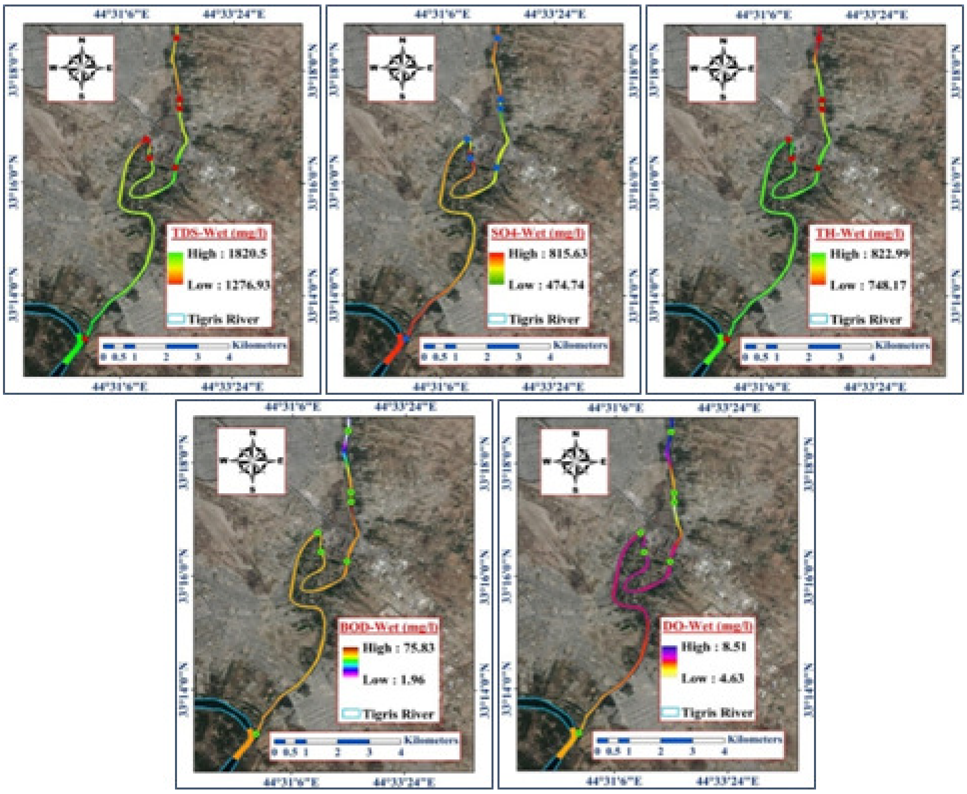
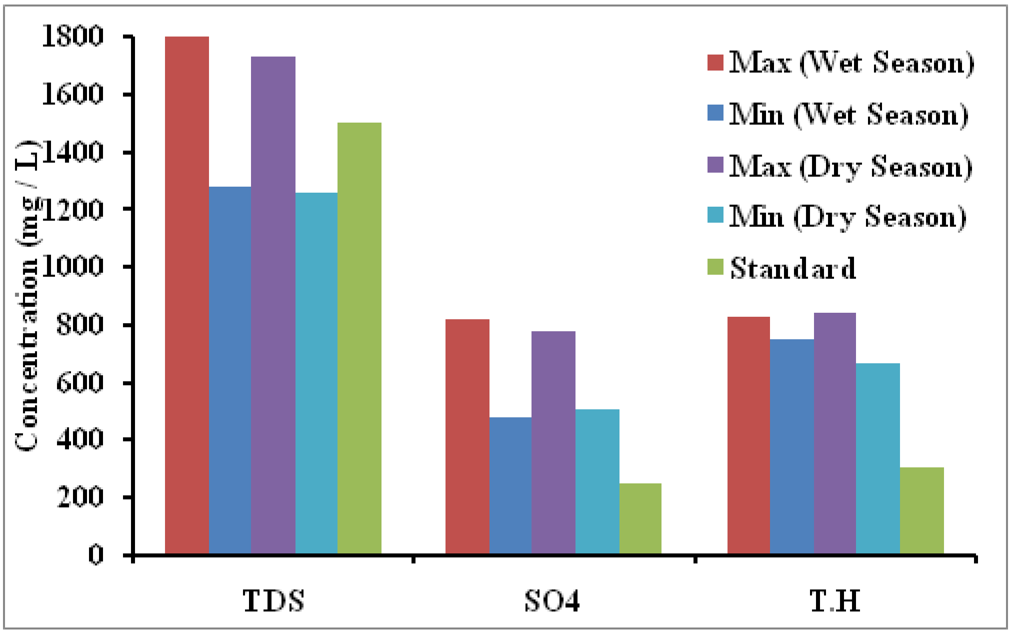


