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Classification Maps for TDS Concentrations in the GIS Along Euphrates River, Iraq

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Abstract Iraq currently undergoing the problem of water shortage, although Iraq has two Rivers (Euphrates and Tigris) pass throughout most of its areas, and they have represented a major source of water supply. In the current research, to evaluate the quality of the Euphrates river in Iraq based on the values of total dissolved salts (TDS), the TDS concentrations were collected from sixteen sections along the river in the three succeeding years (2011, 2012, and 2013). The evaluation of the river was done depending on the classification of (W.H.O. (World Health Organization). (2003). Total Dissolved Salts in Drinking-water: Background document for development of W.H.O. Guidelines for Drinking-water Quality. World Health Organization, 20 Avenue Appia, 1211 Geneva 27, Switzerland). of rivers for drinking uses. Inverse Distance Weighting Technique (IDWT) as a tool in the GIS was employed to establish the maps of the river that using interpolation/prediction for the TDS concentrations to each selected year and the average values of TDS for these 3 years. Based on the five categories of rivers' classification of the TDS concentrations according to the (W.H.O. (World Health Organization). (2003). Total Dissolved Salts in Drinking-water: Background document for development of W.H.O. Guidelines for Drinking-water Quality. World Health Organization, 20 Avenue Appia, 1211 Geneva 27, Switzerland), the Euphrates river was classified, and the maps of classification for the years 2011, 2012 and 2013 and the average values for 3 years were created. The average values for 3 years of TDS along the Euphrates river indicated that the sections from SC-1 to SC-4 as moderate-water-quality-Category-3, the sections from SC-5 to SC-10 as poor-water-quality-Category-4, while the sections between SC-11 to SC-16 as very poor-water-quality-Category-5. The interpolation maps showed that the Euphrates river in Iraq was ranged from moderate water quality (Category-3) to very poor water quality (Category-5).

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1 Introduction

Water quality of the river has a great effect on different aspects of human life, additionally, effect on the environment, industrial and agricultural. Water quality is related to human activities and changing of natural factors (WHO and UNICEF, 2010). In developing countries, most untreated sewage is sent directly out into different water sources (W.H.O. and UNICEF, 2010), and every year more than 300 million tonnes of contaminated materials are dump into water bodies (W.H.O. and UNICEF, 2010). So, many strict instructions and standards to preserve water quality were set which were adopted by several local and international organizations such as World Health Organization (WHO), Environmental Protection Agency (EPA), Food and Agriculture Organization (FAO), and UNICEF (United Nations Children's Fund) (W.H.O., 2017; EPA, 2017).

The population in Iraq is around 40,000,000 in 2018, and its area is about 438,000 km^2. In Iraq, the water consumption that used for agriculture is 38.1 billion m^3/year, 25.38 billion m^3/year for Industry and 16.92 billion m^3/year for human usage. Recently, the discharge of the two main rivers in Iraq is ongoing to reduce, and Iraq is facing water shortage problems now (UN-ESCWA, 2013).

Climate change affected water bodies in Iraq, where many factors contributed to change the water level and environment system in the Tigris and Euphrates rivers such as raise temperatures and decrease the annual precipitation rate (Adamo et al., 2018).

Euphrates river suffered from decreased water level in the previous years that led to the increased salinity in the river over 1500 ppm according to WHO (2017). This is considered a serious problem on the river system, consequently, on the human and surrounding environment. The reasons for increased salinity in the river related to building huge reservoirs in the origination of the river (Turkey and Syria). Moreover, the effects of long series of wars and the erroneous planning of different governments as well as the irrigation system in Iraq are still ancient until the current time (Al Bomola, 2011; Al-Tikrity, 2001).

Iraq is based mainly on the Euphrates Tigris Rivers to provide water for municipal uses and for irrigating the agricultural lands (Murakami, 1995; Rahi & Halihan, 2010). According to WHO (1997), water with a salinity of more than 1000 mg/L is invalid useful for human consumption or drinking, whilst the water to be unsuitable for most municipal uses also for the most main crops when the salinity over 3000 mg/L (Rahi & Halihan, 2010).

Ali and Salewicz (2005) mentioned that the salinity of the Euphrates river is increased with its length (from north to south) and with time from about 500 ppm to more than 4500 ppm to reduce the salinity of the river and to be as a natural river; through retrieving its ecosystem, the flow rate of the river should be in a minimum acceptable of the water level (Rahi & Halihan, 2010).

The water quality with a salinity of 480 ppm was considered valid for human consumption and irrigation usage according to the recommendations FAO (1976), whereas the range from 480 to 1920 ppm was classified for irrigation usage from slight to moderate.

According to the UNEP (2003), and the Arab Science and Technology Foundation (2005), the acceptable level of salinity in the rivers for drinking water as Iraqi standards should not be more than 1000 ppm.

In this study, the total dissolved salts (TDS) along the Euphrates river were sampled from sixteen sections in the years 2011, 2012, and 2013.

Many former researchers studied the quality in the parts of the Euphrates river within the Iraqi border such as (Al Bomola, 2011; Al-Heety et al., 2011; Al-Obeidi, 2017; Abbas & Hassan, 2018; Abdullah et al., 2019). Chabuk et al. (2020) studied the water quality along the Euphrates river within the Iraqi border.

The geographic information system (G.I.S.) is employed for collecting, managing, and analyzing the data. G.I.S. mixes various kinds of information with mathematical models to generate the required maps. G.I.S. and remote sensing were employed to determine the properties of parameters in water bodies such as (Panhalakr and Jarag, 2016; Tomislav, 2009).

The Inverse Distance Weighted Technique (IDWT) in ArcGIS is used to create the maps for physical–chemical parameters of rivers as this technique gives high accuracy to estimate the interpolation

based on the existing known values that are distributing along a river for unidentified points (Madhloom & Alansari, 2018; Chang, 2019).

Several researchers adopted the combining GIS and IDWT in their research papers to produce the interpolation maps for different rivers as a study area such as Longley et al. (2005), Frenken (2009), JICA (2011), Tyagi et al. (2013), Alsaqqar et al. (2015), Al-Jiburi and Al-Basrawi (2015), Iraqi of Ministry of Water Resources (2015) and Chabuk et al. (2020).

