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Water quality index for Al-Gharraf River, southern Iraq

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ABSTRACT

The Water Quality Index has been developed mathematically to evaluate the water quality of Al-Gharraf River, the main branch of the Tigris River in the south of Iraq. Water samples were collected monthly from five sampling stations during 2015–2016, and 11 parameters were analyzed: biological oxygen demand, total dissolved solids, the concentration of hydrogen ions, dissolved oxygen, turbidity, phosphates, nitrates, chlorides, as well as turbidity, total hardness, electrical conductivity and alkalinity. The index classified the river water, without including turbidity as a parameter, as good for drinking at the first station, poor at stations 2, 3, 4 and very poor at station 5. When turbidity was included, the index classified the river water as unsuitable for drinking purposes in the entire river. The study highlights the importance of applying the water quality indices which indicate the total effect of the ecological factors on surface water quality and which give a simple interpretation of the monitoring data to help local people in improving water quality.

Introduction

Drinking water in Iraq comes from rivers, lakes, wells and springs. These sources are exposed to a variety of pollutants caused by the diffusion from nonpoint and point sources which are difficult to control, monitor, and evaluate, such as sewage, agricultural and industrial wastes (Ahuja, 2003). Water quality is determined by the chemical, physical and biological parameters of water. It is a measure of the state of the water with respect to the necessities of human needs or purposes (Abbasi and Abbasi, 2012). The water pollution of rivers requires great efforts, and water quality is an important issue in the field of water resources planning and management and requires data gathering, analysis, and interpretation (Yehia and Sabae, 2011).

The Water Quality Index (WQI) is a simple method utilized as a part of surveying the general water quality using a group of parameters which reduce the large amounts of information to a single number, usually dimensionless, in a simple reproducible manner (Abbasi and Abbasi, 2012).

It gives important data delineating the general water quality status which can be of extraordinary help in the choice of suitable water-treatment technique to address the issue of contamination. The primary WQI was suggested by Horton (1965) and subsequently other ideas were suggested as improvements to the original method. Numerous WQIs have been developed and approved around the world (Prasad and Kumari, 2008; Reza and Singh, 2010; Manoj et al., 2012; Dede, 2013), the differences between them being the statistical incorporation and translation of parameter values (Abbasi and Abbasi, 2012; Alobaidy et al., 2010; Lumb et al., 2011).

Al-Gharraf River is the primary source of water in the south of Iraq. It branches from the Tigris close to Al-Kut city and runs through the Wasit and Dhi-Qar regions. The water from it is utilized for essential uses such as; drinking, raising livestock, irrigation and fishing (Al-Gizzy, 2005). Wastewater and rural seepage water from these utilizations frequently come back to the waterway as inflows. Any threat, whether natural or anthropogenic, can conceivably greatly affect socio-economic aspects of the area (Ewaid, 2011).

The aim of this research is to develop a water quality index (WQI) for Al-Gharraf River based on physicochemical water quality parameters, to help the local people towards proper management of water resources and to build up gauge information which will help in future water administration and protection arrangements.

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Materials and methods

Description of the study area

Al-Gharraf is the principle branch of the Tigris River; it branches from the Tigris, south of Baghdad at Al-Kut Dam to the Euphrates basin passing Wasit and Dhi-Qar governorates and diminishes north of Nassyria City, in the south of Iraq. Its highest flow rate is 622 m^3/s, with a length of around 230 km and its drainage area is 435052×10^6 m^2. Fifty-two channels and 968 water system trench branching from it which irrigate an area of 700,000 hectares (Al-Sahaf, 1965; U.S. Department of Agriculture, 2009).

The watercourse land position, Table 1 provides the valley semi-arid atmosphere qualities, like high temperature in summer, low humidity, little mean yearly precipitation of around 150 mm, high rate of sun radiation and high rate of dissipation (Atiaa, 2015). Al-Gharraf experiences human and natural issues like; shortage of water, growth of plants such as water hyacinth (*Eichhornia crassipes*), contamination and the accumulation of mud (Ewaid, 2016).