Figure 4 Maps of the spatial distribution of concentrations for wet season (**a**) T.D.S; (**b**) $SO_4^{=}$; (**c**) T.H; (**d**) BOD_5; (**e**) DO



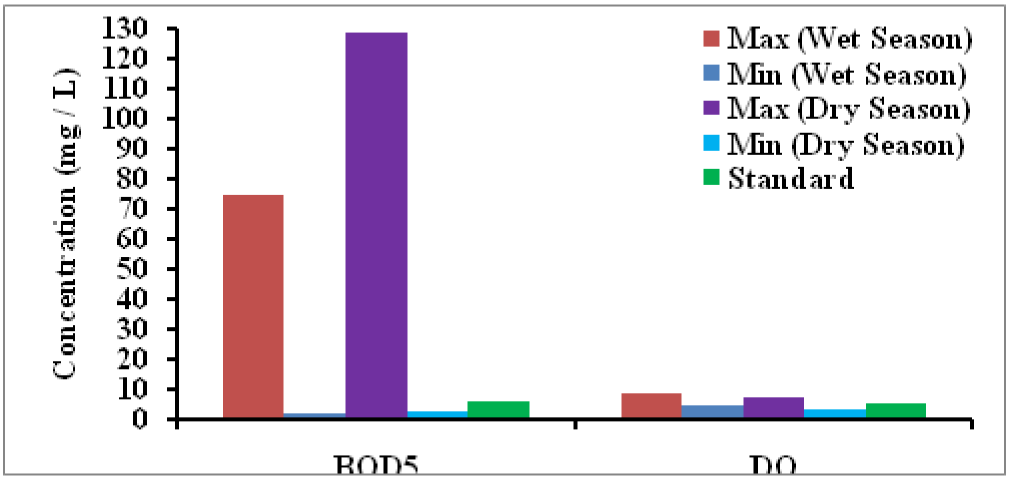


Figure 5 Comparison between Seasonal variations of Max., Min.,and Standard concentration values for **a**) T.D.S; $SO_4^{=}$; T.H; **b**) BOD_5; (**e**) DO

3.2. Water Quality Index groups

WQI values of the southern part of the DiyalaRiver were calculated for wet and dry seasons as listed in Table 6. By the application of GIS and IDW, the outputs data of the pollution for two seasons adopted in this analysis have been plotted for the studied region and were low moderately high, very high, and extremely polluted zones where this variation is very important in the visualization of most polluted region.

In the wet season (Fig. 6.a), the sites near St-2 and St-3 were characterized by very high and extremely polluted zones, while sites near St-6, St-5, St-1 can be classified as highly polluted zones and the sites near St-7 may vary from moderate to low pollution zones. In the dry season (Fig. 6.b), more regions are extremely polluted and the sites near St-6 may be classified as the highly polluted, but sites near St-7 remained as low polluted zones.

The difference in in the WQI map for both seasons (Fig. 6.c) showed that St-7 has a much lesser change based on WQI values. The remaining stations such as St-3, St-4, St-5, and St-6 showed a maximum change in the WQI values. This means that the surface run-off resulting from rainfall played a significant role in the reduction of the pollution which arrived in the river and this dilution varied spatially dependent on the site of the pollution source.

Table 6 Water Quality Index of the southern part of Diyala River for wet anddry seasons.

