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Water quality index toward a reliable assessment for water supply uses: a novel approach

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Abstract

The present work sheds the light on a novel approach developed for water quality index, aiming to assess the water quality of the Tigris River for potable abstractions. The Tigris River water quality index (TrWQI) was devised via utilizing unlike tools and data, this includes; availability of water quality data, statistical correlations, water quality guidelines, and the experts' opinions. Ten water quality parameters were involved in the adopted index: turbidity, pH, water temperature, biochemical oxygen demand, dissolved oxygen, iron, sulfate, alkalinity and total coliform bacteria. Five sampling stations were selected to perform the TrWQI for the period of April 2019. Generally, the results of the index have manifested that the water quality was within "Fair" to "Poor" range. With considering the application of TrWQI, reasonable results have been achieved if compared with the raw data of the Tigris River. Indeed, the index was capable to endow serviceable information for managers and decision-makers to sustain the quality of the river.

Keywords Drinking water · Potable abstractions · Water quality assessment · Water treatment

Introduction

Substantial efforts have been devoted in the last few decades to diminish the problematic water quality deterioration in the Middle East and North Africa (MENA) region (Ismail et al. 2019). Inadequate quality in water has presented a serious threat to the arid and semi-arid areas in the Middle East, especially, with the absence of permanent water resources such as rivers or water bodies. Unlike other middle-east countries that rely on groundwater and desalination, Iraq has two major rivers for water supply; Tigris and Euphrates Rivers along with many other tributaries and lakes (Ismail et al. 2018).

One of the unfolded issues, in the recent past years, is the low flow of the Tigris River. This was ascribed to the South-eastern Anatolia Project (GAP), a big Turkish project that utilizes Tigris and Euphrates rivers water. This mega project consists of 22 dams and 19 hydroelectric power plants (Ismail et al. 2019). The low flow of the Tigris River has brought up an outgrowth in the water salinity (Zowain and Ismail 2015). Besides the deterministic challenges like increased water demand, wastewater discharge and climate change, the lack of management support of water resources, as a result of Iraq's political instability, has led up to inferior water quality (Ghalib 2017; Ismail et al. 2014). This indeed has loaded more pressure on the current water treatment units in the water treatment plants (WTPs) (Mahmood et al. 2019).

Water quality index (WQI) is a powerful tool that is commonly harnessed in water treatment multi-disciplines owing to its functionality to express a large amount of water quality data into a single number. WQI can be used to express the quality of versatile water samples such as drinking, irrigation and industrial. The benefits of WQIs are not limited to expressing the water quality, for possible uses of a given water body, in a simple way, but also make them easily understandable for water managers, especially those who are non-specialists in the water sector. Besides, it provides a

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good basis for optimum selection of an appropriate treatment technique to meet the targeted issues (Kannel et al. 2007; Sargaonkar et al. 2008; Tyagi et al. 2013; Mostafaei 2014). WQI has been extensively used as a tool to evaluate surface and groundwater quality (Farhan et al. 2020; Karunanidhi et al. 2020; Ukah et al. 2020).

A first numerical WQI model publicized by Horton (1965) based on eight water quality parameters. Limitless attempts have been made following the Horton index to promote WQI in various water sectors (Brown et al. 1973; Prati et al. 1971; Walski and Parker 1974; Bascaron 1979; Bhargava 1983; Dinius 1987; House and Ellis 1987; Smith 1990; Wepener et al. 1992; Cude 2001; Sargaonkar and Deshpande 2003; CCME 2001; Boyacioglu 2007; Hanh et al. 2011; Sany et al. 2019; Sahoo and Patra 2019). An extensive review concerning WQIs development can be found elsewhere Lumb et al. (2011) and Sutadian et al. (2016). Nevertheless, computer software to figure out the WQIs also became available for the first instance in the twentieth century (Sarkar and Abbasi 2006; Sharma et al. 2013). Occasionally, it should be noted that the tabulation and interpretation processes of water quality parameters are troublesome even for those specialists in the water industry (Pesce & Wunderlin 2000). Besides that, it does not necessarily confer a comprehensive vision and integrated concept on the water quality status (Kannel et al. 2007).

Furthermore, numerous researches have been carried out to evaluate the water quality in the Tigris River using the WQI technique. Al-Obaidy et al. (2016) and Chabuk et al. (2020) have used the weighted arithmetic method to compute the WQI. However, they have chosen water quality parameters such as (calcium, magnesium, sodium, potassium, chloride, bicarbonate, total hardness). These parameters are within the limits of the standard set by WHO (2011) and shown little mean and standard deviation along Tigris River as confirmed by previous studies (Ismail et al. 2014; Ewaid et al. 2020). Alazawii et al. 2018 have used the Canadian Water Quality Index (CCME WQI) to assess the effects of an electrical power plant on the quality of Tigris River within Baghdad. Despite the CCME WQI may provide realistic results in comparison to the raw data, it considers all the water quality parameters have the same degree of importance, and it can be applied only when there are available guidelines on water quality parameters (Ismail and Robescu 2019a). Therefore, the current research work presented a meaningful endeavor to develop a novel water quality index aiming to assess the water quality of the Tigris River, within the Baghdad region, for water supply uses (potable abstractions). The present study is conducted during the year 2019 in Iraq. The adopted WQI exploited a combination of five techniques, instead of one or two, including; availability of data, statistical analysis, expert's opinion, water quality standards and literature. This would be beneficial for those managers and technicians working in WTPs to obtain a reliable WQI.

Materials and methods

Study area

Bagdad city, the capital of Iraq, lies between latitudes 33°10′0″ and 33°30′0″ North and longitudes 44°10′0″ and 44°35′45″ East (Ismail et al. 2019). It is the most populated and industrialized city in Iraq. Municipal and industrial wastewaters are released directly into Tigris River without satisfactory treatment (Ismail 2014). The river divides Baghdad into two parts, Karkh and Rusafa with a flow direction from north to south. Tigris River with a catchment area of 235,000 km^2 and 1,900 km long is the leading source of water supply in the capital city of Baghdad (Ismail et al. 2014). This area has been characterized by an average rainfall rate of 150 mm/year and an evaporation rate exceeding 2,400 mm/year (Alhayani 2010).

With a population of more than 7 million (Aenab and Singh 2012), the ater has been supplied via eleven WTPs, namely Alkarkh, East Tigris, Alsadar, Albaladyiat, Alwathba, Alkarama, Alkadhimyiah, Alqadisyiah Aldora, Alwahda and Alrasheed (Fig. 1). These WTPs comprise a sequence of traditional treatment techniques (i.e., sedimentation, coagulation, filtration, and chlorination). All the aforementioned plants use the Tigris River water as raw water for their treatment process.

