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Drinking water quality assessment by using water quality index (WQI) for Hillah River, Iraq

Zaid Abed Al-Ridah[1], Hussein A. M. Al-Zubaidi[2], Ahmed Samir Naje[1]* and Isam Mohamad Ali[3]

[1]College of Water Resources Engineering, Al-Qasim Green University, Babylon, Iraq.
[2]Department of Environmental Engineering, College of Engineering, University of Babylon, Babylon, Iraq.
[3]Karbala Technical Institute, Al-Furat Al-Awsat Technical University, 56001 Karbala, Iraq

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ABSTRACT

This study evaluated the water quality for drinking by using two models, which were the Weighted Arithmetic and Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI). Results of these two models were also compared. The study area included four water treatment stations: Al-Tayarah (TA), New Hilla (NH), Al-Hesain (HE) and Al-Hashimyah (HA) on the Hilla River, which is a branch of the Euphrates River in the middle of Iraq. Water samples were collected monthly from January to December 2018, and nine parameters of raw and treated water were examined, such as turbidity (Tur), pH, electric conductivity (EC), alkalinity (Alk), total hardness (TH), calcium (Ca), magnesium (Mg), chloride (Cl^-), and total dissolved solids (TDS). For all stations, the Weighted Arithmetic model showed that the raw water quality was categorised from "severely polluted" to "unfit for human consumption" and the treated water quality ranged from "excellent" to "severely polluted". However, the CCME WQI method categorised the river water as "fair" and treated water as "good" for drinking. The comparison results of two models showed that CCME WQI gave greater water quality value than the value from the other method, or the CCME WQI was possibly considered as more flexible.

Keywords : *Water quality index (WQI), Raw water, Treated water, CCME WQI method, Weighted arithmetic method, Hilla river*

Introduction

Rivers are the most important natural resource for human progress (Osunkiyesi, 2012). These resources are polluted by increased human activities, illegal sewage and industrial waste disposal which affect the physicochemical and microbiological water quality. This may cause the decline of river water quality and thus it is necessary to monitor the water quality to assess its problem and cause (Alsaqqar *et al.,* 2013); (Udousoro and Umoren, 2014). The term water quality is a conventional collection of chemical, physical and biological parameters formed in a certain group. It expresses the probability of its anthropic usage to meet a definite purpose, such as drinking, agricultural, recreational and industrial water usages (Khudair, 2013). Water quality index (WQI) is one of the most important techniques for classifying and shifting water quality data to citizens and relevant policy makers (Okab, 2015); (Oko *et al.,* 2014). Therefore, it has become an important parameter for water management and assessment. WQI is defined as a rating technique to reflect the composite influence of different water quality parameters. It is calculated from the fitness point of view of different water sources for human use (Al-

***Corresponding author's email:** ahmednamesamir@yahoo. com

Shujairi, 2013), (Ramakrishnaiah, *et al.,* 2009). WQI is a mathematical tool used to convert large amount of water quality data into a single cumulatively derived number. It represents a certain water quality level and eliminates the subjective assessments of such quality. It turns complex water quality data into information that is clear and practical to the public. Many WQIs were formulated all over the world, in which the overall water quality within a particular area can be promptly and efficiently evaluated. Some examples include Weighted Arithmetic method (Lumb *et al.,* 2011; Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) model [12], Oregon Water Quality Index (OWQI), National Sanitation Foundation Water Quality Index (NSFWQI) (Udousoro and Umoren, 2014).

The studied area included four water treatment plant stations located near the banks of Hilla River. The Hilla River is branched from Euphrates River after crossing the Al-Hindiya barrage. It is one of the main water sources in Iraq (Salman *et al.,* 2015). Many researchers have addressed the water quality in the river and its branches, such as ecological study, physicochemical and heavy metals and water quality index (Al-Hussein, 2015; Al-Fatlawi, 2005; Al-Taea, 2010; Al-Tai, 1999; Hammoud and Rabee, 2017; Hassan *et al.,* 2010). The studied area suffers from water pollution and high water consumption due to human activities, whereby many water treatment plants are installed on the river and a few research studies were focused on comparing the water quality studies of this river. Therefore, the objectives of the present study is are to assess the suitability of Hilla River water for drinking based on the results of the two water quality indices, which are weighted arithmetic method and CCME WQI , and comparing the results of two indices.