Station No.	WQI for Wet season	WQI for Dry season	Difference in WQI
St-1	624	974	350
St-2	676	1118	442
St-3	804	1005	201
St-4	504	1000	496
St-5	624	974	350
St-6	634	858	224
St-7	530	617	87

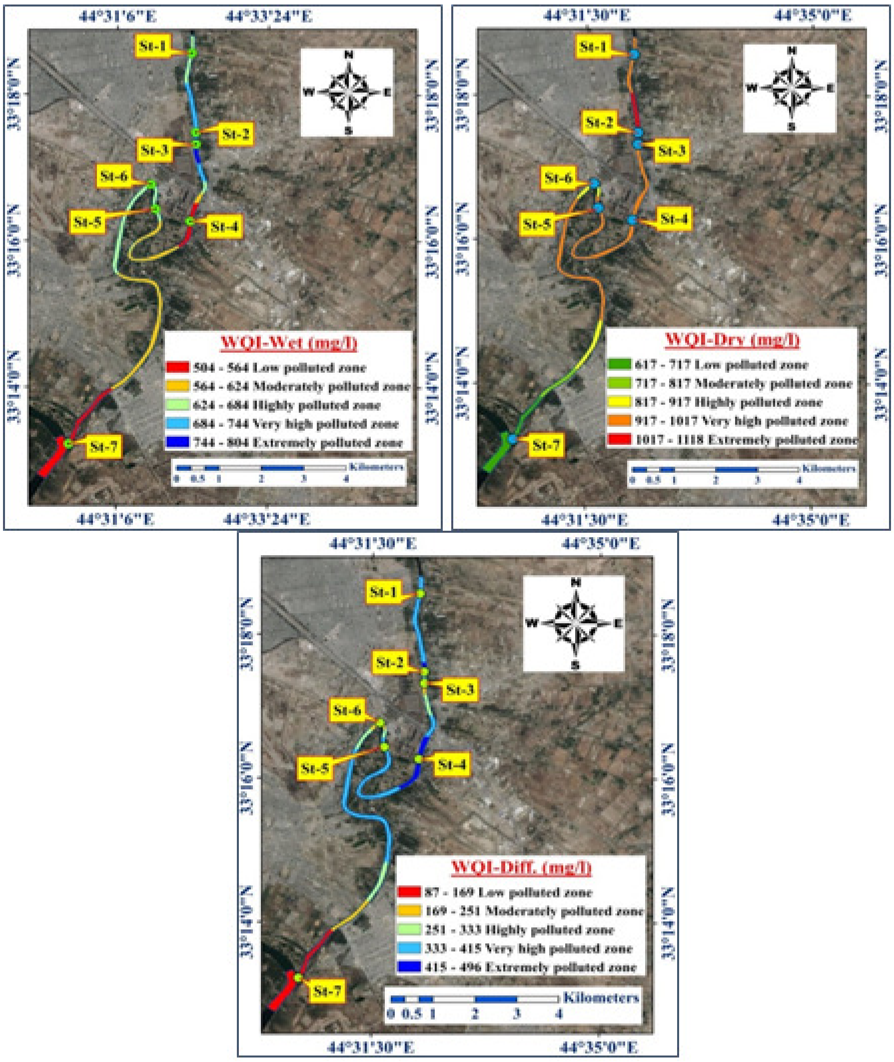


Figure 6 Spatial distribution of WQI of southern Diyala River for.**a**) Wet seasons, b) Dry season, and c) Difference in WQI.

4. CONCLUSION

Spatial interpolation of GIS using WQI parameter was utilized for plotting the digital pollution maps in order to describe the suitability of water for human needs in the regions located on the southern part of Diyala River. These maps represent an efficient tool for managing the water quality of the river and minimizing the negative impacts on the ambient environment. The field monitoring for the selected reach started between January and December 2016 based on the TDS, TH, SO_4, and BOD_5 signified that these parameters have values greater than the permissible limits specified by Iraqi and WHO regulations for the dry and wet seasons. Conversely, the values of DO fluctuated from acceptable to unacceptable for all stations based on the season type. However, WQI can be collected from all the measured values and can be converted into a single value for each site, and these values proved that the pollution was graded from extremely polluted zones (in the locations near to the outfalls of wastewater) to low polluted zones in the locations near to the confluence of Diyala and Tigris rivers. Finally, this study signified that the GIStechnique has the ability to connect the information of the water quality, and through this method the problems in the management of water resources can be solved in a successful manner.

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