Five sampling stations were chosen, Fig. 1. The initial station, at the start, had the same propertied of the Tigris, without any urban areas for 200 km. Near the second station, there were numerous horticultural fields on both banks and the water was affected by residential wastewater from Al-Hay town. The third station had salt zones on the left side and farming fields on the right. The urban wastewater from Qalaat Sekar and Rifai towns affect the waterway. The fourth station near the main Al-Bada'a sluice gate has four refinery stations on the right side before Shatrah town, which supply drinking water to Dhi-Qar and Basrah governorates. The fifth station had low water level and restricted width, located south of Shatra town and affected by its wastewater; see Fig. 1.

Table 1
The coordinates of the water sampling station.

No.	Points	Coordinates	
		N	E
1.	GR-1	32°30′00.32″	45°44′60.00″
2.	GR-2	32°11′16.10″	46° 0′26.32″
3.	GR-3	31°53′13.87″	46° 3′17.65″
4.	GR-4	31°34′32.48″	46° 7′26.55″
5.	GR-5	31°18′9.82″	46°14′17.06″

Field sampling and Analytical procedures

Water samples were collected monthly from December 2015 to January 2016 at each sampling station. Samples were preserved and analyzed according to American Public Health Association (APHA) standard methods (American Public Health Association (APHA), 2012). Biological oxygen demand (BOD), total dissolved solids (TDS), hydrogen ion concentration (pH), dissolved oxygen (DO), turbidity (Tur.), phosphates (PO_4), nitrates (NO_3), chlorides (Cl^-), total hardness (TH) electrical conductivity (EC) and alkalinity were measured by the methods in Table 2.

Calculation of the WQI

The Water Quality Index for the river was calculated from eleven parameters namely: BOD, TDS, pH, DO, turbidity, PO_4, NO_3, chlorides, TH, EC, and alkalinity for five sampling stations to assess the suitability of Al-Gharraf River water for drinking purposes. The WQI was calculated using the weighted arithmetic water quality index method which was proposed by Horton (1965), developed by Brown et al. (1970) and then by Cude (2001) in which water parameters are multiplied by a weighting factor and are then