Materials and Methods

Area description

The study area involved four stations along the Hilla River, which extended from Hilla city to Al-Hashimiah town within the Babylon Governorate. These stations represented the water treatment plants of Al-Tayarah, New Hilla, Al-Hesain, and Al-Hashimyah. The latitudes and longitudes of each station are listed in Table 1. Geographical location of the study area is shown in Figure 1.

Table 1. Latitude and longitude of stations

Station	Latitude	Longitude
Al-Tayarah	32º29´45´´	44º25´38´´
New Hilla	32º30´55´´	44º24´40´´
Al-Hesain,	32º23´33´´	44º32´09´´
Al- Hashimyah	32º22´41´´	44º39´24´´

Data collection

The historical water quality data were provided by the Laboratory of Babylon Water Directorate, Ministry of Municipals and Public Works. The data represented nine monthly average water quality values

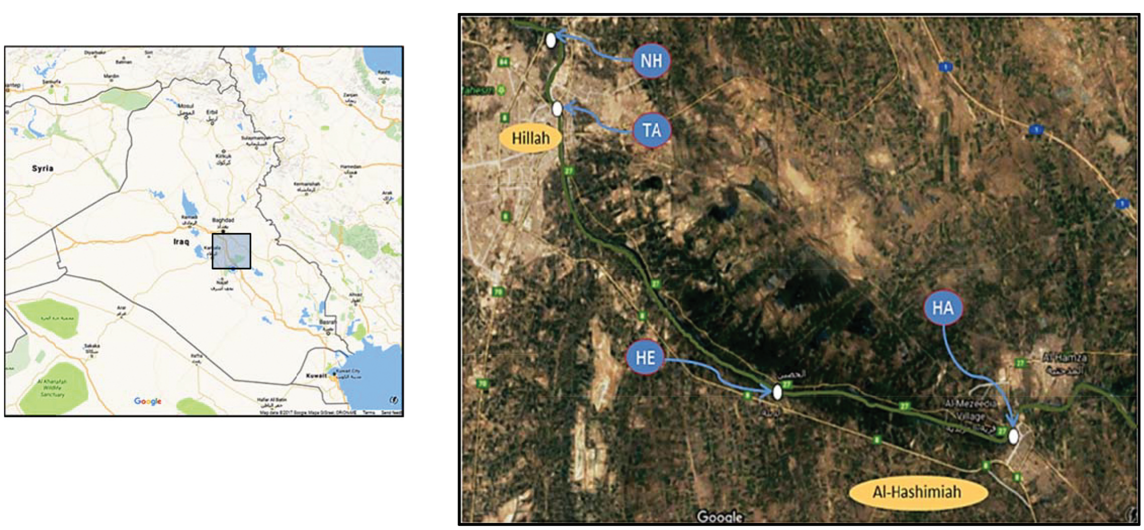

Fig. 1. Location of studied stations

which covered the raw and treated water for the period from January to December 2018. These water quality values were turbidity (Tur), pH, electric conductivity (EC), alkalinity (Alk), total hardness (TH), calcium (Ca), magnesium (Mg), chloride (Cl^-), and total dissolved solids (TDS).

WQI calculations

Weighted arithmetic index method

The method that was used to calculate WQI was first suggested by Horton in 1965 and developed by Brown in 1972. The method was also adopted by many researchers (Deepak and Singh, 2013); (Khwakaram, 2012); (Yisa and Jimoh, 2010), which took the following form:

$$WOI=\sum_{i=1}^{n} w_i q_i / \sum_{i=1}^{n} w_i \quad .. (1)$$

Where, n is the number of variables or parameters, w_i is the relative weight of the i^{th} parameter, q_i is the water quality rating of the i^{th} parameter and wi is the unit weight of water quality parameter where:

$$w_i = k/s_i \quad .. (2)$$

Where, k is the constant of proportionality and it is given as:

$$k=\frac{1}{\frac{1}{Vs1}+\frac{1}{Vs2}+\,.........+\frac{1}{Vsn}} \quad .. (3)$$

