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Research Article

Water Quality Index Assessment using GIS Case study: Tigris River in Baghdad City

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Abstract

In this study water quality index (WQI) was calculated to classify the flowing water in the Tigris River in Baghdad city. GIS was used to develop colored water quality maps indicating the classification of the river for drinking water purposes. Water quality parameters including: Turbidity, pH, Alkalinity, Total hardness, Calcium, Magnesium, Iron, Chloride, Sulfate, Nitrite, Nitrate, Ammonia, Orthophosphate and Total dissolved solids were used for WQI determination. These parameters were recorded at the intakes of the WTPs in Baghdad for the period 2004 to 2011. The results from the annual average WQI analysis classified the Tigris River very poor to polluted at the north of Baghdad (Alkarkh WTP) while it was very poor to very polluted in the south (Alrasheed WTP). WQI reached a maximum value of 912 at Alwathba WTP in 2011and 602 at Alqadisia in 2009 (WTPs at the center part of Baghdad). This classification considers the river unfit for drinking water purposes. Eight color maps of the river were constructed by GIS all gave clear images of the water quality along the river. GIS helped to join the calculated WQI in such an organized and scientific allowing decision making easier to solve pollution problems.

Keywords: *Water quality index, WTPs , Tigris River, GIS, classification.*

1. Introduction

Water scarcity is increasing worldwide and pressure on the existing water recourses is increasing due to the growing demands in several sectors such as, domestic, industrial, agriculture, hydropower generation, etc. Therefore, the evaluation of water quality in various countries has become a critical research topic in the recent years (Ongley, 1998). Water resources in Iraq; have suffered of remarkable stress in terms of water quantity due to different reasons such as: the dams on the Tigris and Euphrates, the global climatic changes, the local severe decrease of the annual precipitation rates and improper planning of water uses inside Iraq (Jones, *et al*, 2008). Water quality is affected by the quantity and quality of supplies coming from different sources. Therefore, overall planning and resource management in respect to water for different uses is necessary. The term water quality gives an indication of how suitable the water is for various purposes (Vaux, 2008).

Aim of the study

1-Determine water quality index of the flowing water in the Tigris River that may give an indication of how suitable the water is for drinking purposes in Baghdad city.
2-Classify the water areas using GIS technology to build colored maps for the water quality indices of the Tigris River in Baghdad city.

2. Water Quality Index (WQI)

WQI is an arithmetical tool used to transform large quantities of water quality data into a single cumulatively derived number.

Water quality indices (WQIs) have been developed to assess the suitability of water for a variety of uses. The concept of WQIs is based on the comparison of the water quality parameter with respective regulatory standards (Husain, 1998), (Khan, *et al*, 2003). The WQIs are not intended to replace a detailed analysis of environmental monitoring and modeling. The advantages of these indices include their ability to represent measurements of a variety of variables in a single number; the ability to combine various measurements with a variety of measurement units in a single unit; and the facilitation of communication of the results (Zandbergen and Hall, 1998). There are many approaches forwater quality index quantification which are: formulas that are independent on water quality standards and others depending on water quality standards (Khan, *et al*, 2003).

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2.1 Formulas to determine WQI

The most common formulas used for WQI determination are:

1. Cumulative Formulation

This formula was used by (Horton, 1965), who suggested the water quality index idea, and it was used as a basis to develop the index. This formula is expressed as:

$$\mathrm{WQI} = \frac{\sum_{i=1}^{n} Ci.Wi}{\sum_{i=1}^{n} Wi} M1.M2 \qquad (1)$$

Where:
WQI: water quality index.
Ci : the rating for the ith determinant.
n: number of determinants.
M1, M2: additional determinant parameters.
Wi: the weighting for the ith determinant.

2. Arithmetic weighted formula

This formula has been developed by (Brown *et al*, 1970), (Couillard and Lefebarre, 1986), and was given as:

$$\mathrm{WQI} = \sum_{i=1}^{n} qi.Wi \qquad (2)$$

Where:
qi: represents the rating for the ith determinant, this value varies from (0-100).
Wi: represents the weighting for the ith determinant and this value varies from (0-1) and ΣWi =1.
n: number of determinants.