The major objects in the present study can be observed in the schematic diagram (Fig. 1). This research aims to assess the (TDS) concentrations in three years (2011, 2012, and 2013) as well as the average values for the 3 years at sixteen sections along the Euphrates river within the Iraqi border. Furthermore, producing the maps of TDS concentrations for Euphrates river after implementing the interpolation between their readings in ArcGIS for each year and their average values through applying the I.D.W.T. Classifying of the quality of total length-way of the Euphrates river for drinking uses based on the TDS concentrations at sixteen sections. Creating prediction maps after classification the (TDS) concentrations along the river according to WHO for 3 years and the average concentrations of the TDS for the three years.

2 2. Methodology

2.1 Study Area

The length of the Euphrates river is 2786 km which represented the longest river in southwest Asia also in the Middle East (Fig. 2). The river length is divided into three main Sects. (455 km, Turkey), (661 km, Syria), and (1670 km, Iraq) (Al Bomola, 2011; Balciogullari, 2018; UN-ESCWA, 2013; Abdullah, 2017). The Euphrates river shares its total catchment area (444 thousand km^2) by four countries which are Turkey, Syria, Iraq, and Saudi Arabia, where the sharing catchment areas in these countries are (respectively) 28, 17, 41 and 14% (Mahmoud, 2010; UN-ESCWA, 2013). From the southeastern part of Turkey by two main tributaries (Karah Su, and Murad Su), the Euphrates river originates. The tributary Karah Su