Si: Standard permissible value of i^{th} parameter according to the Iraqi standard (Table 2). The value of qi is calculated by using the following equation:

$$qi = 100\,[(V_a - V_i)\,/\,(S_i - V_i)] \quad .. (4)$$

Table 2. Iraqi Drinking Water Standard (COSQC, 2001)

Parameter	Unit	Iraqi Standard
pH	-	8.5
Electrical Conductivity (EC)	µs/cm	2000
Alkalinity (Alk)	mg/L	200
Total Hardness as $CaCO_3$(TH)	mg/L	500
Calcium (Ca^{+2})	mg/L	150
Magnesium (Mg^{+2})	mg/L	100
Chloride (Cl^-)	mg/L	350
Total Dissolved Solids (TDS)	mg/L	1000
Turbidity (TUR)	NTU	5

Va : average water sample values at one station for three months.

Vi: ideal value for pure water (0 for all parameters, except pH).

S: Standard parameter value.

Therefore, Equation (4) becomes

$$qi = 100\,[Va\,/\,S_i\,] \quad .. (5)$$

But for pH: the ideal value (pure water) = 7.0 [6]; Max. Permissible value (polluted water) = 8.5, then

$q_{pH} = 100\,[(Va- 7.0)/\,(8.5-7.0)]$

and $WQI_{pH} = q_{pH} * W_{pH}$ .. (6)

by repeating the above calculations for all water quality parameters, and then calculate WQI for each station from Equation (1). Based on the calculated WQI, the water quality levels classification is shown in Table 3. The mean efficiency (E %) was calculated by using the equation below [5]:

Table 3. Classification of water quality (Reza and Singh, 2010)

Class	WQI level	Water quality classification
I	0-25	Excellent
II	26-50	Good
III	51-75	Moderately polluted
IV	76-100	Severely polluted
V	>100	Unfit and unsuitable for drinking

$$E\% \; \frac{RWQI-TWQI}{RWQI} \times 100 \quad .. (7)$$

CCME WQI method

The (CCME WQI) index was described by Canadian Council of Ministers of the Environment Water Quality (Hurley *et al.*, 2012), (Jafarabadi *et al.*, 2016) and (Mladenovic-Ranisavljevic and Erajic, 2017). The index scores are computed as:

$$\text{CCME WQI} = 100 - \left(\frac{\left(\sqrt[2]{F_1^2+F_2^2+F_3^2}\right)}{1.732}\right) \quad .. (8)$$

Where, the index includes three components: F_1 (scope) represents the variables number not compliant with water quality limits :

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right) * 100; \quad .. (9)$$

F_2 (frequency) represents the number of times these limits are not compliant:

$$F_2 = \left(\frac{\text{Number of failed Tests}}{\text{Total number of Tests}}\right) * 100; \quad .. (10)$$

and F_3 (amplitude): represents the quantity by which failed tested values are not compliant with their objectives (limits), which is calculated as follows:

(i) The excursion calculated from Equation (11) when the test value must not be greater than the objective

$$excursion_i = \frac{\text{Failed Test Value}_i}{\text{Objective}_j} - 1 \quad ..\ (11)$$

or from Equation (12), where the test value is not less than the objective

$$excursion_i = \frac{\text{Objective}_j}{\text{Failed Test Value}_i} - 1 \quad ..\ (12)$$

(ii) The normalised sum of excursions (*nse*) represents the collective quantity by which single tests that are out of agreement are computed by summing the single-test excursions from their objectives and dividing by the total tests number (all tests), is computed as:

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{\text{Total number of Tests}} \quad ..\ (13)$$

(iii) F_3 can be calculated as:

$$F_3 = \left(\frac{\text{nse}}{0.01 * \text{nes} + 0.01}\right) \quad ..\ (14)$$

After the CCME WQI value was calculated, water quality was classified by linking it to the classes listed in Table (4).