3. Geometric weighted mean

(Brown *et al*, 1970) concluded the multiplicative weighted formula depending on the Arithmetic Weighted Formula using the same symbols. The formula is expressed as:

$$\mathrm{WQI} = \pi \sum_{i=1}^{n} qi.Wi \qquad (3)$$

4. Modified arithmetic weighted formula

(The Scottish Development Department (SSD), 1976) suggested a modified arithmetic weighted formula. It was considered as sufficiently sensitive formula for water quality conditions in Scotland and is given as:

$$\mathrm{WQI} = 1l100 \sum_{i=1}^{n} (qi.Wi)_2 \qquad (4)$$

2.2 Classification of water quality

Any water source can be classified into various grades indicating the beneficial use(s) to which it can be put to. The grades are based on the permissible limits of relevant pollution parameters (water quality variables) or standards set by various authorities. Depending on the quality of water in the region, it can be zoned according to stretch suitability for the beneficial use(s).The region under study could be classified according to drinking water specifications using Table 1.

Table 1 Water quality classification based on WQI value

WQI value	Water Quality
< 50	Excellent
50-100	Good
100-200	Poor
200-300	Very Poor
300-400	Polluted
> 400	Very Polluted

3. Geographic Information System (GIS)

Geographic information system (GIS) technology provides the tools for creating, managing, analyzing, and visualizing the data associated with developing and managing infrastructure. GIS is more than just a software, it refers to all aspects of managing and using digital geographical data. GIS technology has been utilized in the last two decades in a wide range of geographic, engineering, planning, and environmental applications. Examples of such utilizations include: flood hazard monitoring (Dawod, *et al*, 2012), urban planning (Arnous, 2013), underground water quality (Alqadi, *et al*, 2013), transportation networks analysis (Aljoufie, *et al*, 2013), water resources management (Dawoud, 2013), land degradation monitoring (Mohamed and Saleh, 2012), tourism management (Abomeh, *et al*, 2013), and agriculture sustainability (Abdel Kawy, 2011).

4. Case study

Baghdad has an area of 800 km2, and 65% of all the industrial institutions and factories are located in Baghdad. This condition generates ecological problems threatening the ecosystem of Baghdad city, due to the drainage of sewages and byproducts of these institutions and factories directly to the body of Tigris River.

The river water is used for irrigation, domestic water supply, industrial and other uses. Tigris River is one of the rivers that suffer from the effect of conservative pollutants as it receives wastewater discharged from domestic and industrial effluents.

Table 2 WQI Calculations for Alkarkh WTP in year 2005

Month- 1 /2005		Data	Si	Wi	qi	Wi*qi	WQI
Turbidity	NTU	71	5	0.2	1420	284	96.75
Alkalinity	mg/l as CaCO3	136	500	0.002	27.2	0.05	
T. Hardness	mg/l as CaCO3	301	500	0.002	60.2	0.12	
Calcium	mg/l as Ca	65	150	0.007	43.33	0.29	
Chloride	mg/l as Cl	53	250	0.004	21.2	0.08	
Magnesium	mg/l as Mg	33	100	0.01	33	0.33	
pH		7.9	7.5	0.133	105.3	14.04	
Sulfate	mg/l as SO4	146	250	0.004	58.4	0.23	
Total Solids	mg/l	400	500	0.002	80	0.16	
Iron	mg/l as Fe	0.34	0.3	3.333	113.3	377.8	
Nitrite	mg/l as NO2	0.003	3	0.333	0.1	0.03	
Nitrate	mg/l as NO3	0	50	0.02	0	0	
Ammonia	mg/l as NH3	0.01	0.5	2	2	4	
Ortho-phosphate	mg/l as PO4	0.01	1	1	1	1	
Sum				7.051		682.1	

Data= average monthly recorded measurement
Si = standard values according to the Drinking Iraqi limitation , Wi= 1/Si
qi = 100*(Data /Si) , WQI =∑(Wi*qi)/∑Wi.