Information and tools

The general schematic diagram of the proposed TrWQI is illustrated as in Fig. 2.

In this paper, different information and tools were used to formulate TrWQI such as water quality data for 20 water quality parameters at eleven different sites along the river from 2008 to 2017. A nonparametric test, namely the Spearman correlation was used to measure the degree of association between two water quality parameters. The statistical calculations were performed using IBM-SPSS 25 software for Windows (Ismail and Robescu 2019b).

Moreover, a panel of experts was also considered in the current research procedure. This was executed by providing nine experts with a questionnaire encompassed more than thirty-five water quality parameters (using the modified Delphi method). They were requested to pick out the utmost ten (less or more) significant parameters that may impress the quality of the Tigris River water. Furthermore, the water quality standards set by different agencies and organizations located in different parts of the world were also considered for TrWQI formulation.
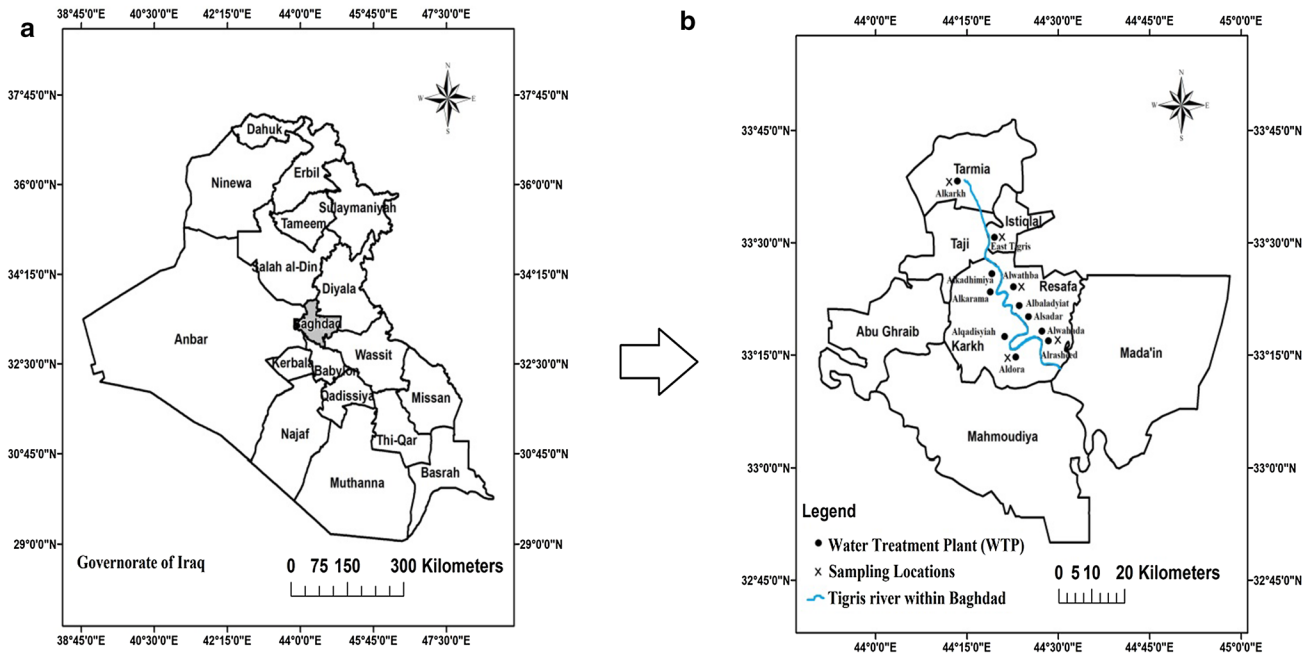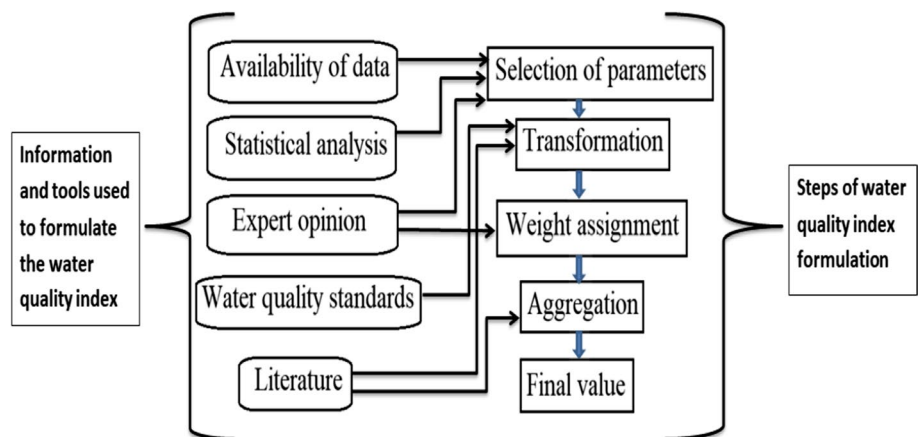
Fig. 1 Map of the study area, **a** Governorate of Iraq, **b** Water treatment plants and sampling locations along the urban area of Baghdad

Fig. 2 Schematic diagram of TrWQI development steps

Selection of Parameters

Virtually, the selection of paramount water quality parameters for the final WQI is reckoned to be an intricate process. Herein, this step targeted selection of parameters with greater influence on the water quality of the investigated region. In reality, approaching 100% objectivity or accuracy at this step is arduous to achieve, Abbasi and Abbasi (2012). As given in the literature, unlike methods were employed for parameter selection in WQIs developing processes. Some indices utilized experts' judgments through many rounds (Delphi Method) to extract the most significant parameters. Other indices harnessed statistical tools such as correlation coefficient or factor and cluster analysis (Kumari and

Sharma 2019). Meanwhile, several indices did not showcase any particular guidelines at all to clarify how the selection of parameters was carried out (Sutadian et al. 2016).

The current research enclosed a novel approach by coupling of distinct techniques aiming to materialize the most leading parameters that influence the water quality of the Tigris River throughout the city of Baghdad. The twenty water quality parameters (3584 observations for each parameter) were collected at eleven different sites along the river from 2008 to 2017. These parameters include water temperature (WT), turbidity, alkalinity, total hardness (TH), calcium (Ca^{2+}), Chloride (Cl^-), Magnesium (Mg^{2+}), pH, Electrical conductivity (EC), Sulfate (SO_4^{2-}), total dissolved solids (TDS), total suspended solids (TSS), iron (Fe), fluoride

(F), Aluminum (Al), nitrite (NO_2), nitrate (NO_3), ammonia (NH_3), silica (SiO_2) and orthophosphate (PO_4).