Results and Discussion

Variation of water quality parameters

The monthly variations of water quality characteristics (raw and treated) at the studied stations on Al-Hilla River are illustrated in Figure 2 and Fig. 3. Table 4 shows that the statistical description of water quality parameters is represented by the minimum, maximum and mean monthly values. The pH values at all stations did not exceed the Iraqi standard limits (maximum pH = 8.5), as shown in Figure 2a. This indicated that the water samples were semi-alkaline to neutral (Alsaqqar *et al.*, 2013). The EC values (Figure 2b) ranged from 1272 (µs/cm) at TA station to 1675 (µs/cm) at HE station for raw water, and were relatively high but within the limits allowed by the Iraqi standard (2000 µs/cm). High EC values may occur due to human activities or the soil surface runoff which causes an increase in the river water dissolved salts (Tyagi *et al.*, 2013). As indicated in Figure 2c, the alkalinity concentration values are changed from 136 mg/L for raw water at HA station to 88 mg/L for treated water at NH station, which corresponded to the allowable level (200 mg/L). Generally, the mean value of alkalinity is decreased after purification processes at all stations due to additions of chlorine and alum, which dismantled the free carbon dioxide and bicarbonates (Okab, 2015). Total hardness (TH, measured as $CaCO_3$) will produce hard water with high mineral content that will not harm human health (Ewaid *et al.*, 2017). The maximum values of total hardness were higher than the Iraqi standards (500 mg/L), while the minimum and mean values were slightly lower than the established standards, as shown in Figure 2d. The maximum concentration of magnesium in raw water was 59 mg/L at TA station, while the maximum concentration of calcium was 137 mg/L at HE station. These concentrations were within the permissible limits (magnesium 100 mg/L and calcium 150 mg/L), as shown in Figure 2e and Figure 2f. Chloride concentrations (Figure 3a) were within the allowable limits (350 mg/L) and the highest concentration of chloride in raw water was at the HE station. Chloride values of greater than 10 mg/L were the results of human activities by septic systems, sewage, fertilisers, or landfill (WHO, 1996).

Table 4. CCME WQI Classification Plan

Class	Rank	CCME WQI Value	Description
I	Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels. These index values can only be obtained if all measurements are within objectives virtually all of the time
II	Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
III	Fair	65-79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
IV	Marginal	45-64	Water quality is frequently threatened or impaired;conditions often depart from natural or desirable levels
V	Poor	0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