Table 4 The average annual WQI for each water treatment plant for the period 2004 to 2011.

WTP	2004	2005	2006	2007	2008	2009	2010	2011
Alkarkh	207.02	112.31	344.92	228.72	102.70	205.66	181.73	368.85
East Tigris	210.77	189.87	363.24	343.57	210.48	374.02	334.26	531.02
Alkarama	277.56	75.91	199.71	144.59	75.43	287.19	469.33	395.17
Alwathba	205.41	121.97	516.93	342.21	163.19	183.31	134.93	912.37
Alqadisiya	287.58	283.23	496.43	559.60	239.28	602.93	423.24	380.95
Aldora	268.56	220.95	536.00	263.84	135.26	280.09	472.41	266.35
Alwahda				210.10	129.98	452.63	274.46	284.58
Alrasheed	385.70	244.58	459.00	336.29	139.00	480.70	259.47	275.29

5. Results

5.1. WQI determination

In Baghdad city there are eight water treatment plants (WTPs) located on the banks of the Tigris River along a distance of 50–60km. These plants are Alkarkh, East Tigris, Alkarama, Alwathba, Alqadisya, Aldora, Alwahda and Alrashed WTPs. The water quality of the river at the intakes of these plants was taken as the necessary water parameters for the determination of the water quality indexes in this study. The recorded water parameters were provided from Baghdad Mayoralty (Amanat Baghdad) for the period from January 2004 to December 2011. Fourteen water: Turbidity, pH, Alkalinity, Total hardness, Calcium, Magnesium, Iron, Chloride, Sulfate, Nitrite, Nitrate, Ammonia, Orthophosphate and Total dissolved solids were used for WQI determination.

A sample of calculations for WQI determination at the intake of Alkarkh WTP north of Baghdad for year 2005 is shown in Table 2. Table 4 represents the calculated annual average WQI for each WTP for the period 2004 to 2011.

Figs.1 to 8 show the variation of WQI in Tigris River in the region of Baghdad city. These figures are drawn as colored maps using the GIS technology representing WQI variation in the Tigris River as explained in section 5.2.