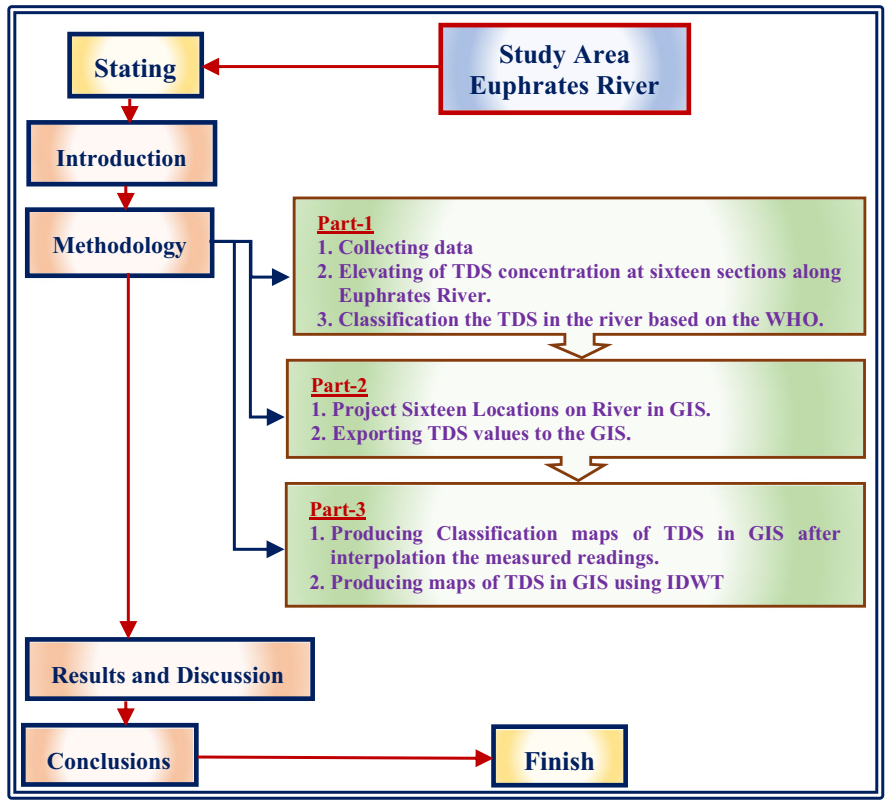

Fig. 1 The schematic diagram of main outlines of research

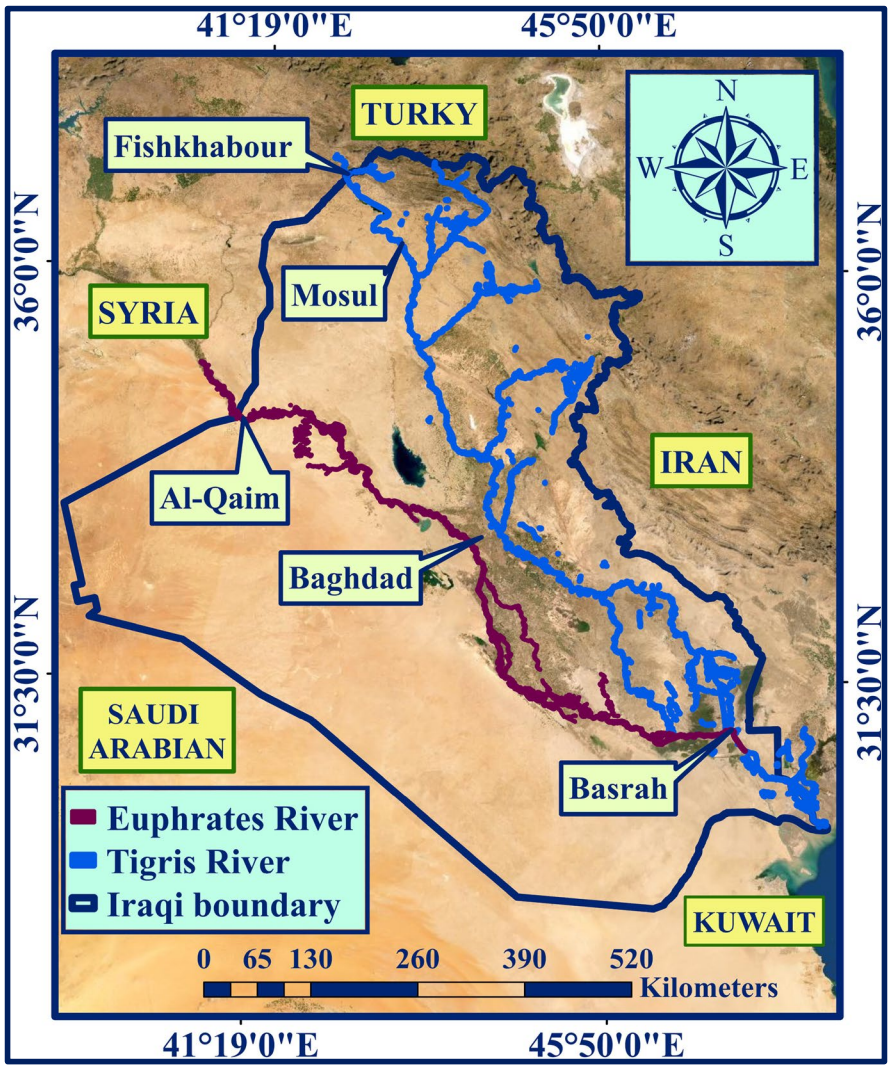

Fig. 2 Study area: the Euphrates and Tigris rivers, Iraq

links with tributary Karah Su at Kharbut-city where it is situated in north Kuban city, where after this city the river defines as Euphrates river (Mahmoud, 2010). Then, a small number of tributaries flow in the major stream of the river in this area; then, a small number of tributaries flow in the major stream of the river in this area. The river passes through Taurus Mountain Range to the border of Turkish-Syrian, and then, at Jarablis city the river enters the second country Syria with an elevation of 325 m (above mean sea level) (Mahmoud, 2010).

The Euphrates river length inside Syria is 675 km. Three tributaries that join with the mainstream of the river are Shajur, Balikh, and Khabur. The last city where the river leaves the Syrian lands is Albukamal, while Hisaybah-city is the first city that the river enters the Iraqi border (Mahmoud, 2010; Al-Ansari, 2013).

Nearby Baghdad city, the stream of Euphrates river (inside Iraq border) comes close to the Tigris River stream. Inside Iraq, there is no tributary (Al-Ansari et al., 2019). After Hadithah city, the river flows towards the south, where during flood season part of the river water is transferred to the south of Al-Ramadi city into Habaniya reservoir. After the river passes the Al-Fallujah city and flows toward the south, it reaches the Al-Hindiyah barrage. The water at this barrage is diverted into small parallel channels. et al.-Kifll city, the Euphrates river divides into two major channels (Shamiyah city and Kufah city), and

then, these channels link et al.-Mushkhab city (Al-Ansari et al., 2019).

The river continues flowing toward the south until reaching Al-Samawah city. Two main channels form when the river enters the Hamar marsh. The first channel (et al.-Qarnah-city) links to the Tigris river to form Shat Al-Arab river. At Qarmat Ali city, the second channel joins the Shat Al-Arab River (Al-Ansari et al., 2019).

In Turkey, the constructed dams on the Euphrates river contain Ataturk dam, Birecik dam, Camgazi dam, Hancagrz dam, Karakaya dam, Karkamis dam, and Keban dam, while the suggested dams in Turkey on the river consist of Buykcay dam, Catallepe dam, Gomikan dam, Kahta dam, Kayacik dam, Kemlin dam, Koeali dam and Sirmtas dam. In Syria, there are three concentered dams on the Euphrates river, and these dams are Forat dam, Baath dam, and Teshreen dam. Hadithah dam was constructed in 1987 with constructed several barrages on it to regulate the flow of the river within Iraq on the Euphrates river (Al-Ansari, 2013; ESCWA, 2013; Al-Ansari et al., 2019).

2.2 Collection Data

The TDS values were collected from sixteen sections by the Iraqi of Ministry of Water Resources (2015) on the Euphrates river (inside Iraqi borders) for the years 2011, 2012 and 2013 (Fig. 3). The sixteen sections along the direction of the river from north to the south are Qaim city, Before Hadithah dam, Hadithah dam, Hit city, Al-Ramadi city, Al-Saqlawyah city,

Fig. 3 Euphrates river, Iraq, and sections of sampling data

Al-Fallujah city, Al-Yusfiyah city, Al-Hindiyah city, Al-Kifl city, Al-Shinafyah city, Al-Samawah city, Al-Nasiriyah city, Al-Madinah city, Al-Ayz city and Al Qarnah city (Table 1).

2.3 Classification of the Water River for Drinking Uses

The TDS concentrations for raw water were divided into five categories for drinking and other uses according to the WHO (2003). For Category-1, the values of less than 300 ppm were classified as excellent for drinking and other uses, whilst the category and range of Category-2 from 300 to 600 ppm, Category-3 from 600 to 900 ppm, Category-4 from 900 to 1200 ppm and Category-5 for values more than 1200 ppm were classified for drinking and different uses of domestic (respectively) as good, moderate, poor and very poor (Table 2).

Table 2 Total dissolved salt classification of raw water for drinking uses (W.H.O., 2003)

Categories	Range ppm	Status
Category-1	0–300	Excellent
Category-2	300–600	Good
Category-3	600–900	Moderate
Category-4	900–1200	Poor
Category-5	> 1200	Very poor

2.4 Predicting Maps of TDS Concentration Using I.D.W. Technique

To generate maps of TDS concentrations for the whole length of Euphrates river after applying the interpolation for each year (2011, 2012 and 2013), the Inverse Distance Weighted Technique (I.D.W.T.) was performed. The IDWT is used to estimate the accuracy of interpolation for unknown points based on known local points (Panhalakr & Jarag, 2016). According to, the IDWT is considered more accurate than other techniques for interpolating purposes

Table 1 TDS Concentrations were collected from the Euphrates river for the years 2011, 2012 and 2013 (Iraqi of Ministry of Water Resources, 2015)

