Applied of CCME Water Quality Index for Protection of Aquatic Life in the Tigris River within Baghdad city

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Abstract

In the present study, Tigris River within Baghdad city was monitored for a variety of physical and chemical parameters to determine water quality during 2010. Water quality indices (WQIs) were calculated for protection of aquatic life, using the model of CCME WQI (Canadian Council of Ministers of the Environment Water Quality Index). Twelve parameters were selected namely: Lead, Iron, Zinc, Manganese, Turbidity, pH value, Dissolved Oxygen, Water Temperature, Phosphate, Ammonia, Nitrate and Nitrite. The results revealed that station 3 which was located in south of Baghdad was more polluted than the other stations. The WQI ranking was between marginal in station 1, 2 to poor in station 3. The highest deviation occurred in lead, Iron and Turbidity, this parameter made a big contribution in decreasing the value of WQI.

Keywords: Water quality index, Aquatic life, Tigris River.

Introduction

Tigris & Euphrates Rivers in Iraq are the main sources of water. It is used for strategically important water uses such as drinking, fishing, industrial, livestock and irrigation [1]. The aquatic ecosystem is composed of the biological community (producers, consumers, and decomposers), the physical and chemical (abiotic) components, and their interactions. Within the aquatic ecosystem, a complex interaction of physical and biochemical cycles exists, and changes do not occur in isolation. Aquatic systems undergo constant change However, an ecosystem has usually developed over a long period of time and the organisms have become adapted to their environment. In addition, ecosystems have the inherent capacity to withstand and assimilate stress based on their unique physical, chemical, and biological properties. Nonetheless, systems may become unbalanced by natural factors, which include drastic climatic variations or disease, or by factors due to human activities. Any changes, especially rapid ones, could have detrimental or disastrous effects. Adverse effects due to human activity, such as the presence of toxic chemicals in industrial effluents, may affect many components of the aquatic ecosystem, the magnitude of which would depend on both biotic and abiotic site-specific characteristics [2].

A water quality index (WQI) plays an important role in such a translation process. It is a communication tool for transfer of water quality data [3]. The communication of water quality data is especially challenging when the intended audience is the general public who not be directly interested in water quality data. Members of the public are more interested in the information that the water quality data conveys and are even more interested in the knowledge that follows from the information [4]. Political decision-makers, non-technical water managers, and the general public usually have neither the time nor the training to study and understand a traditional, technical review of water quality data. A number of indices have been developed to summarize water quality data in an expressible and easily understood format[5]. As a synthetic indicator, WQI provides overall summaries of water quality and potential trends on simple and scientific basis [6]. The concept of indices to gradations water quality was first proposed by [7]. The need for such readily understood evaluation tool was ultimately realized, a remarkable contribution in WQI development is a model proposed by the Canadian Council of Ministers of the Environment (CCME). Khan et al (2003) [8] reviewed and analyzed the water quality of three watersheds using the CWQI 1.0 model [9]. The advantage of an index includes the ability to represent

measurements of a variety of variables in a single number, the ability to combine various measurements in a variety of different measurement units in a single metric value, and the facilitation of communication of the results [10]. The main objective of the project was to research and develop a capability in Iraq to detect and predict adverse changes in water quantity and quality in Tigris River in real time allowing for response to any threat to water quality.

Materials and Methods
Study Area

The study area included 3 stations on Tigris River Within Baghdad city, the first was located at north of Baghdad in Sader Al-Qanat (between latitudes 20°33′33.55″N and longitudes 20°44′ 45.58″E), and the second was at middle part in Al-Aoadia (between latitudes 21°33′53.98″N and longitudes 22°44′ 19.56″E), whereas the third station was located at south part in Al-Zafrania (between latitudes 17°33′55. 57″N and longitudes 27°44′54.43″E) Fig.(1). The river divides the city into the right (Karkh) and left (Risafa) section with a flow direction from north to south [11].

Fig.(1) Bagdad City Showing Sampling Station on Tigris River.

Sampling

Subsurface water samples were collected from the middle and two banks of Tigris River during February to December 2010 from each station using clean polyethylene bottles. Samples were analyzed for chemical and physical properties immediately after collection.

The CWQI was calculated by selecting a set of twelve parameters based on both importance and availability of data. These parameter are Lead, Iron Zinc, Manganese, Turbidity, pH value, Dissolve Oxygen, water Temperature, Phosphate, Ammonia, Nitrate and Nitrite, all the parameter analyzed according to [12]. CCME WQIs were computed to the CCME guideline for the protection of aquatic life [13].