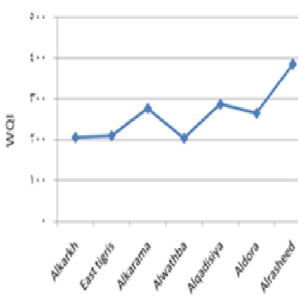

Fig.1 WQI Variation in the Tigris river for the year 2004

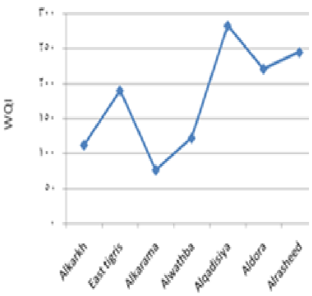

Fig.2 WQI Variation in the Tigris river for the year 2005

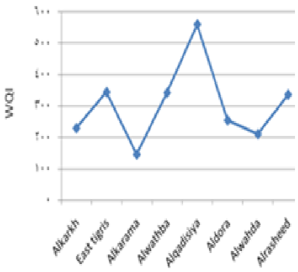

Fig.3 WQI Variation in the Tigris river for the year 2006

Fig.4 WQI Variation in the Tigris river for the year 2007

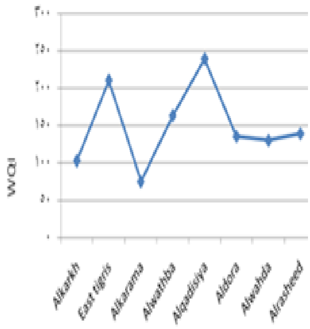

Fig.5 WQI Variation in the Tigris river for the year 2008

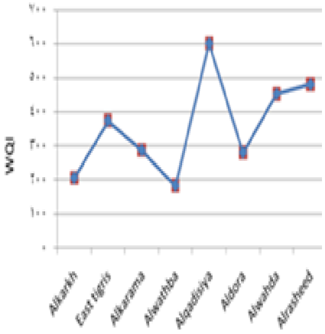

Fig.6 WQI Variation in the Tigris river for the year 2009

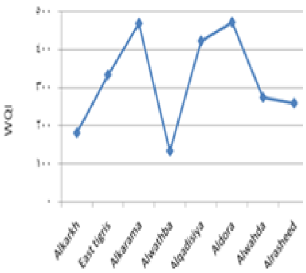

Fig.7 WQI Variation in the Tigris river for the year 2010

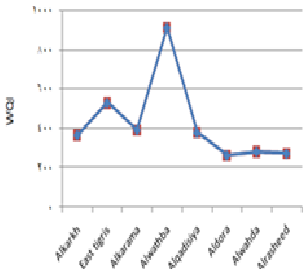

Fig.8 WQI Variation in the Tigris river for the year 2011

5.2 Programming and analyzing

Arc GIS software 9.3 stores the information about the study area as a collection of thematic layers that can be linked together by geography.

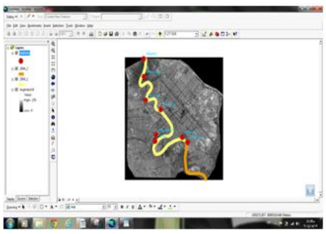

Fig.9 GIS Map for WQI Variation in the Tigris river in the year 2004

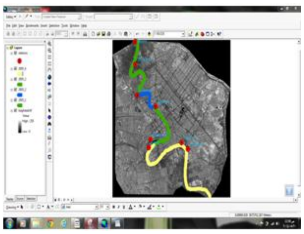

Fig.10 GIS Map for WQI Variation in the Tigris river in the year 2005

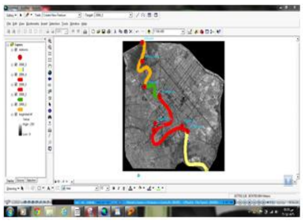

Fig.11 GIS Map for WQI Variation in the Tigris river in the year 2006

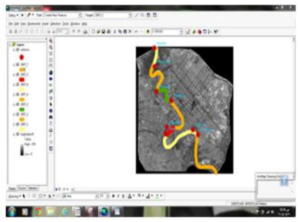

Fig.12 GIS Map for WQI Variation in the Tigris river in the year 2007

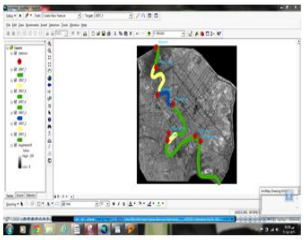

Fig.13 GIS Map for WQI Variation in the Tigris river in the year 2008

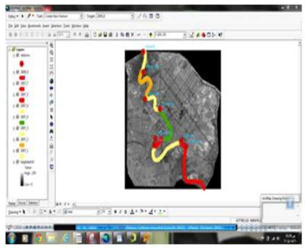

Fig.14 GIS Map for WQI Variation in the Tigris river in the year 2009

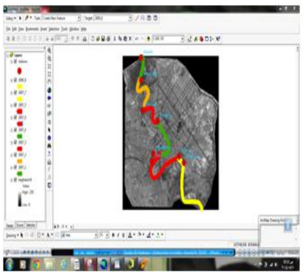

Fig.15 GIS Map for WQI Variation in the Tigris river in the year 2010

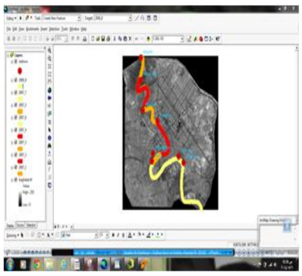

Fig.16 GIS Map for WQI Variation in the Tigris river in the year 2011

The GIS maps representing WQIs of the Tigris River in Baghdad city are shown in Figs.9 to Fig.16 for the period 2004 to 2011 between the intakes of the eight water treatment plants. Table 5 shows the color indicator used in the GIS maps according to WQI classification in Table 1.