Sub-index development

Herein, at this stage, transforming the measurements of the preferable water quality parameters into a common scale was performed. This was executed since the authentic values of the parameters have their own different units. For aggregating the water quality parameters, it is necessary to have the same common scales. As given by Sutadian et al. (2016), there are three, unlike methods that are commonly employed to set up the sub-index rating curves. These are expert judgment, the use of water quality standards and statistical techniques. In the present research, the sub-index development process was performed based on the application of water quality standards and the previously developed WQIs in the literature. Table 1 elucidates the water quality standards set by other agencies and organizations located in different parts of the world. Table 1 shows some required characteristics of surface water in order to be suitable for use in the treatment of potable water.

Assignment of weights

In some circumstances, the weights assignment step was neglected in some previously developed water quality indices (Cude 2001). This infers that water quality parameters have the same degree of importance and might result in a biased index (Abbasi and Abbasi 2012). However, in the present work, the weights assignment step was carried out with the aid of the experts' panel.

Aggregation method

Aggregation of sub-indices was the final step and usually conducted after the weight's assignment towards obtaining the final index value. The most frequent aggregation methods, been employed in literature to obtain a single number, were based on the additive (arithmetic) and multiplicative (geometric) aggregations (Horton 1965; Brown et al. 1973; Bhargava 1985; Dinius 1987). A number of modified versions of aggregation methods have been proposed later in the literature (SRDD 1976; Pesce and Wunderlin 2000; Debels et al. 2005). The reason stands behind that, the occurrence of ambiguity or eclipsing problems in some indices (Swamee and Tyagi 2000; Sutadian et al. 2016). The eclipsing issue happens if the final index value does not exceed the critical level (unacceptable value) although one or more of the sub-indices exceeding the critical level. Thus, the index would not reflect the actual state of the overall water quality. Ambiguity issue arises when the final index value lay within unacceptable quality although all the sub-indices are acceptable

Table 1 Water quality standards

Parameter	Iraqi standards for drinking water (IQS 2009)	WHO Guidelines for drinking water quality (WHO 2011)	EuC standards for surface waters used for potable abstractions (A1, Guide Limit) (EC 1975)	McKee and Wolf 1963* Excellent	Good	Poor	EuC freshwater fish water quality standards (Coarse fish)	EuC bathing water standards (Guide Limit)	EuC drinking water standards GL	MAC
Turbidity (NTU)	5	5	–	0–10	10–250	>250	–	–	1	10
pH	6.5–8.5	6.5–8.5	6.5–8.5	6.0–8.5	5.0–9.0	3.8–10.5	6–9	–	6.5–8.5	–
TDS (mg/L)	500	1000	–	–	–	–	–	–	–	1500
WT (°C)	–	22	–	–	–	–	28	–	12	25
BOD (mg/L)	–	–	<3	1–3	3–4	>4	6	–	–	–
DO (mg/L)	–	–	–	4.0–7.5	4.0–6.5	4.0	–	–	–	–
DO % saturation	–	–	>70%	75% or better	60% or better	–	–	80–120% saturation	–	–
Fe (mg/L)	0.3	0.3	0.1	–	–	–	–	–	0.05	0.2
SO_4^{2-} (mg/L)	400	250	150	–	–	–	–	–	25	250
Alkalinity (mg/L)	125	–	–	–	–	–	–	–	–	–
TC (MPN/100 mL)	Absent in 100 mL	Absent in 100 mL	50	50–100	50–5000	>5000	–	500	–	<1

*Ranges of promulgated standards for raw water sources of water supply

(Abbasi and Abbasi 2012). Therefore, in the present work, various aggregation methods were employed to procure the final value of the proposed index.

Sampling

In order to apply the proposed water quality index to assess the water quality in the Tigris River, grab water samples were collected during April 2019, at five stations along the Tigris River, namely Alkarkh, East Tigris, Alwathba, Aldora and Alrashed (Fig. 1). Water samples were collected in one-liter polypropylene bottles and stored at 5 °C for further laboratory analysis. The pH and water temperature (WT) were measured in situ by a digital pH meter and thermometer, respectively. The TDS concentrations were determined through a temperature-controlled oven method. Alkalinity was determined titrimetrically while Fe was measured by the flame emission photometry. Sulfate (SO_4^{2-}) concentration was detected with the aid of the spectrophotometric technique. BOD and DO were determined via Winkler's method (incubation for 5 days at 20 °C). Turbidity value was found through utilizing a digital turbidity meter, whereas total coliform (TC) was estimated by the most probable number method (MPN).

Results and discussion

Selection of parameters

Figure 3 elucidates the variations of each parameter against 3584 observations, over ten years period along with its corresponding drinking water quality standards value, as set by Iraqi standards (IQS 2009). Parameters like WT, EC, TSS, NH_3 and SiO_2 are not involved here since IQS (2009) did not specify any drinking water guidelines for them yet. Instead, WT, EC and TSS were plotted according to the European Community (EuC) standards for surface waters used for potable abstractions (Fig. 4). It is worth mentioning that WTPs located at the Tigris River banks in Baghdad are employing conventional treatments (normal physical and chemical treatment with disinfection) for the water supply. In other words, all the water quality parameters mentioned earlier are not treated by the plants except turbidity.

As shown in Fig. 3, it can be seen that some water quality parameters were exceeding the prescribed limits (Table 1) (IQS 2009) in the majority of observations during 10 years monitoring period in the Tigris River such as turbidity (Fig. 3a), alkalinity (Fig. 3b), calcium, Ca^{++} (Fig. 3d), TDS (Fig. 3i) and Fe (Fig. 3j). Other parameters were within the prescribed limits in the majority of observations such as TH (Fig. 3c), Cl^- (Fig. 3e), Mg^{++} (Fig. 3f), pH (Fig. 3g), fluoride (Fig. 3k), Al (Fig. 3l), NO_2 (Fig. 3m), NO_3 (Fig. 3n)

and PO_4 (Fig. 3o). In the case of sulfate, the samples were exceeding the prescribed limits in almost half of the samples and within the prescribed limits in the other half (Fig. 3h). As depicted by Fig. 3 and Fig. 4, the water quality parameters that exceeded the prescribed limits, for the majority of the 10 years observations, are turbidity, alkalinity, Ca^{2+}, SO_4^{2-}, TDS, TSS, WT, Fe and EC.