WQI calculation

The detailed formulation of WQI, as described in the Canadian WQI 1.0– Technical Report [9], is as follows:

$$CWQI = 100 - \left[\frac{\sqrt{F_1{}^2 + F_2{}^2 + F_3{}^2}}{1.732} \right]$$

Calculation of the index is based on three terms: **scope** (F1) – number of parameters that are not compliant with the water quality guidelines, **frequency** (F2) – number of times that the guidelines are not respected, and **amplitude** (F3) – the difference between non-compliant measurements and the corresponding guidelines.

Division of these terms by 1.732 is based on the fact that each of the three factors contributing to the index can reach the value of 100.

Explanation of each term of the index

First of all, **the term F_1** (scope) expresses the percentage of parameters for which at least one measurement did not comply with the corresponding guideline during the period under study:

$$-Scope, F_1 = \left[\frac{Number\ of\ failed\ Variables}{Total\ Number\ of\ Variables} \right] \times 100$$

The term F_2 (frequency) represents the percentage of analytical results that do not comply with the guidelines.

$$-Frequency, F_2 = \left[\frac{Number\ of\ Failed\ Tests}{Total\ Number\ of\ Tests} \right] \times 100$$

Finally, the term F_3 (amplitude) represents the *difference* between the non-compliant analytical results and the guidelines to which they refer. The term F_3 is an asymptotic function, representing the normalized sum of

excursions (*nse*) in relation to guidelines within the range of values from 0 to 100.

$$-Amplitude, F_3 = \left[\frac{nse}{0.01\,nse + 0.01}\right]$$

To calculate the overall degree of non-compliance, we add the excursions of non-compliant analytical results and divide the sum by the total number of analytical results. This variable is called the normalized sum of excursions (*nse*).

$$nse = \frac{\sum_{i=1}^{n} excursion}{Number\ of\ Tests}$$

There are two possible ways of determining the excursion:

When the test value must not exceed the objective:

$$ecursion = \left[\frac{Failed\ Test\ Value\ i}{Objective}\right] - 1$$

When the test value must not fall below the objective:

$$excursion = \left[\frac{Objective}{Failed\ Test\ Value}\right] - 1$$

CCME WQI categorization scheme for aquatic:

Excellent: (CWQI value 95.0-100), 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.

Good: (CWQI value 80.0-94.9), water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.

Fair: (CWQI value 65.9-79.9), water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.

Marginal: (CWQI value 45.0-64.9), water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.

Poor: (CWQI value 0-44.9), water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

Results and Discussion

The calculated values and the rating of WQI is presented in Fig.(2) where water quality of Tigris River ranked between marginal in station 1, 2 to poor in station 3. The results of the physico-chemical analysis of Tigris River water are represented in Table (1).

Table (1)
Physical and Chemical properties (mean & standard deviation) of water in
Tigris River during 2010. (ND= not valid).

Parameters	*Station 1*	*Station 2*	*Station 3*	*CCME guideline*
PO_4 (mg/L)	0.3± ND 0.09-0.11	0.03± ND 0.1-0.1416	0.24±0.001 0.1198-0.0974	0.3
Pb (mg/L)	0.36±-0.02 0.22-0.11	0.36±0.01 0.2364-0.12113	0.35±0.02 0.2588-0.1204	0.007
Fe (mg/L)	0.64±0.05 0.3331-0.2376	0.27±0.27 0.4615-0.18323	0.03±0.78 0.4189-0.2956	0.3
Zn (mg/L)	0.02± ND 0.005-0.007	0.02± ND 0.006-0.0088	0.04± ND 0.0169-0.0218	0.03
Mn (mg/L)	0.07±0.01 0.037-0.024	0.08±0.02 0.049-0.0202	0.08±0.01 0.0392-0.0392	0.1
pH	±٨,٤7.1 8.0-0.473	8.2±7.3 0.3868-7.8167	8.4±7.3 8.0-0.3816	6.5-9
Water Temp. (°C)	29.90±10.10 21.61-8.18	30.50±10.2 21.65-8.355	31.20±10.8 22.26-8.6113	15
Turbidity (NTU)	40.33±13.15 33.39-10.55	40.68±27.9 35.941-5.143	41.03±17.52 34.59-8.97304	5
DO (mg/L)	7.9±6.5 7.23-0.463	7.9±6.9 7.3667-7.3667	8.2±6.3 7.3833-0.7026	5.5-9
NH_4 (mg/L)	0.19±0.02 0.117-0.06	±٠,٩٨٤ ND 0.322-0.36454	1.31±0.22 0.537-0.4301	1.37
NO_3 (mg/L)	31.45±2.22 10.262-10.89	33.23±3.1 12.03-11.281	24.8±2.66 9.303-8.0815	13
NO_2 (mg/L)	0.03± ND 0.011-0.016	0.03± ND 0.0055-0.01343	0.04± ND 0.012-0.01872	0.06
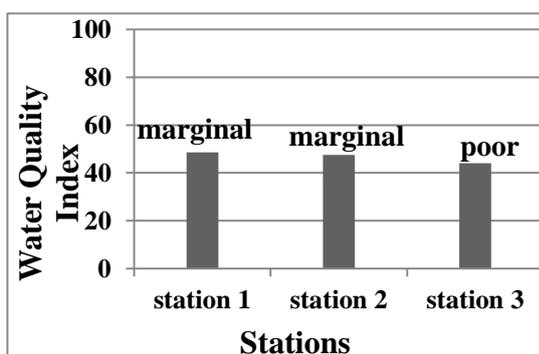
Fig. (2) Water quality index for aquatic life at different locations along Tigris River.