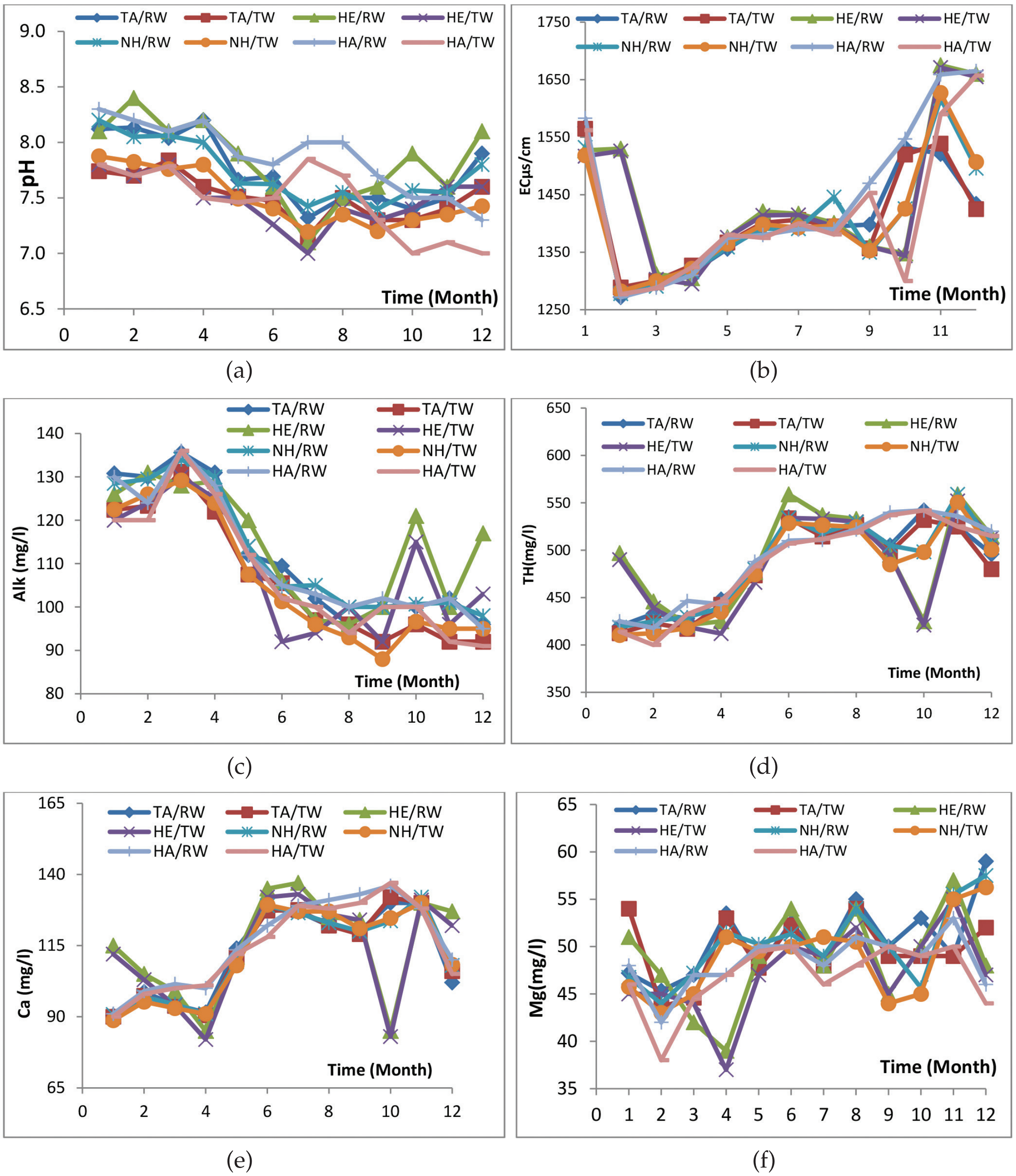

Fig. 2. pH, EC, alkalinity, hardness, Ca^{2+}, and Mg^{2+} monthly values of raw and treated water for the specified stations.

As shown in Figure 3b, the upper concentrations of the total dissolved solid (TDS) were within the the Iraqi standards limits of 1000 mg/L, whereas the minimum and mean concentrations were somewhat acceptable. TDS in the water occur as a result of decaying compounds, which produced positive and negative ion elements (Tyagi, 2013). Furthermore, Figure 3c shows the monthly fluctuations of turbidity at each station. The lowest concentration of turbidity in raw water was outside the Iraqi standards, except for the results at HA station. Most of the treated water turbidity concentrations were within the permissible limits (5 NTU), except for some concentrations at HE station (5.9 NTU) and HA station (10.4 NTU). Turbidity fluctuates with land use and river hydrology, and the runoff of surrounding ar-