The Spearman correlation of these parameters is tabulated in Table 2. Turbidity disclosed a significant positive relationship with TSS (0.86). It is well established that TSS is the main cause of turbidity in which both offer an indication of the amount of suspended solids presented in the water. Minimizing the number of parameters and their associated costs were given a prior concern in this study. Thus, TSS was eliminated from the parameter selection process. Similarly, Debels et al. (2005) eliminated ammonia and orthophosphate due to their high correlation with chemical oxygen demand (COD). Besides that, TDS manifested a high positive correlation with EC (0.98), Ca (0.90) and SO_4^{2-} (0.88). Particularly, TDS composes monovalent and multivalent inorganic salts (Ca, Mg, K, Na, HCO_3, Cl, and SO_4^{2-}) along with some small amounts of organic matter dissolved in water. EC is a measure of salinity in the water and an indirect measurement of TDS. EC and Ca were also eliminated from the parameter's selection process, while SO_4^{2-} was kept due to its importance. The presence of SO_4^{2-} in drinking-water can cause taste issues while higher levels of sulfate may result in bowel problems in the human body (Akoteyon et al. 2011).

Nevertheless, bacteriological monitoring has a pivotal role in the process of water quality assessment. The microbiological quality of a river is usually evaluated in terms of indicator microorganisms such as coliform bacteria. The absence of coliform bacteria in the water is deemed as an indication of bacteriologically safe water for human consumption. Livestock and domestic wastewater discharges are reckoned as the leading source participated in the bacteriological pollution of the rivers. For eleven years, the total coliform bacteria (TC) data were harvested throughout seven monitoring stations at the Tigris River (Fig. 5). A closer look at the figure discloses that TC concentrations were much higher during the years (2000–2004) if compared with other monitoring years. The average values of TC in 2005, 2006, 2007, 2008, 2009 and 2010 were 29,664.67, 32,704.51, 34,258.92, 8583.57, 29,298.38 and 20,888.92 MPN/100 mL, respectively. TC was very high in the Tigris River and surpassed the limit of 50 MPN/100 mL, set by EuC standards for surface waters applied for potable abstractions (EC 1975). Therefore, it was involved in the parameters selection process.

Furthermore, the water quality parameters that have been selected by the nine experts and were more frequent among others are turbidity (9), pH (8), BOD (8), TSS (7), TDS (7),
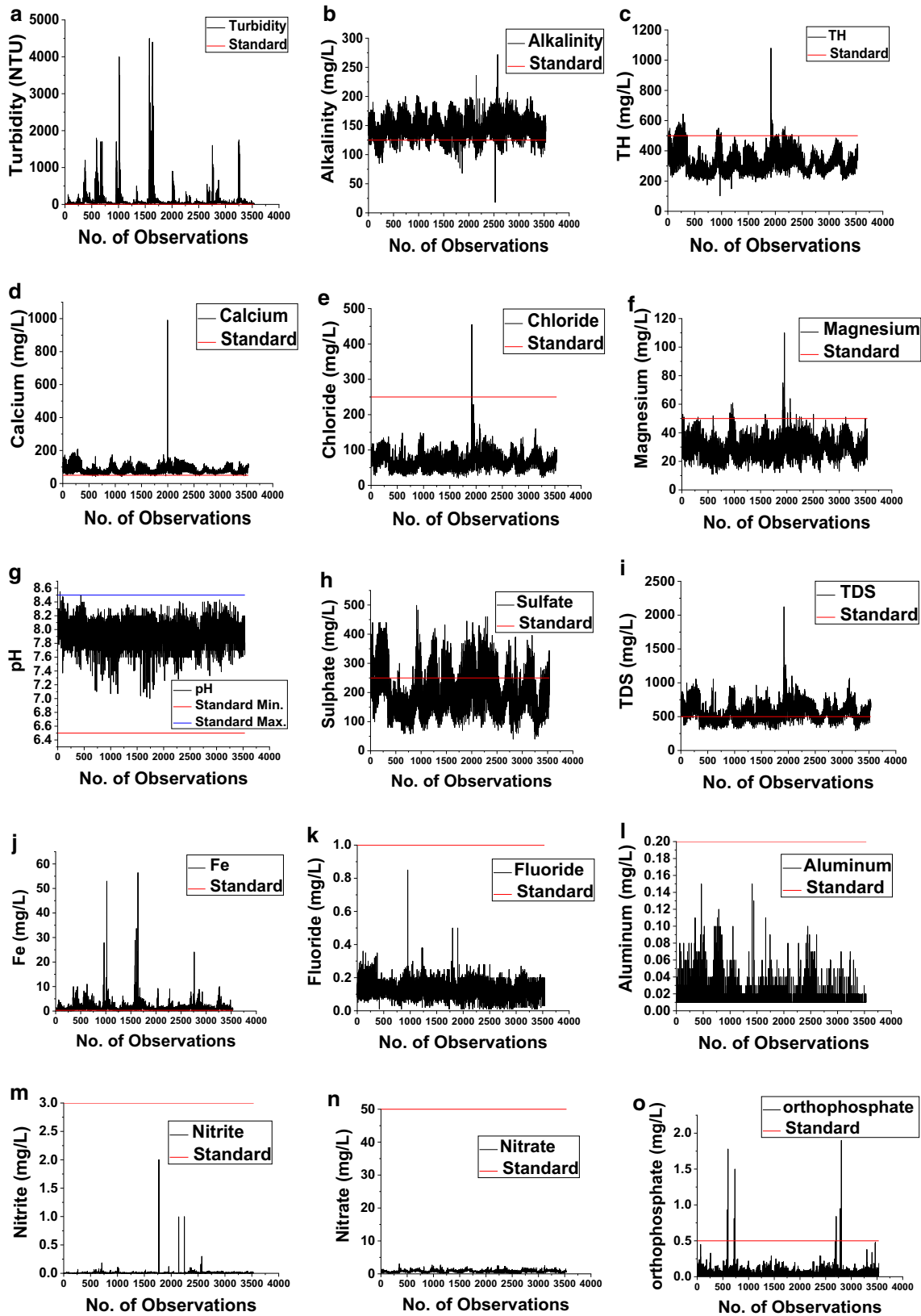
◄Fig. 3 The variations of water quality in the Tigris River for 10 years monitoring along with the drinking water quality standards value set by IQS (2009), **a** Turbidity versus No. of Observation, **b** Alkalinity versus No. of Observation, **c** TH versus No. of Observation, **d** Ca^{++} versus No. of Observation, **e** Cl$^-$ versus No. of Observation, **f** Mg^{++} versus No. of Observation, **g** pH versus No. of Observation, **h** SO$_4{}^{2-}$ versus No. of Observation, **i** TDS versus No. of Observation, **j** Fe versus No. of Observation, **k** F$^-$ versus No. of Observation, **l** Al versus No. of Observation, **m** NO$_2$ versus No. of Observation, **n** NO$_3$ versus No. of Observation, **o** PO$_4{}^{2-}$ versus No. of Observation

DO (6), TH (6), TP (5), EC (5), TN (4), TC (4), Alkalinity (3), NO$_3$ (3), COD (3) and SO$_4{}^{2-}$ (3). The value between the parentheses represents the recurrence number of parameters as selected by the experts. Based on the above, the adopted water quality parameters to be involved in the WQI for the assessment of Tigris River are listed in Table 3.