Sections	X-direction	Y-direction	TDS (ppm)			
			2011	2012	2013	Average
Qaim-city (SC-1)	145,828.49	3,811,145.8	864	812	774	817
B. Hadithah-Dam (SC-2)	256,792.14	3,802,575.4	897	813	732	814
Hadithah-Dam (SC-3)	256,315.88	3,788,270.9	960	808	729	832
Hit city (SC-4)	298,338.05	3,724,987.7	1008	869	785	887
Al-Ramadi city (SC-5)	338,975.11	3,701,450.8	1046	935	834	938
Al-Saqlawiyah city (SC-6)	377,614.99	3,693,759.2	1014	929	881	941
Al-Fallujah city (SC-7)	384,706.16	3,690,033	1040	983	897	973
Al-Yusfiyah city (SC-8)	419,299.97	3,656,543	1020	993	937	983
Al-Hindiyah-city (SC-9)	431,424.75	3,621,488.3	1028	962	921	970
Al-Kifl city (SC-10)	439,923.68	3,566,078.8	1048	1029	959	1012
Al-Shinafyah-city (SC-11)	466,370.21	3,493,999.8	3465	2803	3186	3151
Al-Samawah city (SC-12)	526,825.86	3,465,069.7	3675	2991	3607	3424
Al-Nasiriyah city (SC-13)	619,289.06	3,434,936.4	4369	3589	3978	3979
Al-Madinah city (SC-14)	715,643.82	3,427,070.4	4397	2777	2016	3063
Al-Ayz city (SC-15)	727,681.52	3,429,874.3	2510	2051	2259	2273
Al Qarnah city (SC-16)	731,745.72	3,432,712.3	2515	1824	1373	1904
Average			1928	1573	1554	1685
S.D			1298	927	1078	1080
Max			4397	3589	3978	3979
Min			864	808	729	814

for separate points and long rout (Panhalakr & Jarag, 2016).

3 Results and Discussion

The values of TDS concentration along the Euphrates river in the years 2011 and 2012 were ranged (respectively) from 864 ppm (SC-1) to 4397 ppm (SC-14) and from 808 ppm (SC-3) to 3589 ppm (SC-13). In 2013, the TDS readings were ranged between 729 ppm (SC-3) and 3978 ppm (SC-13). The values of TDS for the average of three years were varied from 814 ppm (SC-2) to 3979 ppm (SC-13).

The TDS concentrations at all sections (SC-1 to SC-16) on the Euphrates river have exceeded the allowable limit of the WHO (500 ppm) (W.H.O., 2003; EPA, 2018). Comparing with the Iraqi standard limit of 1000 ppm, the values of the TDS readings from (SC-1) to (SC-3) in 2011 and from (SC-1) to (SC-10) in 2012 and 2013 were within the allowable limit. Other values of TDS between (SC-4) and (SC-16) in 2011 and between (SC-11) and (SC-16) were exceeded the standard limit. The values of it that exceeded maximum limit are related to many factors such as the Euphrates river receives different pollutants discharging into the river such as industrial wastes, runoff of agricultural waste and domestic wastewater consequently, to the effect of salts accumulated from upstream sections on the downstream sections of the river.

Generally, the trends of TDS levels at all chosen sections along the river were increased from Qaim city in the western part of Iraq (section SC-1) toward the Al-Qurnah city in the southern part of Iraq (SC-16).

In the current study, for the average values of the 3 years, the peak concentration of TDS was recorded at the section (SC-14) at the Al-Nasiriyah city, whereas the lowest value of TDS recorded at the section (SC-2) (Before Hadithah-Dam) is because at this part of the river route there are low agricultural and industrial activities comparing with the activities for part of Euphrates river from section SC-11 to section SC-16.

After sections SC-14, the readings at SC-15 and SC-16 were decreased comparing with the readings at stations SC-11–SC-14 (Fig. 4). This is due to the Tigris river and Euphrates river is mixing at these sections to create the Shatt Al-Arab river; consequently, the concentration of TDS in the Tigris River is lower than the TDS concentration in Euphrates river, where this is acted as a dilution factor to decrease the TDS concentration in these sections. The concentrations of TDS increased gradually from the north (section (SC-1)) to the south (section (SC-16)) along the river (Fig. 4). The increase has resulted in the presence of major projects of irrigation on both banks of the river that influence the water quality of the river, as well as existence high dense population within main cities that the river passing throughout them, moreover, discharge contaminants into the river the irregularly from several sources.

In general, the concentrations of TDS were changed from 1 year to another. Figure 4 shows the TDS reading in 2011 was higher than the readings in 2012 and 2013. This is due to the increasing in the flow rate; subsequently, raise the water level of the Euphrates river in 2011 compared with it in

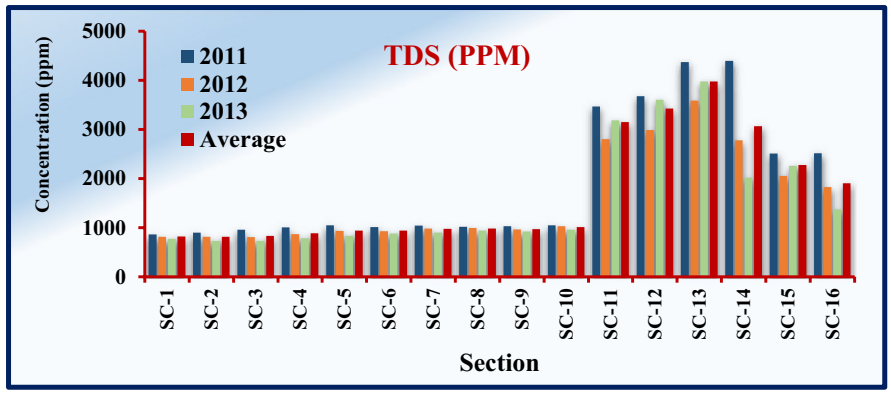

Fig. 4 TDS readings at sixteen sections on the Euphrates river for three years and their average values

2012 and 2013. The increased water level of the river is related to an increase in the flow rate, where this relationship leads to dilution and decreasing the concentration of TDS in the river. The trend line of average values of the TDS concentration for 3 years and its equation on the chart as well as the R-squared value can be seen in Fig. 5.

The maps of the TDS concentrations which were predicted based on the values measured at sixteen sections along the Euphrates river for the years 2011, 2012 and 2013 can be seen in Figs. 6, 6 and 6 respectively, while Fig. 6 shows the average values of the TDS concentrations for the 3 years.

In this study, the values of TDS concentration were divided into five categories for the resulted readings at sixteen sections of the river to determine the water quality of the river based on the classification of TDS by the World Health Organization in 2003 (WHO, 2003) (see Table 3).