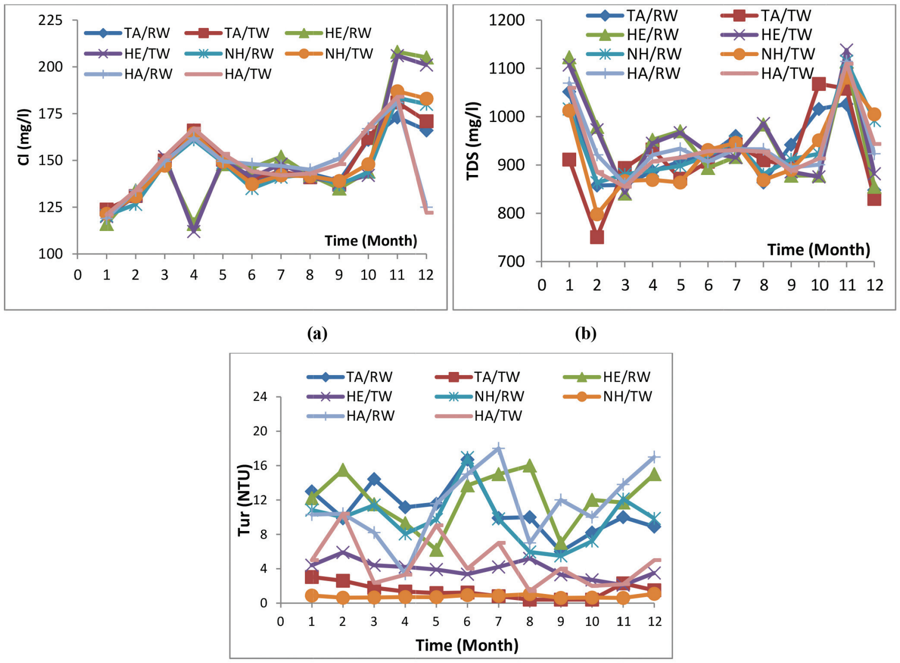

Fig. 3. Cl^-, TDS, and Tur. monthly values of raw and treated water for the specified stations.

Table 5. Raw and treated water quality characteristics for all stations

Station Parameter		TA RW	TA TW	HE RW	HE TW	NH RW	NH TW	HA RW	HA TW	Iraqi standard
pH	Min.	7.32	7.15	7.1	7	7.4	7.2	7.3	7	8.5
	Max.	8.2	7.84	8.4	7.8	8.2	7.88	8.3	7.85	
	Mean	7.75	7.51	7.84	7.49	7.74	7.5	7.87	7.47	
EC(µs/cm)	Min.	1272	1289	1305	1295	1278.2	1282.2	1272	1277	2000
	Max.	1568	1564.8	1675	1671	1617.5	1627	1665	1657	
	Mean	1405.9	1407.68	1444.3	1439.1	1407.7	1407.2	1444.1	1415.5	
Alk (mg/L)	Min.	96	92	96	92	98	88	95	91	200
	Max.	135.6	131.2	131	130	134	129.2	136	133	
	Mean	112.08	106.41	114.25	108.75	112.11	106.18	111.42	107.75	
TH(mg/L)	Min.	419.8	412.4	421	412	418.75	410.5	418	400	500
	Max.	542	533.75	559	552	559	550.5	542	542	
	Mean	487.86	481.55	490.75	483.67	486.8	480.34	491.79	486.04	
Ca^{+2} (mg/L)	Min.	90.4	90	85	82	90.75	88.75	91	90	150
	Max.	130	132	137	133	132	130	136	135	
	Mean	112.29	112.2	114.83	112.67	112.05	111.94	116.17	114.67	
Mg^{+2}(mg/L)	Min.	45.33	43.67	39	37	44	43	42	38	100
	Max.	59	54	57	55	57.5	56.25	53	50	
	Mean	50.65	49.69	48.67	47.17	50.23	48.83	48.42	46.83	
Cl^- (mg/L)	Min.	121.6	123.8	116	112	120.5	121.5	119	121	350
	Max.	173	181	208	206	183.5	187	181	184	
	Mean	148.37	149.8	149.58	148.5	147.3	149.25	148.17	148.21	
TDS (mg/L)	Min.	848	750.79	841	843	863.53	798.19	860.82	854.98	1000
	Max.	1051.6	1068	1123	1138	1115	1081	1114.5	1109.5	
	Mean	928.1	914.56	948.77	953.67	936.58	923.73	942.67	938.7	
Tur (NTU)	Min.	6	0.4	6.2	2.1	5.5	0.6	3.4	1.4	5
	Max.	16.7	3.04	16	5.9	16.93	1.09	18	10.4	
	Mean	10.81	1.41	12.09	3.93	9.78	0.78	11.39	4.64	

eas reveals greater levels of river water turbidity. Increase in surface runoff will increase the turbidity of river water (Huey and Meyer, 2010).

Variation of water quality index

According to Iraqi water quality standard limits and by using the prior equations, the monthly raw and treated WQI were calculated as shown below.