Sub-index development

The sub-indices rating curves of the chosen water quality parameters are given in Fig. 6. Versatile types of sub-index rating curves could be employed such as linear, nonlinear, segmented linear and segmented nonlinear, inverse parabolic and the step rating curves (Abbasi and Abbasi 2012). The adopted sub-indices here are the inverse parabolic for pH and temperature and the steps-type for the other parameters (Turbidity, TDS, BOD, DO, SO4^{2-}, Fe, alkalinity and TC). To the best of the authors' knowledge, Bascaron (1979) was the first one who applied the step rating curve when developed a water quality index (BWQI). This index has been widely spread over the scientific community related to the water industry (Lumb et al. 2011). Water quality parameters such as WT, DO, BOD, SO$_4{}^{2-}$ and TC were adopted from other works carried by Pesce and Wunderlin (2000), Debels et al. (2005), and Kannel et al. (2007). On the other hand, other parameters were formulated depending on their prescribed limit set by various agencies. For example, Pesce and Wunderlin (2000) suggested that a TDS value of less than 100 mg/L indicates excellent water quality (rating curve = 100). A TDS with less than 2000 mg/L refers to moderate water quality (rating curve = 50), whereas, more than 20,000 mg/L suggests a poor water quality (rating curve = 0). This classification of the TDS cannot be considered here for the Tigris River since the WTPs located at the river banks are harnessing conventional treatment techniques for water supply. Thus, the removal of water TDS is not possible for the current research case. Particularly, TDS removal necessitates the application of advanced separation techniques such as membrane technology. The guideline value of TDS in the drinking water was set at 1000 mg/L for WHO (2011) and 500 mg/L for IQS (2009). Accordingly, it was proposed that if the TDS concentration was lower than 100 mg/L, then this suggests an excellent water quality (rating curve = 100),

however, the worst scenario of TDS (rating curve = 0) was when it hits a concentration of higher than 1300 mg/L.

McKee and Wolf (1963) proposed a range of promulgated standards for raw water sources of water supply (Table 3). They classified the water turbidity into three classes; excellent (from 0 to 10 NTU), good (from 10 to 250 NTU) and poor (more than 250 NTU). Furthermore, the prescribed limit of turbidity in the drinking water was set at a value of 5 NTU by WHO (2011) and IQS (2009). In the adopted index, it was proposed that excellent water quality (rating curve = 100) could be obtained if the turbidity value was lower than 5 NTU, whereas, a value of more than 200 NTU referred to the worst turbidity scenario (rating curve = 0). The same manner was applied for other parameters; Fe, alkalinity and pH.

Assignment of weights

The experts' panel was requested to assign a number from 1 to 4, for each selected water quality parameter. The number 1 denotes a less significant parameter, while 4 refers to the highly important one. The temporary weights given by the experts for each parameter along with the final weights are shown in Table 4. Each temporary weight was divided by the sum of all the temporary weights to obtain the final weight.

Aggregation method

The aggregation methods selection was implemented aiming to probe the one that exemplifies the actual characteristics of Tigris River water quality. Worth mentioning here that aggregations based on multiplicative have not been considered. This could be explained that if one or more of the sub-indices were equal to zero, then the final index number would be equal to zero too. The additive aggregation functions used in the current study are described as follows:

The simple additive aggregation with unequal weights proposed by Brown et al. (1970) with the support from the National Sanitation Foundation (NSF) of USA.

$$WQI = \sum_{i=1}^{n} S_i w_i \qquad (1)$$

where *WQI* is the aggregated index, *n* is the number of sub-indices, w_i is *i*th weight (final weight given in Table 4) and S_i is the *i*th sub-index.

The modified additive aggregation with unequal weight advocated for use in England (Tyson and House 1989).

$$WQI = \frac{1}{100}\left(\sum_{i=1}^{n} S_i w_i\right)^2 \qquad (2)$$

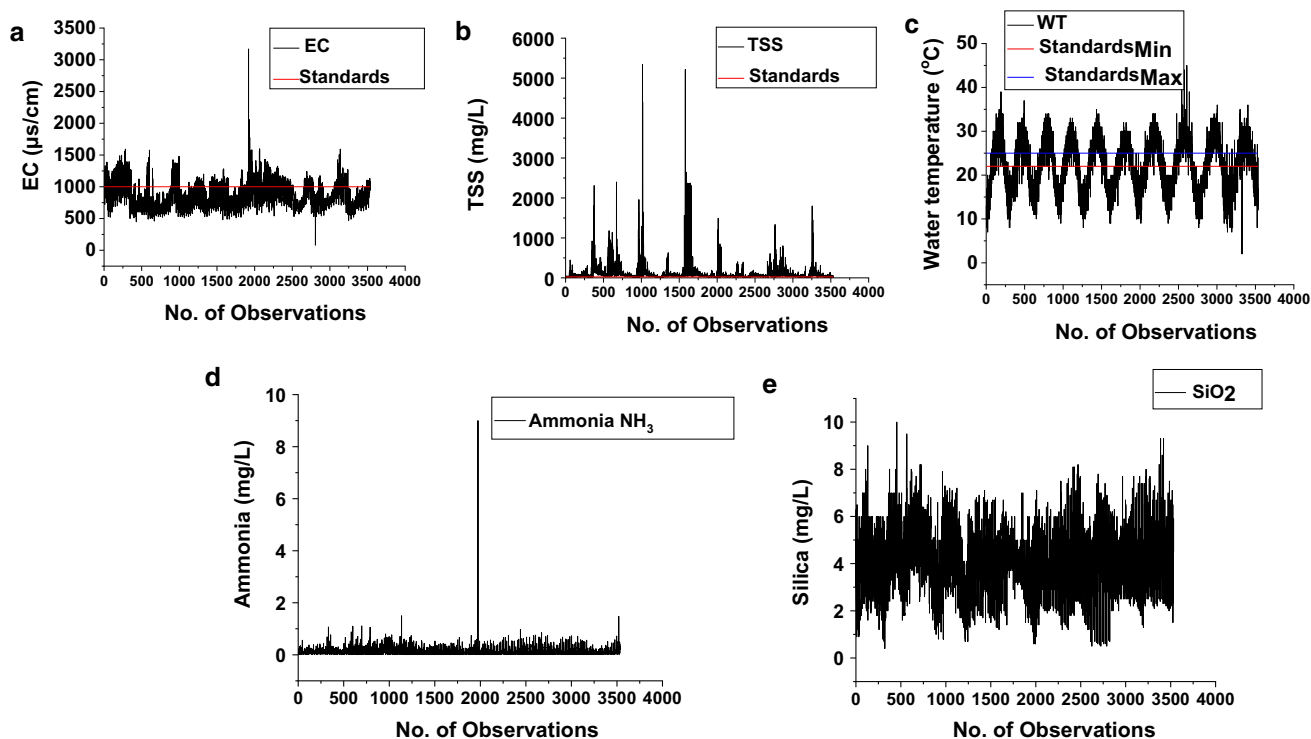Another modified version of the additive aggregation suggested by Bascarón (1979)