In 2011, the TDS concertation readings at sections (SC-1, and SC-2) were classified as Category-3 (Moderate for drinking uses) with range of 600–900 ppm whilst for sections from CS-3 to S-10 were classified as poor drinking uses (Category-4), and their range is from 900 to 1200 ppm. Moreover, the water quality based on the TDS concentrations at the section from (SC-11) to section (SC-16) was classified as very poor (Category-5) with a range of over 1200 ppm.

Based on the TDS concertation values, the water quality of the Euphrates river at sections from SC-1 to SC-4 in 2012 and from SC-1 to SC-7 in 2013 were classified as moderate for drinking uses (Category-3) with the range of 600–900 ppm, whereas the sections from CS-5 to S-10 (2012) and the sections from CS-8 to S-10 (2013) were within the range of 900–1200 ppm and classified as poor drinking uses (Category-4). For both years (2012 and 2013), the readings at sections between CS-11–CS-16 were more than 1200 ppm and classified as very poor (Category-5).

For the average values of the TDS concentrations for 3 years, the water quality along the route of the Euphrates river was divided into three parts which are as follows: (1) part 1 with sections (SC-1–SC-4) was moderate for drinking uses (Category-3) with a range 600–900 ppm, (2) part 2 was classified as poor water quality (Category-4) for sections of (SC-5–SC-10) with a range from 900 to 1200 ppm) and (3) part 3 the readings with a range of 900–1200 ppm for sections (SC-11 – SC-16).

To create the maps of the TDS concentrations of the Euphrates river in 2011, 2012 and 2013 and their average values that predicted through applying the Inverse Distance Weighted technique in the GIS environment. These maps give a strong idea for distributing the TDS concentrations along the Euphrates river and available to

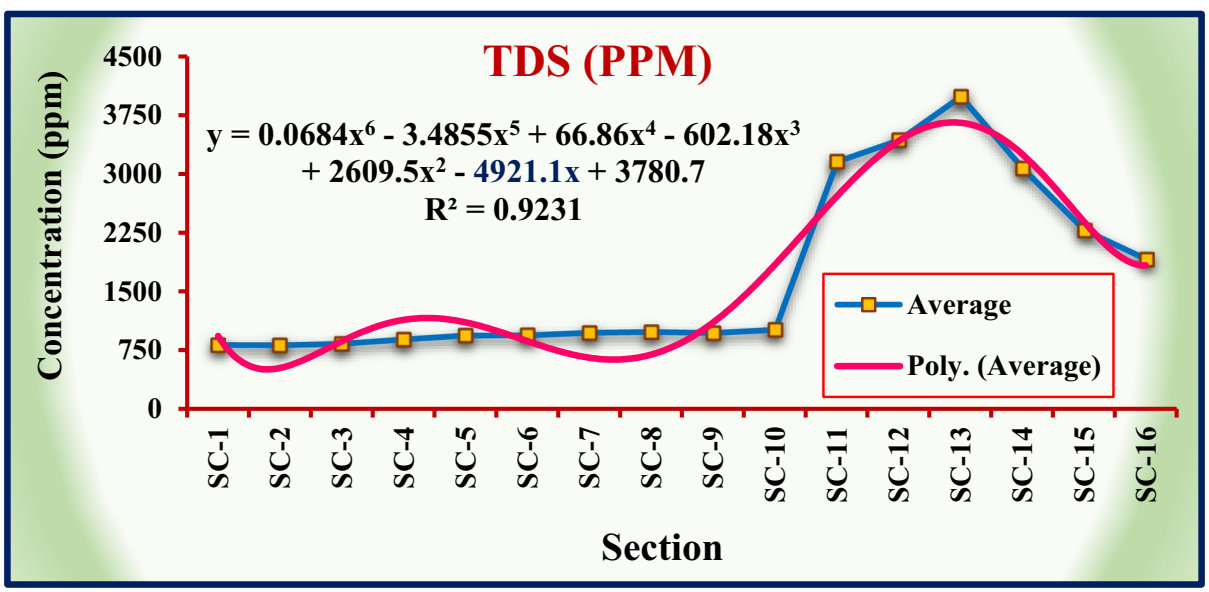

Fig. 5 The trend line of average values of TDS for 3 years with its equation and the R-squared value