Weighted arithmetic index method

Raw water quality index (RWQI)

The results for all stations' raw water quality index are listed in Table 6. All stations showed that (RWQI) value was ranged between (76.37) at HA station in April and (296.20) at HE station in August. In addition, the mean WQI of the river ranged from (137.72) at NH station to (180.14) at HE station. From these WQI values and according to Table 2, river water was categorised as "severely polluted" to "unfit for human consumption" for the studied stations during the study period. The low water quality of Hilla River was caused by the untreated domestic pollutants disposal site, which directly discharged by the lateral streams (Reza and Singh, 2010). Magnesium and phosphate concentrations were high because of human activities on the river banks (Alhashimi and Mustafa, 2012). The monthly values (WQI) of raw water are showed in Figure 4 for the specified stations during the study period.

Treated water quality index (TWQI)

Table 7 shows the variation in (WQI) monthly values of treated water for the specified stations during the study period. The treated water quality index (TWQI) value was between (16.19-31.49), (16.31-56.98), (43.46-88.89) and (28.46-140.58) at NH, TA, HE and HA, respectively. This means that the treated water ranged from "excellent" to "good" at NH station , "excellent" to "moderately polluted" at TA station, " good" to" severely polluted" at HE station and " good" to "unfit and unsuitable for drinking" at HA station. The monthly values (WQI) of treated water are plotted in Figure 5 for the specified stations during the study period. The mean efficiency (E%) was calculated by using Equation (7). As listed in Table 8, the new Hilla treatment plant was efficient as compared to the other water treatment plants. The treated water quality was decreased along the river (from NH station to HA station) due to low quality of raw water and low water efficiency (E%) at treatment plant.

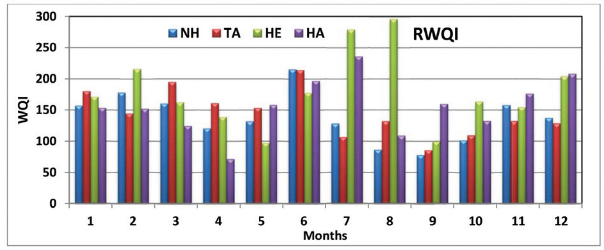

Fig. 4. Monthly values of raw WQI (RWQI) for the specified stations.

Table 6. Raw water quality index (RWQI) values of the stations

Month	NH	TA	HE	HA
1	157.11	180.51	171.28	153.37
2	178.11	144.56	216.01	152.09
3	160.71	195.20	162.62	124.70
4	120.68	161.19	139.13	76.37
5	131.78	153.61	97.16	158.38
6	215.29	214.23	177.56	196.82
7	128.16	106.70	279.40	236.10
8	86.51	132.22	296.20	108.87
9	77.70	85.77	99.48	160.01
10	101.29	109.30	163.88	132.38
11	158.05	132.31	154.63	176.42
12	137.30	128.44	204.34	208.29
Mean	137.72	145.34	180.14	156.90

Table 7. Treated water quality index (TWQI) values of the stations

Month	NH	TA	HE	HA
1	31.49	56.98	73.96	80.54
2	30.44	50.48	88.89	140.58
3	29.49	44.25	73.67	49.77
4	31.03	34.08	64.08	54.37
5	24.01	29.95	61.35	120.12
6	25.10	30.26	49.91	62.64
7	19.38	17.59	53.74	105.32
8	25.15	21.11	74.43	37.08
9	16.19	16.31	49.81	58.30
10	19.16	16.66	44.84	28.46
11	20.34	40.90	43.46	32.95
12	27.32	35.81	59.72	62.46
Mean	24.93	32.86	61.49	69.38

Table 8. Mean efficiency (E%) of the stations

Station	NH	TA	HE	HA
E%	81.02	77.55	62.83	54.17

CCME WQI method

A summary of F1 (scope), F2 (frequency), F3 (amplitude), CCME WQI values and water quality classification for all stations is shown in Table 9. The CCME WQI results of raw water at all stations ranged between 76 and 78, indicating that the water quality can be ranked as "fair" for drinking since some parameters of the raw water samples like Tur, TDS and TH exceeded the drinking water quality standards (Rachedi and Amarchi, 2015). This may reflect the influence of anthropogenic actions, domestic sewage pollution and agri-cultural runoff from the land near the river (Hassan *et al.,* 2018).