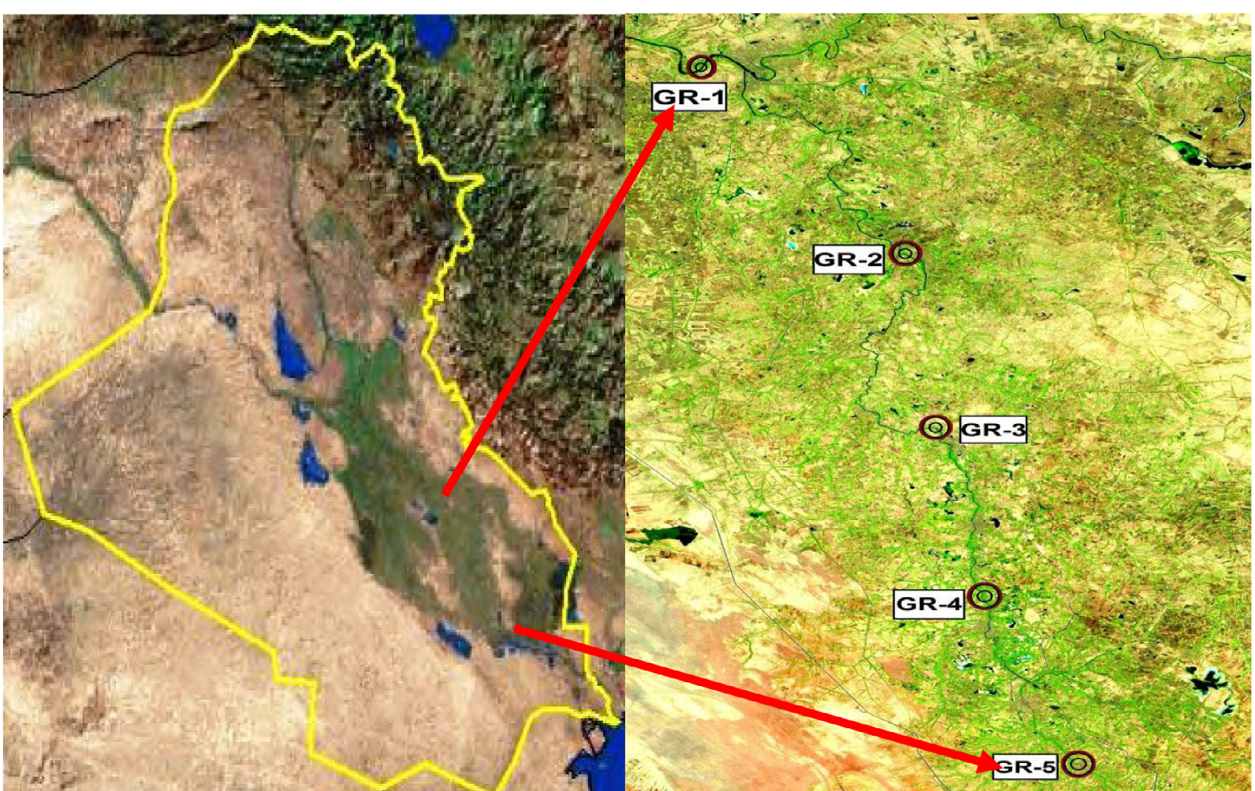

Fig. 1. The map and the sampling stations of the study area.

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Table 2
Measurement methods for the water quality parameters.

No	Parameter	Unit	Method	Site
1	BOD	mg/l	Azide modification at 20 °C (5 D)	Laboratory
2	TDS	mg/l	Temperature controlled oven	Laboratory
3	pH	pH units	WTW portable multi-meter 340i	*in situ*
4	DO	mg/l	WTW portable multi-meter 340i	*in situ*
5	Tur.	NTU	WTW portable turbidity meter TURB 355 IR/T	*in situ*
6	PO_4	mg/l	Molybdate ascorbic acid method	Laboratory
7	NO_3	mg/l	Cadmium reduction method	Laboratory
8	Cl^-	mg/l	Silver nitrate titrationmethod	Laboratory
9	TH	mg/l	Titration with EDTA-2Na and EBT as an indicator.	Laboratory
10	EC	μS/cm	WTW portable multi-meter 340i	*in situ*
11	Alkalinity	mg/l	As $CaCO_3$ by titration method	Laboratory

Table 3
The WQI categories.

Range	Quality
0–25	Excellent
26–50	Good
51–75	Poor
76–100	Very Poor
>100	Unsuitable for drinking

aggregated using a simple arithmetic mean by these three equations:

$$Qi = \frac{(Mi - li)}{(Si - Ii)} x100 \quad (1)$$

$$Wi = \frac{K}{Si} \quad (2)$$

$$WQI = \sum_{i=1}^{n} \frac{WiQi}{\sum_{i=1}^{n} Wi} \quad (3)$$

where, *Qi* is the sub-index of the *ith* parameter, *Wi* is the unit weightage of the *ith* parameter, *n* is the number of parameters included, *Mi* is the monitored value of the parameter, *Ii* is the ideal value and *Si* is the standard value of the *ith* parameter.

The ideal value for pH = 7, dissolved oxygen = 14.6 mg/l, and for other parameters, it is equal to zero (Tripaty and Sahu, 2005; Chowdhury et al., 2012).

The weightage unit (*Wi*) of each parameter was calculated a value inversely proportional to the standard of the World Health Organization (*Si*) World Health Organization, 2011.

Based on the calculated WQI, the category of water quality types is shown in Table 3 according to Shweta et al. (2013).