Table 5 Color indicator for WQI in the GIS maps

WQI value	Water Quality
0<WQI<100	blue
100<WQI<200	green
200<WQI<300	yellow
300<WQI<400	orange
WQI>400	red
0<WQI<100	blue

Discussion

The results from the annual average WQI analysis classified the Tigris River very poor to pollute at the north of Baghdad (Alkarkh WTP) while it was very poor to very pollute in the south (Alrasheed WTP).

WQI reached a maximum value of 912 at Alwathba WTP in 2011and 602 at Alqadisia in 2009 (WTPs at the center part of Baghdad).

The main water parameter causing these high WQI values is the high concentrations of Iron (Fe) in the flowing water. The recorded data indicated Fe concentrations of 8.4 mg/l at Alkarkh WTP, 10.7 mg/l at Alwathba , 8.5 & 14.75 mg/l at Aldora and 7& 9.4 mg/l at Alrashed WTP in year 2006. While in year 2009 at Alqadisiya the concentration reached 7.55 & 6.85 mg/l, at Alwahda 6.33 mg/l and at Alrashed 6.33mg/l. In the year 2010 Fe concentrations did not exceed 6.75mg/l at Alkarama and Aldora. Finally in year 2011 high Fe concentrations were measured at Alwathba reaching 14.34 & 27.55 mg/l,7.2& 6.4 mg/l at East Tigris and 6.7mg/l at Alqadisiya. These high values add to the remaining parameters taken into consideration when calculating WQI as shown in Table.2.

The main sources of Fe in the river are:

1-Outlets of combined and storm sewers that discharges their flowing wastewater into the river.

2- The disposal of effluents from some industries as, Altaji gas factory, wool & textile factories upstream Alkarama WTP. Vegetable oil factory, detergent factory and the cement factory near Alwahda.

3- Effluents from Aldora refinery upstream Aldora WTP and the effluent from Aldora power plant which uses large amounts of water in its cooling towers.

4-There is several raw water pumping stations that provide irrigation water to the nearby lands. At the end of the working day the flow is reversed in the pipes for cleaning the system from the sediments, this may lead to the corrosion of the pipes.

5- Finally Fe may precipitate in the coagulation & flocculation process in the WTPs, so high concentrations of Fe are found in the settled sludge which is discharged into the river.

Another parameter which had an influence in WQI determination is the turbidity. As the recorded data show high turbidity values reaching 1200 NTU at Alrashed WTP and 519 NTU at Aldora in 2006. While in 2011 the turbidity reached 2015 NTU at Alkarkh, 1115 NTU at Alwathba and between 300 to 600 NTU in the other plants. High flow rates may cause the erosion of the river banks and high suspended solid concentration may increase turbidity readings. This maybe observed in the rainy season, as these readings were recorded in February through April. Also industry effluents may add to the turbidity readings to a small content.

The results from the annual average WQI analysis consider the Tigris River unfit for drinking water purposes. To produce potable water within WHO or/and Iraqi drinking water standards, different treatment processes are required. All the water treatment plants in Baghdad are designed as conventional plants that deal with suspended solids and turbidity. Effluents from these plants are all within the drinking water standards; if not special treatments have to be considered. WQI values may point out the proper treatment but more related research has to be performed to correlate WQI with water treatment methods.

Conclusions

The results from the annual average WQI analysis classified the Tigris River very poor to pollute at the north of Baghdad while it was very poor to very pollute in the south. WQI reached a maximum value of 912 at Alwathba WTP in 2011and 602 at Alqadisia in 2009 (WTPs at the center part of Baghdad). This classification considers the river unfit for drinking water purposes. Using GIS techniques in this study helped to join the collected data in such a way that the data were organized in a scientific method and became easy to be presented spatially (in its true geographical location) together with its related analysis, calculation, graphs and results, it became so editable and easy to reanalyzed and updated. The GIS technique contains so many options and facilities. Some of these options and applications are used in the study such as hyperlinks and metadata; it would be more suitable that the subsequent studies will complete this work by using other options of the program such as SQL and other analysis tools to present more about WQI studies.

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