Fig. 4 The variations of EC, TSS, WT, ammonia and silica in the Tigris River for 10 years monitoring along with the European Community (EuC) standards for surface waters used for potable abstractions, **a** EC vs. No. of Observation, **b** TSS vs. No. of Observation, **c** WT vs. No. of Observation, **d** NH_3 vs. No. of Observation, **e** Silica vs. No. of Observation

Table 2 Spearman correlation of the water quality parameters that have exceeded the prescribed limits

	WT	Turbidity	Alkalinity	Ca^{2+}	TDS	TSS	SO_4^{2-}	EC	Fe
WT	1.00								
Turbidity	0.29	1.00							
Alkalinity	− 0.00	0.48	1.00						
Ca^{2+}	− 0.06	0.00	0.23	1.00					
TDS	− 0.10	0.00	0.25	0.90	1.00				
TSS	0.25	0.86	0.42	− 0.02	− 0.03	1.00			
SO_4^{2-}	− 0.07	− 0.06	0.16	0.87	0.88	− 0.08	1.00		
EC	− 0.10	− 0.01	0.24	0.92	0.98	− 0.05	0.88	1.00	
Fe	0.19	0.55	0.36	− 0.08	− 0.08	0.58	− 0.09	− 0.09	1.00

$$WQI = \frac{\sum_{i=1}^{n} C_i P_i}{\sum_{i=1}^{n} P_i} \qquad (3)$$

where *WQI* is the aggregated index, *n* is the number of parameters, C_i is the sub-index value and P_i is the relative weight of each parameter (temporary weight given in Table 4).

Final index value interpretation

According to what have been illustrated earlier in the previous subsections, the final index value can be categorized as;

- Excellent: 95–100 (Need simple physical treatment and disinfection).
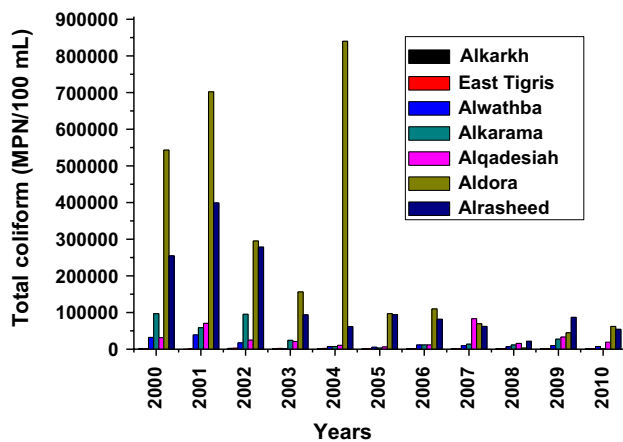
Fig. 5 TC values at 7 monitoring stations in the Tigris River for 11 years (see Fig. 1 for sampling locations)

Table 3 Water quality parameters adopted in TrWQI

Seq.	Selected parameter	Reason for selection
1	Turbidity (NTU)	Experts choice + exceeding the limit
2	pH	Experts choice
3	TDS (mg/L)	Experts choice + exceeding the limit
4	WT (°C)	Exceeding the limit
5	BOD (mg/L)	Experts choice
6	DO (mg/L)	Experts choice
7	Fe (mg/L)	Exceeding the limit
8	SO_4^{2-} (mg/L)	Experts choice + exceeding the limit
9	Alkalinity (mg/L)	Exceeding the limit
10	TC (MPN/100 mL)	Experts choice + exceeding the limit

- Good: 75–94 (Normal full physical treatment and disinfection).
- Fair: 50–74 (Normal full physical, chemical treatment and disinfection).
- Poor: 25–49 (Intensive physical and chemical treatment with disinfection).
- Very poor: 0–24 (Advanced separation techniques could be employed such as membrane technology).

Application of TrWQI for evaluating the Tigris River water quality

The analytical results of the Tigris River water quality are presented in Table 5. As can be seen, turbidity has exceeded the prescribed limit of 5 NTU (Table 1) set by IQS (2009) in all sampling locations. The pH values of the Tigris River revealed an alkaline nature throughout all stations. The BOD value was relatively high (4.1 mg/L) with a DO value of 5.3 mg/L at Alrasheed station. This station is located downstream of the domestic and industrial wastewater discharge

sources. This also explains the high value of TC in Aldora and Alrasheed stations in comparison with other stations. In the meantime, TDS was crossed over the limit of 500 mg/L (IQS 2009) at two stations, East Tigris and Alrasheed. Nevertheless, Fe ions concentration has surpassed the drinking limit of 0.3 mg/L (IQS 2009) within all stations. Alkalinity was found exceeding the drinking limit of 125 mg/L (IQS 2009) for all stations except Alkarkh. Finally, Sulfate was within the limit of both IQS (2009) and WHO (2011), for all sites.

The main outputs of the proposed TrWQI are shown in Fig. 7. TrWQI can be calculated using sub-indices shown in Fig. 6 or using Table 6. Based on the aggregation function suggested by Brown et al. (1970), the water quality classification for the entire sampling stations was rated as "Fair" in Alkarkh, East Tigris and Aldora, whereas "Poor" in Alwathba and Alrasheed. Similar behavior was obtained when applying the aggregaltion function proposed by Bascarón (1979) as shown in Fig. 7. The calculated WQI based on Tyson and House (1989) aggregation function revealed that the water quality classification for sampling stations was also rated as "Poor" in Alkarkh, East Tigris and Aldora, whereas "Very poor" in Alwathba and Alrasheed.