Results and discussion

The annual Water Quality Index for the five stations along the river was determined using the weighted arithmetic index method and the eleven physicochemical parameters, the overall water quality data (range, mean and annual mean) of the river are presented in Table 4.

There was a little difference between parameter values measured in this study for the five stations as a result of the similar atmospheric conditions and source of water, yet there were significant differences according to season.

The reduction in WQI value downstream is an indication of various pollutants entering the waterway because of different anthropogenic and natural factors like the release of untreated local sewage and spillover water from horticultural areas (Al-Obaidy and Al-Khateeb, 2013), and the decrease in river water levels that promotes drainage from the ground water into the waterway (Jerry and Webb, 2004).

There are large yearly fluctuations in the river water level in the dry seasons (summer and autumn); water comes from the reservoirs full of organic materials, plankton, algae and plants with dark green color, reducing in pH and oxygen, raising turbidity, total dissolved solids and affecting the overall water quality (Iraq Ministries of: Water Resources, 2006).

The river can't self-purify because of the low level of water and shortage caused by limited rains, the many dams which had been built in Iraq's neighboring countries besides the poor planning with the old methods used in irrigation (Issa et al., 2013; Al-Obaidy et al., 2015).

The results of the analysis physicochemical parameters for WQI calculation (Table 3) supported the low water quality observed.

BOD is the amount of oxygen utilized by the microorganisms to break down organic compounds during five days in the laboratory (Smitha and Shivashankar, 2013). In Al-Gharraf River it extended from 0.8 to 10.1 mg/l with an annual mean of 3.95 mg/l. It was generally low according to the quality standard of <5 mg/l of the WHO

Table 4
Simple statistical analysis of water quality parameters. pH in pH unit, EC in μS/cm, Tur. in NTU and the rest in mg/l.

	1st Station		2nd Station		3rd Station		4th Station		5th Station		Annual Mean
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	
BOD	0.8–2.6	1.6	1.9–3.4	2.75	2.8–4.4	3.8	2.2–4.7	3.5	2.6–10.1	8.12	3.95
TDS	620–790	691	63–760	700	610–870	727	640–760	710	630–750	700	686
pH	7.1–7.8	7.4	7.3–7.9	7.5	6.8–7.7	7.175	7.2–8.0	7.5	7.1–7.9	7.5	7.4
DO	7–9.6	8.2	6.2–10	7.95	6.8–7.8	7.325	6.2–7.8	6.825	6–8.8	7.125	7.48
Tur.	75–91	81	64–92	75.25	55–84	68	60–78	67	40–70	58.5	50
PO_4	0.1–0.21	0.13	0.11 0.27	0.195	0.13–0.65	0.3	0.46–0.66	0.59	0.4–0.7	0.6	0.363
NO_3	2.9–5.6	4.1	2.6–7	4.55	3–7.5	4.7	3.4–6.3	4.775	3–6.5	4.68	4.56
Cl^-	123–225	167	160–240	196	165–265	216	168–235	192	170–220	205	195
TH	250–390	321	320–395	361	300–410	355	290–435	337	300–400	335	341
EC	928–1100	997	980–1200	1075	970–1210	1082	990–1200	1027	1020–1270	1067	1043
Alk.	145–175	165	143–240	189	150–240	200	165–270	196	155–265	195	189

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(World Health Organization, 2011). Subsequently, the BOD at the initial four stations achieved the criteria, but at the fifth station, it did not.

The TDS level within the river water fluctuated from 620 mg/l to 870 mg/l with an annual mean of 686 mg/l during the study, and there were no differences across the stations but there were between the different seasons. Water containing more than 1000 mg/L of TDS is not palatable as drinking water. (USGS, 2015).

The pH of water at the river stations fell within the 6.8–8 range and had an annual mean of 7.4; it had a marginally alkaline average value as in numerous past research studies about Iraqi surface water (Atiaa, 2015; Al-Abadi, 2014).