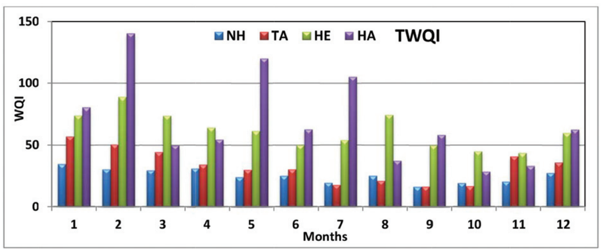

Fig. 5. Monthly values of treated WQI (TWQI) for the specified stations.

The results revealed that CCME WQI value of treated water was between 80 and 87, indicating that the quality of treated water at four stations was ranked as "good". The "good" quality can be attributed to parameters that exceeded the objective (i.e., TH & TDS for NH station and TA station and Tur, TH & TDS for HE station and HA station). It reflected the intervention between natural effects and those of anthropogenic activities. The highest concentration of parameters may be caused by either domestic sewage pollution and presence of high river velocities or too high precipitation and high soil leaching (Alobaidy *et al.,* 2010), (Rachedi and Amarchi, 2015) and (Hassan *et al.*, 2018).

Score water quality comparing of the two indices

Table 10 summarizes the rank of water quality at each station determined by weighted arithmetic method and CCME water quality indices. The score of treated water shows a convergence between the indices at NH station and TH station with a little divergence at the HE station and HA station. Meanwhile the score difference was clearly revealed in the case of raw water at all stations, whereby the water quality was "unfit" and "fair" according to the weighted arithmetic method and CCME WQIs, respectively. The study believed that the score difference may be related to the index theory which index was built on and CCME gave a higher water quality, and thus it could be considered as more flexible than the weighted arithmetic method. Although indices to determine water quality are used

Table 9. F_1, F_2, F_3 and CCME WQI values and water quality Classification of the stations

Stations	NH	TA	HE	HA	
Rawwater	CCME WQI Value	77	77	78	76
	Classification	Fair	Fair	Fair	Fair
	F_1	33.33	33.33	33.33	33.33
	F_2	18.51	19.44	18.51	19.44
	F_3	9.10	11.74	3.71	13.27
Treated water	CCME WQI Value	87	87	80	80
	Classification	Good	Good	Good	Good
	F_1	22.22	22.22	33.33	33.33
	F_2	7.41	6.48	9.2	9.71
	F_3	0.33	0.85	2.10	0.90

Table 10. The ranking of water quality of each station and each index

WQI	NH		TH		HE		HA	
	Raw water	Treated water	Raw water	Treated water	Raw water	Treated water	Raw water	Treated water
Mean of weighted arithmetic	137.72 (Unfit)	24.93 (Excellent)	145.34 (Unfit)	32.86 (Good)	180.14 (Unfit)	61.49 (Moderately	156.9 (Unfit)	69.38 (Moderately
CCME	77 (Fair)	87 (Good)	77 (Fair)	87 (Good)	78 (Fair)	80 (Good)	76 (Fair)	80 (Good)

worldwide, no index is yet accepted as universal. This gives the opportunity for researchers, environmental agencies, decision makers and others to continue explore and modify the existing ones and adjust them for a more accurate, transparent, comprehensive and universal index.

Conclusion

The main conclusions of this study can be summarised as:

1. The results of applying weighted arithmetic method shows that the water quality is varied from "excellent" to "unfit", while the CCME WQI classification of the water is good for the same purpose.
2. Quality of treated water has decreased along the river (from NH station to HA station) due to the low quality of raw water and low water efficiency (E%) at the treatment plants.
3. The new treatment plant at Hilla River(NH station) is efficient as compared to the other water treatment plants.
4. CCME WQI method gives greater water quality value as compared to the other method, in other words, CCME WQI is considered as more flexible.
5. It is necessary to improve the performance of water treatment plants at the studied area.

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