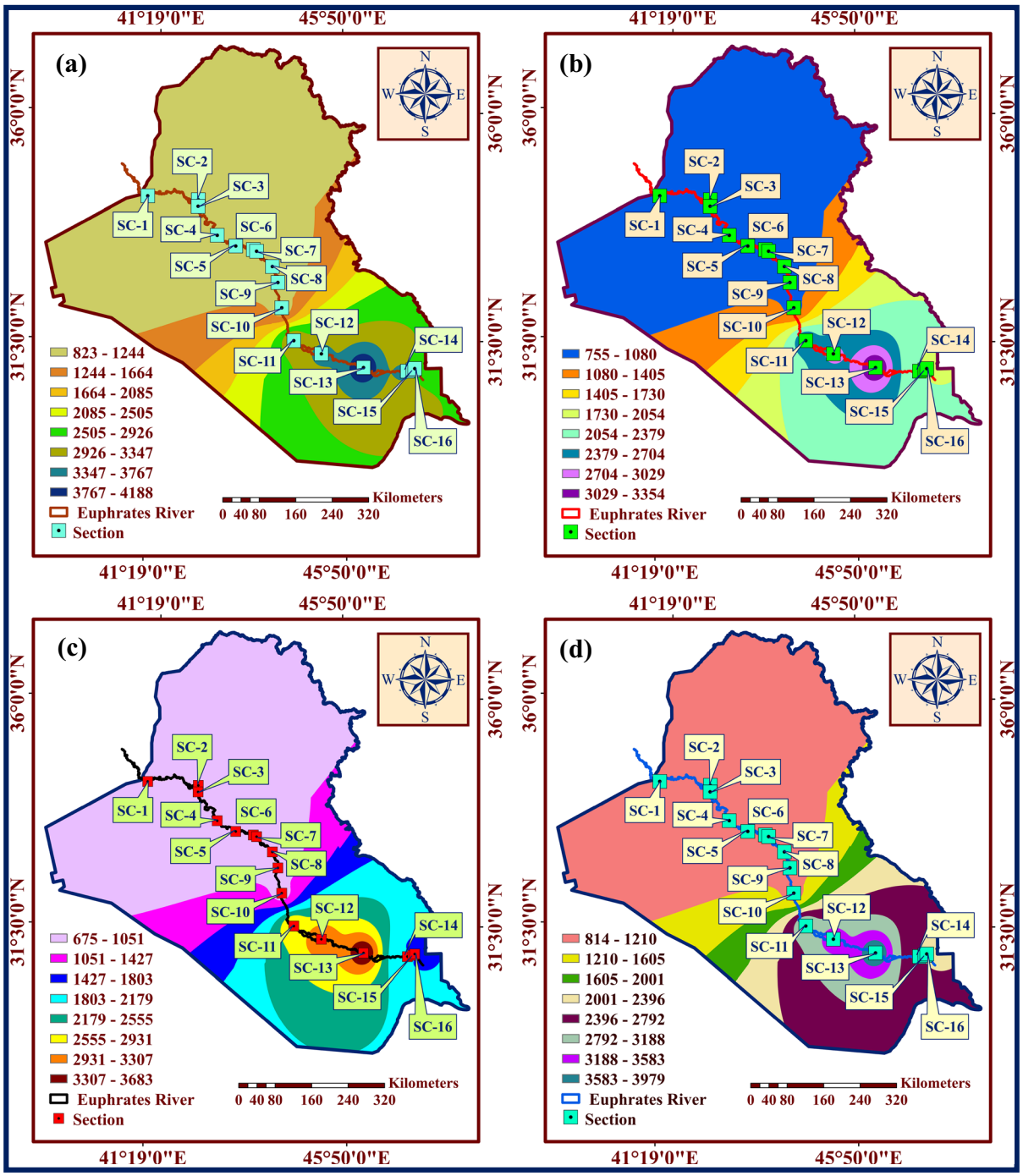

Fig. 6 Prediction maps of the (TDS) concentration on Euphrates river for the years (**a**) 2011, (**b**) 2012 and (**c**) 2013. (**d**) The average concentrations of the TDS for the 3 years

the researchers a bank of information to compare their data with the data in the current study.

Figures 7a, b, c and d show the maps of the TDS concentration for the river that predicted (using IDWT) after classification for the years of 2011, 2012 and 2013, as well as the average values for 3 years (WHO, 2003).

According to Ayers and Westcot (1985) after modifying, the restriction degree of water for irrigation

uses was divided into four categories which are (Table 4) (a) none restriction (NR-TDS) if the TDS concentration less than 450 mg/l, (b) slight restriction (SLR-TDS) when the TDS concentration ranges between 450 and 1000 mg/l; (c) moderate restriction (MR-TDS) when the TDS concentration ranges between 450 and 1000 mg/l, and (c) severe restriction (SR-TDS) if the TDS concentration with a range of 1000–2000 mg/l. Therefore, the TDS concertation readings along the Euphrates river were classified according to the degree of restriction water uses for irrigation as shown in Table 4.

Table 4 shows the sections (SC-1–SC-3), (SC-1–SC-9), (SC-1–SC-10) and (SC-1–SC-9) on the river based on the TDS concentration were classified as a Slight restriction (SLR-TDS) for irrigation uses with ranges of 450–1000 mg/l in 2011, 2012 and 2013 and average values for 3 years, respectively. The values of TDS concentration at the sections (SC-4–SC-10), (SC-10 and SC-16), (SC-10 and SC-16), (SC-16) and (SC-10 and SC-16) (respectively) in 2011, 2012 and 2013 and average values for 3 years were ranged from 1000 to 2000 mg/l, and these sections on the river were classified as a moderate restriction (MR-TDS) for irrigation uses. The sections of SC-11–SC-16 in 2011 and SC-11–SC-15 in 2012 and 2013 and for the average readings of three 3 were classified based on the TDS concentration of more than 2000 mg/l as a severe restriction (SR-TDS).

Figure 7a, b, c and d show that the prediction maps after classification the TDS concentrations along Euphrates river according to WHO (2003) were ranged between moderate water quality (Category-3) and very poor water quality (Category-5).

The area of each category (km^2) that is occupied by the interpolation maps is presented in Figs. 7a, b, c and d is listed in Table 5.

4 Conclusions

This study was employed to collect the TDS concentrations from sixteen sections along the Euphrates river within the Iraqi border in 3 years which are 2011, 2012 and 2013 and their average years. Then, producing the prediction maps of distributing the TDS concentrations after using the interpolation technique for the total waterway of the Euphrates river in Iraq. This work will give a clear idea to researchers and to who interesting in the fields of environment and water resources for using the water of the Euphrates river for drinking to population and for irrigation uses for the agricultural lands that locate on both banks of the river.

Table 3 Total dissolved salt classification for the sixteen sections on Euphrates river for drinking uses in 2011, 2012 and 2013 and their average values according to WHO (2003)

Section	TDS (ppm)							
	2011	Status	2012	Status	2013	Status	Average	Status
Qaim city (SC-1)	864	M-C-3	812	M-C-3	774	M-C-3	817	M-C-3
B. Haditha Dam (SC-2)	897	M-C-3	813	M-C-3	732	M-C-3	814	M-C-3
Haditha Dam (SC-3)	960	P–C-4	808	M-C-3	729	M-C-3	832	M-C-3
Hit city (SC-4)	1008	P–C-4	869	M-C-3	785	M-C-3	887	M-C-3
Al-Ramadi city (SC-5)	1046	P–C-4	935	P–C-4	834	M-C-3	938	P–C-4
Al-Saqlawiyah city (SC-6)	1014	P–C-4	929	P–C-4	881	M-C-3	941	P–C-4
Al-Fallujah city (SC-7)	1040	P–C-4	983	P–C-4	897	M-C-3	973	P–C-4
Al-Yusfiyah city (SC-8)	1020	P–C-4	993	P–C-4	937	P–C-4	983	P–C-4
Al-Hindiyah city (SC-9)	1028	P–C-4	962	P–C-4	921	P–C-4	970	P–C-4
Al-Kifl city (SC-10)	1048	P–C-4	1029	P–C-4	959	P–C-4	1012	P–C-4
Al-Shinafyah city (SC-11)	3465	VP-C-5	2803	VP-C-5	3186	VP-C-5	3151	VP-C-5
Al-Samawah city (SC-12)	3675	VP-C-5	2991	VP-C-5	3607	VP-C-5	3424	VP-C-5
Al-Nasiriyah city (SC-13)	4369	VP-C-5	3589	VP-C-5	3978	VP-C-5	3979	VP-C-5
Al-Madinah city (SC-14)	4397	VP-C-5	2777	VP-C-5	2016	VP-C-5	3063	VP-C-5
Al-Ayz city (SC-15)	2510	VP-C-5	2051	VP-C-5	2259	VP-C-5	2273	VP-C-5
Al Qarnah city (SC-16)	2515	VP-C-5	1824	VP-C-5	1373	VP-C-5	1904	VP-C-5