Dissolved oxygen is the most important parameter for assessing water quality as it affects aquatic life and the distribution of (Rabee et al., 2011; Naubi et al., 2016). In this study, it ranged from 6.2 to 10 mg/l with an annual mean of 7.48 mg/l which was more than 5 mg/L higher than the standard set by the WHO and decreased downstream.

It was found that the turbidity value of 40 to 92 NTU and annual mean of 50 NTU was higher than the 5 NTU suggested by the WHO, 2011 for drinking water, and that greatly affects the WQI value, it also diminished downstream.

The observed values for phosphates were 0.1 mg/l to 0.7 mg/l and the annual mean was 0.36 mg/l which is below the 5 mg/l recommended by the WHO in 2011.

Table 5
Calculation of Water Quality Index (WQI) of the river. pH in pH unit, EC in μS/cm, Tur. in NTU and the rest in mg/l.

	Station	Standard Value (*Si*)	Ideal value (*Ii*)	Monitored values (*Mi*)	Sub-index (*Qi*)	Weightage unit (*Wi*)	*Wi* x *Qi*
BOD	1	5	0	1.6	30	0.2	6
	2	5	0	2.75	55	0.2	11
	3	5	0	3.8	76	0.2	15.2
	4	5	0	3.5	70	0.2	14
	5	5	0	8.12	162.4	0.2	32.5
TDS	1	1000	0	691	69.1	0.001	0.07
	2	1000	0	700	70	0.001	0.07
	3	1000	0	727	72.7	0.001	0.073
	4	1000	0	710	71	0.001	0.071
	5	1000	0	700	70	0.001	0.07
pH	1	7.5	7	7.4	80	0.133	10.64
	2	7.5	7	7.5	100	0.133	13.3
	3	7.5	7	7.175	35	0.133	4.65
	4	7.5	7	7.5	100	0.133	13.3
	5	7.5	7	7.5	100	0.133	13.3
DO	1	5	14.6	8.2	66.6	0.2	13.32
	2	5	14.6	7.95	69.27	0.2	13.854
	3	5	14.6	7.325	75.78	0.2	15.156
	4	5	14.6	6.825	70.57	0.2	14.114
	5	5	14.6	7.125	77.86	0.2	17.572
Tur.	1	5	0	81	1620	0.2	324
	2	5	0	75.25	1505	0.2	301
	3	5	0	68	1360	0.2	272
	4	5	0	67	1340	0.2	268
	5	5	0	58.5	1170	0.2	234
PO4	1	5	0	0.13	2.6	0.2	0.52
	2	5	0	0.195	3.9	0.2	0.78
	3	5	0	0.3	6	0.2	1.2
	4	5	0	0.59	11.8	0.2	2.36
	5	5	0	0.6	12	0.2	2.4
NO3	1	50	0	4.1	8.2	0.02	0.164
	2	50	0	4.55	9.1	0.02	0.182
	3	50	0	4.7	9.4	0.02	0. 188
	4	50	0	4.75	9.5	0.02	0.19
	5	50	0	4.68	9.36	0.02	0.187
Cl	1	350	0	167	47.7	0.003	0.143
	2	350	0	196	56	0.003	0.168
	3	350	0	216	61.7	0.003	0.185
	4	350	0	192	54.8	0.003	0.164
	5	350	0	205	58.6	0.003	0.176
TH	1	500	0	321	64.2	0.002	0.128
	2	500	0	361	72.2	0.002	0.144
	3	500	0	355	71	0.002	0.142
	4	500	0	337	76.4	0.002	0.153
	5	500	0	355	71	0.002	0.142
EC	1	250	0	997	399	0.004	1.6
	2	250	0	1072	429	0.004	1.7
	3	250	0	1082	433	0.004	1.73
	4	250	0	1027	411	0.004	1.64
	5	250	0	1067	427	0.004	1.7
Alk.	1	200	0	165	82.5	0.005	0.41
	2	200	0	189	94.5	0.005	0.47
	3	200	0	200	100	0.005	0.5
	4	200	0	196	98	0.005	0.49
	5	200	0	195	97.5	0.005	0.49

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Table 6
Water Quality Index value of different sampling sites without and with turbidity.