Discussions

From Fig. 7, it is clearly noticed that the aggregation function of Tyson and House (1989) did not reflect the actual state for the water quality of the Tigris River. The output of TrWQI when employing Brown et al. (1970) or Bascarón (1979) functions has bestowed realistic and reliable results compared to the raw data of the Tigris River. According to TrWQI, the water characteristics of Tigris River ranged from "Fair" to "Poor" quality. Fairwater quality implies that the WTPs required only a normal full physical, chemical treatment and disinfection. However, Poor water quality presupposes that the WTPs seek an intensive physical and chemical treatment with disinfection. Referring to Fig. 1, TDS values of the Tigris River during the ten years period were 2124 mg/L, 290 mg/L and 585.5 mg/L as maximum, minimum and mean value, respectively. The same trend was also observed for other water quality parameters such as turbidity (Max = 4500 NTU, Min = 3 NTU and Mean = 97.2 NTU). The Tigris River water quality could undergo a worse scenario and become "Very poor" if TrWQI being applied for assessment during another season or year. If so, advanced techniques such as membrane separation technology would be necessary to be employed in these WTPs.

Virtually, the water quality of Tigris River, within Baghdad, has been extensively investigated in the literature (Mutlak et al. 1980; ALSuhaili and Nasser 2008; Al-Janabi et al. 2012; Ismail 2014; Ismail et al. 2014). In our previous

Fig. 6 Sub-indices of TrWQI, **a** sub-index of turbidity, **b** sub-index of TDS, **c** sub-index of BOD, **d** sub-index of DO, **e** sub-index of temperature, **f** sub-index of pH, **g** sub-index of SO_4^{2-}, **h** sub-index of Fe, **i** sub-index of alkalinity, **j** sub-index of TC
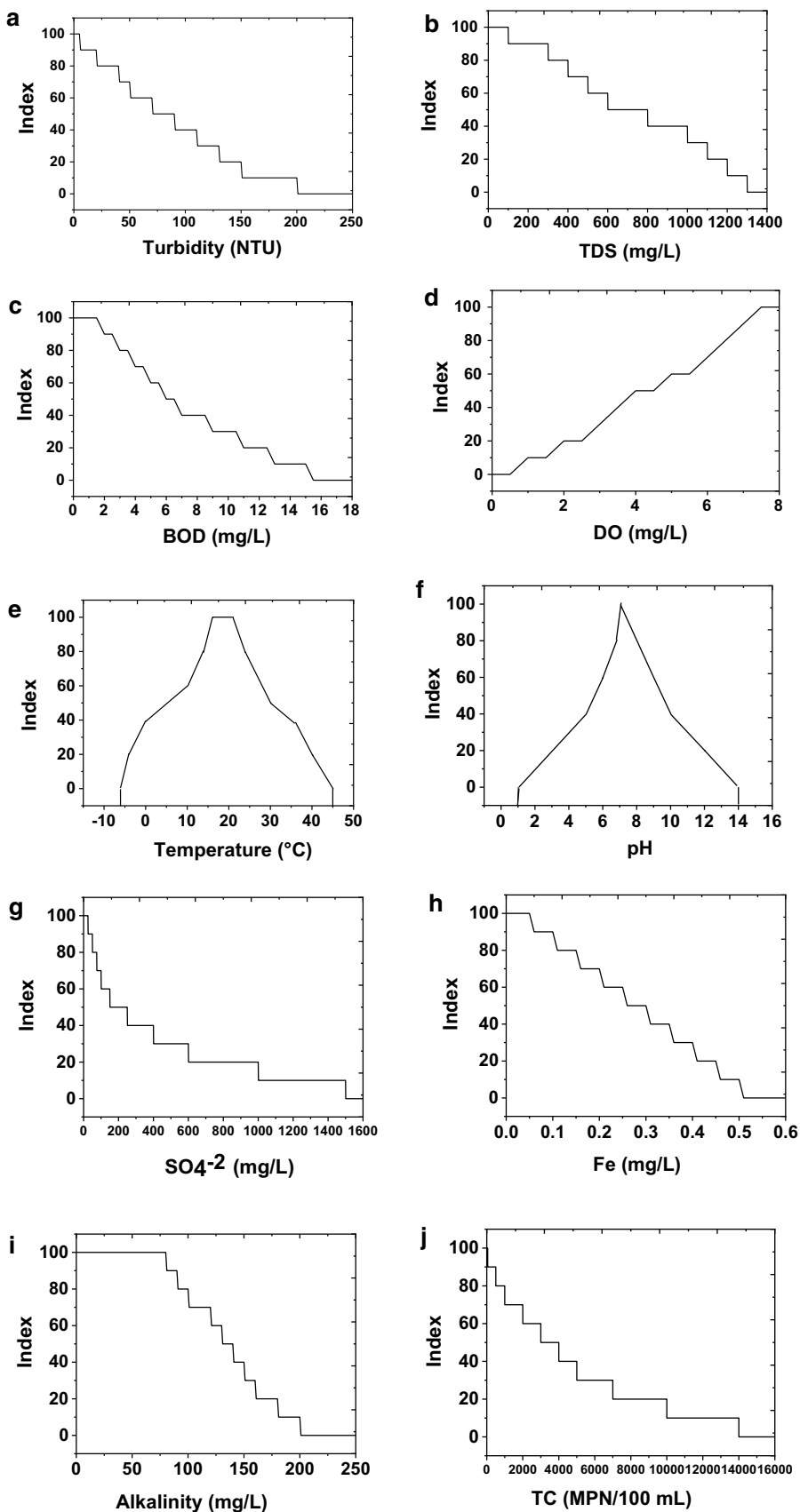
Table 4 Weights assignment of the selected water quality parameters

Parameters	Temporary weights (P_i)	Final weights (w_i)
Turbidity (NTU)	4	0.15
pH	2	0.08
TDS (mg/L)	4	0.15
WT (°C)	1	0.04
BOD (mg/L)	4	0.15
DO (mg/L)	3	0.11
Fe (mg/L)	2	0.08
SO_4^{2-} (mg/L)	2	0.08
Alkalinity (mg/L)	1	0.04
TC (MPN/100 mL)	3	0.12
Sum of weights	26	1

studies, WQI has been employed as a tool to assess the water quality of the Tigris River. However, the conducted studies did not endow reliable results if compared with the raw data of the Tigris River. For instance, Ismail (2014) has applied the overall Index of Pollution (OIP), suggested by Sargaonkar & Deshpande (2003), to the water quality data of Tigris River within the Baghdad region. The OIP has been originally applied to Yamuna River in India and involved thirteen water quality parameters. Results of the Tigris River showcased that the water quality was "acceptable" at most of the sampling stations. Ismail (2014) concluded that OIP did not reflect the actual water quality of Tigris River.