M-C-3: Moderate-Category-3; P–C-4: Poor-Category-4; VP-C-5: Very Poor-Category-5.

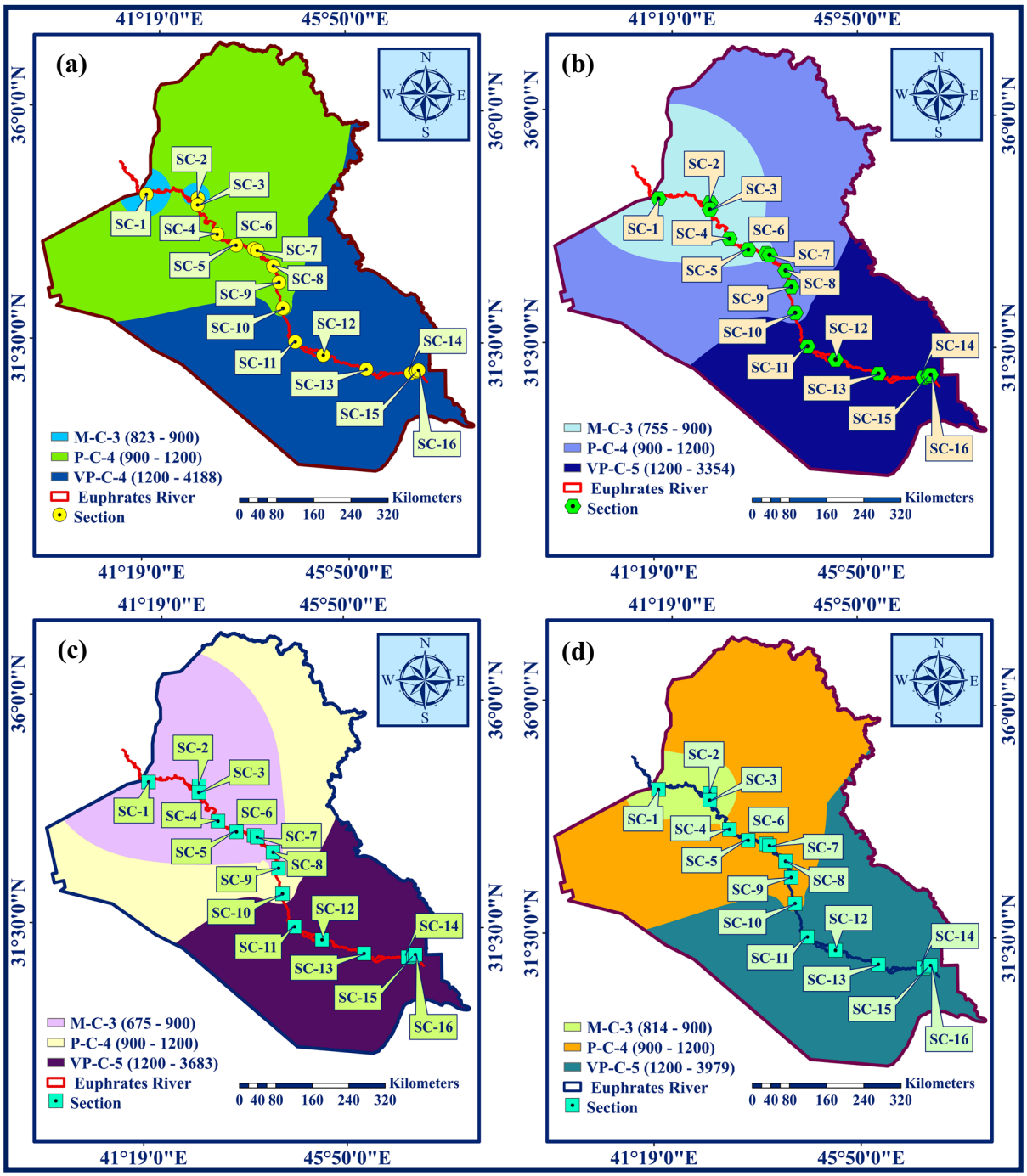

Fig. 7 Prediction maps after classification the (TDS) concentrations along Euphrates River according to (W.H.O., 2003) in (**a**): 2011; (**b**): 2012; (**c**): 2013; (**d**): The average concentrations of the TDS for three years

The range of TDS concentration values of the Euphrates river in the selected years 2011, 2012 and 2013 were varied from 864 to 4397 ppm (SC-1–SC-14), 808 to 3589 ppm (SC-3–SC-13) and 729 to 3978 ppm (SC-3–SC-13) (respectively). For the average values of 3 years, the TDS concentrations

Table 4 Total dissolved salt classification for the sixteen sections on Euphrates river, in terms restricting river water for irrigation uses, in 2011, 2012 and 2013, and their average values according to (modified from Ayers & Westcot, 1985)