Stations	WQI values without including turbidity		WQI values including turbidity	
1	43.0	Good	387.4	Unsuitable for drinking
2	67.2	Poor	364.3	
3	64.1		331.6	
4	73.5		335.2	
5	88.7	Very poor	312.1	
The entire river	67.3	Poor	346.1	

Nitrate is an undesirable ion in water with detrimental health effects. The maximum and minimum average values were 2.9 and 7.5 mg/l and an annual mean of 4.56 mg/l were observed; its values fell far below 50 mg/l, the threshold value of the WHO.

The values of chlorides were 132 to 240 mg/l and an annual mean of 195 mg/l were observed in the river, that was bellow the WHO standard.

Total hardness values were below 500 mg/l, the permissible levels of the WHO for drinking water at all the stations and during all seasons. The average concentration was 250 mg/l to 410 mg/l and the annual mean was 341 mg/l.

The values of electrical conductivity were 928 to 1270 μS/cm and an annual mean of 1043 μS/cm were observed in the river, it was always more than the WHO standard of 250 μS/cm.

Alkalinity values were sometimes above 200 mg/l, the permissible levels of the WHO for drinking water. The average concentration was 143 mg/l to 270 mg/l and the annual mean was 189 mg/l Table 4.

Calculation of the water quality index

The water quality index for the river was ascertained utilizing the weighted arithmetic index equations specified previously, and the values obtained are presented in Table 5, which shows the monitored values (Mi) of the selected eleven water quality parameters, standard drinking water values (Si) according to the WHO (World Health Organization, 2011), weightage unit (Wi), sub-index water quality rating (Qi) and $WiQi$.

Because of the high values of Al-Gharraf River water turbidity, the index values was classified into two classes (without and with turbidity) for each station and the entire river as presented in Table 6.

According to the classification of water quality in light of weighted arithmetic WQI method, as given in Table 3, the observed range of water quality index values of Al-Gharraf River (without turbidity) is 43.0 to 88.7. The lowest WQI value of 43.0 was recorded at station 1, which indicates good water quality. The WQI values of station 2, 3, and 4 were 67.2, 64.1, and 73.5 respectively which indicates poor water quality. A maximum WQI value of 88.7 was recorded at station 5, which can be stated as very poor water quality. The general WQI for the river is 67.3, indicating poor water qualities.

When turbidity is included in the calculation of the WQI for the river, the values ranged from 312.1 to 387.4 which mean that the water is unsuitable for drinking in the entire river according to the classification in Table 3.

All of these WQI values show poor water quality, and this may be due to various natural phenomena and anthropogenic activities occurring along the river. Furthermore, the WQI values obtained mean that untreated water from the river is of low quality and must be treated well before use to minimize water-related illnesses.

The water quality of Al-Gharraf River was examined according to the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) using 17 physicochemical parameters. The model classified the river water as poor for aquatic life and fair for irrigation with annual WQI values of 30–39 on a scale of 100 (Ewaid, 2016). The water quality of the river was evaluated using the National Sanitation Foundation Water Quality Index (NFS WQI) using 13 parameters; the range obtained was 64–70 indicating a medium water quality (Ewaid, 2016).

Recommendation

- We recommend further studies on the targeted area in order to shading more light on this important area that is fed some Iraqi marshes.
- Some parameters are required to add to cover as possible as the current status of Al Gharraf River.
- Create a strategic plan to aware the local people about the pollution that produce for them, and how we can prevent and save our environment from this important issue.
- Launch an environmental program starting from the primary school to the decision maker and involve all of the stakeholders to participate in prevention and mitigate the pollution.

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