Moreover, Al-Janabi et al. (2012) have applied the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) (CCME 2001) to evaluate the Tigris River water quality. Their results disclosed that the water quality was poor throughout all stations. Parameters like DO, BOD, and TC were not considered in the research. On the other hand, Dede et al. (2013) and Ismail and Robescu (2019a) introduced six WQIs models to assess the Kirmir Basin in Turkey and Danube river in Romania, respectively.

Their outcomes revealed that the CCME WQI was the most adequate WQI model among the other selected WQIs. Basically, CCME WQI has a totally different approach and distinct characteristics among others. It comprised three factors for the evaluation process (scope, frequency, and amplitude). However, CCME WQI considers all water quality parameters have the same degree of importance, and it can be applied only when guidelines on water quality parameters are available. Consequently, this index was difficult to be applied in the current work due to the absence of guidelines for surface water used for potable abstractions of some selected parameters. Moreover, Ewaid et al. (2018) have developed a WQI for the Tigris River with the aid of multiple linear regression (MLR) analysis. Twenty-three water quality parameters were considered, and their results revealed that the water quality was inappropriate for drinking purposes. However, the bacteriological parameters have not been taken into consideration.

Generally, water quality deterioration in the Tigris River should be avoided by the authorities as the river is the main source of drinking water for Baghdad. Water quality parameters such as turbidity and TDS are very high in the river
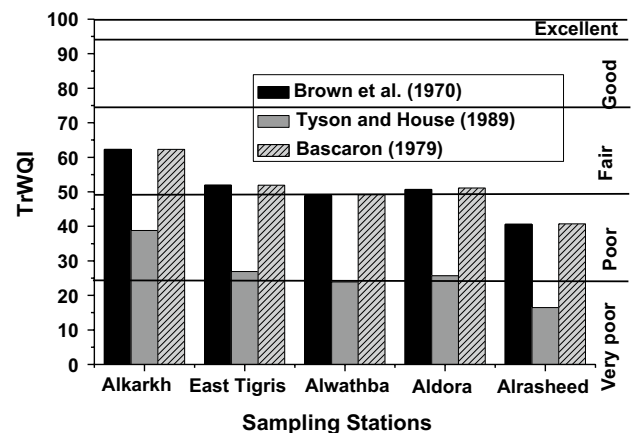

Fig. 7 The calculated results of TrWQI

Table 5 The analytical results of Tigris River water quality

Parameters	Alkarkh	East Tigris	Alwathba	Aldora	Alrasheed
Turbidity (NTU)	218	215	186	152	365
pH	7.98	7.97	8.22	8.07	7.90
TDS (mg/L)	371	510	487	481	510
WT (°C)	22	22	21	21	23
BOD (mg/L)	2.5	3.5	3.3	3.0	4.1
DO (mg/L)	7.2	6.8	6.5	6.4	5.3
Fe (mg/L)	1.25	2.45	3.68	6.00	1.50
SO_4^{2-} (mg/L)	66	196	135	140	142
Alkalinity (mg/L)	122	158	161	173	147
TC (MPN/100 mL)	711	1462	8200	62,136	54,439

Table 6 TrWQI sub-indices calculation

Parameter	Sub-indices of water quality parameters										
	100	90	80	70	60	50	40	30	20	10	0
WT	21/16	22/15	24/14	26/12	28/10	30/5	32/0	36/−2	40/−4	43/−5	>45/<−6
pH	7	6.9–7.5	6.8–8	6.5–8.5	6–9	5.5–9.5	5–10	4–11	3–12	2–13	1–14
DO	>=7.5	>7	>6.5	>6	>5	>4	>3.5	>3	>2	>=1	<1
TDS	<100	<300	<450	<500	<600	<800	<1000	<1100	<1200	<=1300	>1300
SO_4	<25	<50	<75	<100	<150	<250	<400	<600	<1000	<=1500	>1500
Fe	<0.05	<0.1	<0.15	<0.2	<0.25	<0.3	<0.35	<0.4	<0.45	<=0.5	>0.5
Alkalinity	<80	<90	<100	<120	<130	<140	<150	<160	<180	<=200	>250
BOD	<0.5	<2	<3	<4	<5	<6	<8	<10	<12	<=15	>15
Turbidity	<5	<20	<40	<50	<70	<90	<110	<130	<150	<=200	>200
Total coliform	<50	<500	<1000	<2000	<3000	<4000	<5000	<7000	<10,000	<=14,000	>14,000

and need to be studied deeply in order to improve the water quality status. At last, the proposed TrWQI can be employed as an effective tool to evaluate the water quality of the Tigris River for potable abstractions (water supply uses). It could be beneficial for managers and decision-makers by providing a baseline study for the rivers' water quality management. Possibly, the methodology presented in this research can be applied to other rivers, especially those in the MENA region.

Conclusion

The current paper showcased the flourishing research activities for the development of a water quality index (WQI). This was carried to assess the suitability of the Tigris River to be harnessed for drinking water abstractions and to provide baseline information on the selection of appropriate water treatment techniques. Based on the methodology adopted in the paper, ten water quality parameters were investigated to bestow the highest impact on the water quality of the Tigris River. Step and inverse parabolic sub-indices types were employed to develop the sub-indices for the 10 selected water quality parameters. Three types of aggregation functions with unequal weights were used to determine the ultimate value of the index. TrWQI was applied to assess the water quality of the Tigris River at five sampling stations during April 2019. It was demonstrated that only two aggregation functions can be considered for calculating the final value. The outputs of these functions have provided realistic results in comparison to the raw data of the Tigris River. The water quality of Tigris River was "Fair" at Alkarkh, East Tigris and Aldora, whereas "Poor" in Alwathba and Alrasheed. This means that the intakes of WTPs should use normal to intensive full physical, chemical treatment and disinfection. Actions should be taken to employ some advanced water treatment units such as membranes at these WTPs, especially if the quality of river water deteriorates to

a very poor level. TrWQI could be a beneficial and efficient tool for water managers and technicians. It could be applied to other rivers in the MENA region that have the same physico-chemical and biological characteristics.

Declarations

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