Section	TDS (ppm)							
	2011	Restriction degree	2012	Restriction degree	2013	Restriction degree	Average	Restriction degree
Qaim-city (SC-1)	864	SLR-TDS	812	SLR-TDS	774	SLR-TDS	817	SLR-TDS
B. Haditha Dam (SC-2)	897	SLR-TDS	813	SLR-TDS	732	SLR-TDS	814	SLR-TDS
Haditha Dam (SC-3)	960	SLR-TDS	808	SLR-TDS	729	SLR-TDS	832	SLR-TDS
Hit city (SC-4)	1008	MR-TDS	869	SLR-TDS	785	SLR-TDS	887	SLR-TDS
Al-Ramadi city (SC-5)	1046	MR-TDS	935	SLR-TDS	834	SLR-TDS	938	SLR-TDS
Al-Saqlawiyah city (SC-6)	1014	MR-TDS	929	SLR-TDS	881	SLR-TDS	941	SLR-TDS
Al-Fallujah city (SC-7)	1040	MR-TDS	983	SLR-TDS	897	SLR-TDS	973	SLR-TDS
Al-Yusfiyah city (SC-8)	1020	MR-TDS	993	SLR-TDS	937	SLR-TDS	983	SLR-TDS
Al-Hindiyah city (SC-9)	1028	MR-TDS	962	SLR-TDS	921	SLR-TDS	970	SLR-TDS
Al-Kifl city (SC-10)	1048	MR-TDS	1029	MR-TDS	959	SLR-TDS	1012	MR-TDS
Al-Shinafyah city (SC-11)	3465	SR-TDS	2803	SR-TDS	3186	SR-TDS	3151	SR-TDS
Al-Samawah city (SC-12)	3675	SR-TDS	2991	SR-TDS	3607	SR-TDS	3424	SR-TDS
Al-Nasiriyah city (SC-13)	4369	SR-TDS	3589	SR-TDS	3978	SR-TDS	3979	SR-TDS
Al-Madinah city (SC-14)	4397	SR-TDS	2777	SR-TDS	2016	SR-TDS	3063	SR-TDS
Al-Ayz city (SC-15)	2510	SR-TDS	2051	SR-TDS	2259	SR-TDS	2273	SR-TDS
Al Qarnah city (SC-16)	2515	SR-TDS	1824	MR-TDS	1373	MR-TDS	1904	MR-TDS

Table 5 The area that is occupied by interpolation maps in Figs. 7a, b, c and d of each category (km^2)

Map	Category	Area (km^2)	Proportion (%)
Map 2011 (a)	Category-1	8617.55	1.97
	Category-2	232,530.66	53.17
	Category-3	196,150.99	44.86
Map 2012 (b)	Category-1	81,268.1	18.58
	Category-2	190,561.2	43.58
	Category-3	165,469.7	37.84
Map 2013 (c)	Category-1	136,371.5	31.18
	Category-2	134,738.2	30.81
	Category-3	166,189	38.00
Map average (d)	Category-1	26,521.5	6.06
	Category-2	223,278.5	51.06
	Category-3	187,499	42.88

were ranged from 814 to 3979 ppm (SC-2–SC-13). For the Euphrates river within Iraq, the average values of TDS for the years 2011, 2012 2013 and mean values for 3 years (respectively) were 1928, 1573, 1554 and 1685 ppm.

The TDS concentrations of rivers have a high relationship with the increase in the flow rate, and the water level which is varied from different years. Therefore, the TDS values in 2011 were more than the values in 2012 and 2013.

The World Health Organization (WHO) in 2003 was classified the water river for drinking uses into five categories. These five categories with their status are (ppm) excellent (0–300), good (300–600), moderate (600–900), poor (900–200) and very poor (> 1200).

According to the maximum limit of the WHO (2003), the TDS readings at the selected sections from SC-1 in Qaim city to SC-16 in Al-Qurnah city on the Euphrates river were higher than the acceptable limit of 500 ppm.

The TDS concentrations at all sections (SC-1 to SC-16) on the Euphrates river have exceeded the allowable limit of the WHO (500 ppm) (W.H.O., 2003; EPA, 2018).

In the current study, the TDS concertation readings in 2011 were classified as moderate for drinking uses with the range of 600–900 ppm (Category-3) at sections (SC-1, and SC-2) and poor for drinking uses with the range of 900–1200 ppm (Category-4) for sections from (SC-3) to (SC-10), and the sections from (SC-11) to (SC-16) were within the range of more than 1200 ppm and classified as very poor for drinking uses (Category-4).

In 2012 and the average values for 3 years, the Euphrates river for drinking uses based on the TDS readings were classified as moderate with the range of 600–900 ppm) (Category-3) at sections SC-1 and SC-4 and poor with the range of 900–1200 ppm (Category-4),for sections from (SC-5) to (SC-10), and the sections from (SC-11) to SC-16) were more than 1200 ppm and classified as very poor (Category-5).

Depending on the TDS concentrations in 2013, the water quality of the Euphrates river according to WHO.(2003) was classified as moderate for drinking uses (Category-3) with a range of 600–900 ppm at sections (SC-1–SC-4), as poor water quality (Category-4) for sections of (SC-5–SC-10) with a range from 900–1200 ppm) and as very poor water quality (Category-5) with a range of > 1200 ppm at sections (SC-11–SC-16).

The Inverse-Distance-Weighted technique in the GIS was applied to make the interpolation between the readings at sixteen sections on the Euphrates river in 2011, 2012, and 2013 and their average values. Therefore, the predicted maps for the TDS concentrations were created.

According to the classification of the WHO in 2003, the classified maps of the TDS concentration of Euphrates river after implementing the interpolation method using IDWT for the years of 2011, 2012 and 2013 and the average values for 3 years.

These interpolated and classified maps of the TDS concentrations along the river were divided into three parts with category of moderate water quality (Category-3) (600–900 ppm), poor water quality (Category-4) (900–1200 ppm) and very poor water quality (Category-5) (> 1200 ppm).

For the average values of the TDS concentration for 3 years, the sections (SC-1–SC-9) were classified as a slight restriction (SLR-TDS) for irrigation uses with ranges of 450–1000 mg/l. At sections SC-10 and SC-16, the values of TDS concentration were ranged from 1000 2000 mg/l and they are classified as a moderate restriction (MR-TDS) for irrigation uses. The sections of SC-11–SC-15 mg/l were classified as a severe restriction (SR-TDS) based on the TDS concentration over 2000 mg/l.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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