Table (2) presents a summary of three measures of variance, i.e. F_1 (scope), F_2 (frequency) and F_3 (amplitude) of water use for protection of aquatic life. The table shows, F_3 has higher values than F_1 and F_2 at all the selected river stations. It denotes that there are a higher percentage of individual failed tests than percentage of failed variables and the amount by which they failed. Table further denotes that F_3 values show an increasing trend from station 1 to station 2 to station 3. This trend infers that more water quality individual failed tests (did not meet their objectives) in the downstream reach (which represented station 3) polluted by the surface drains [14]. Thus, from these results, it can be concluded with confidence that the quality of Tigris river water deteriorates from the upper to lower reaches.

Table (2)
The calculated values of CCME-WQI in Tigris River.

Term of the Index	Values		
	St. 1	*St. 2*	*St. 3*
Scope, F_1	41.66	41.66	50
Frequency, F_2	22.22	25	25
Excursion	223.21	238.45	256.33
nse	3.10	3.31	3.56
Amplitude, F_3	75.60	76.79	79.11
CCME-WQI	48.56	47.54	44.08

Table (3) provides a detailed insight of the water quality situation at the selected sampling stations and summarizes the calculation of WQIs. The table lists those water quality parameters that exceeded the permissible limits for different uses most of the time during the sampling period. The water quality parameters with the highest value of normalized sum of excursions (*nse*) are also given in the table. It is clear from the Table (3) that Pb constituted the largest values.

Reasoning out for the poor quality of water, Table (3) provides precise information. Lead always exceeds the CCME guideline throughout the study which indicates a serious pollution by lead. Fe, Zn exceed the CCME guideline occasionally, While, Mn never exceeded the CCME guideline. Heavy metals are natural components of the Earth's crust. They cannot be degraded or destroyed. Some heavy metals (e.g. copper, selenium, zinc) are essential to maintain the metabolism of the organisms. However, at higher concentrations they can lead to poisoning. Heavy metals are dangerous because they tend to bioaccumulate. Bioaccumulation means an increase in the concentration of a chemical in a biological organism over time, compared to the chemical's concentration in the environment. Compounds accumulate in living things any time they are taken up and stored faster than they are broken down (metabolized) or excreted. [15] Heavy metals can enter a water supply Naturally by Chemical and physical weathering of igneous and metamorphic rocks and soils often release heavy metals into the sediment and into the air. Other contributions included the decomposition of plant and animal detritus, precipitation or atmospheric deposition of airborne particles from volcanic activity, wind erosion, forest fire smoke, plant exudates, and oceanic spray [16]. Or by Anthropogenic activity like, Domestic wastewater effluent contains metals from metabolic wastes, corrosion of water pipes, and consumer products. Industrial effluents and waste sludges may substantially contribute to metal loading; the combustion of fossil fuels pollutes the atmosphere with metal particulates that eventually settle to the land surface. Urban stormwater runoff often contains metals from roadways and atmospheric fallout [17,18,19]. Currently, anthropogenic inputs of metals exceeded natural inputs.

Another related factor that is of importance in reducing the water quality index is turbidity, which was considerably high, which exceeded the CCME guideline throughout the study. Turbidity in water is caused by presence of suspended particles such as clay, silt, finely divided organic matter, plankton and other microscopic organisms [20]. Turbidity refers to water clarity. The greater the amount of suspended solids in the water, the murkier it appears. Water bodies that have high transparency values typically have good water quality [21]. The increasing of Turbidity refers to most of the anthropogenic activities that take place along the river. These activities discharge suspended matter into the water and displace the settled matter. Hence, more soil particles, which constitute the major part of suspended matter contributing to the turbidity in most natural waters, were discharged into, or displaced in the water [22].

Table (3)
Summary of water quality index calculations for aquatic life protection
used at selected sites of Tigris River.

Stations	Number of failed variables	Number of failed tests	Variables with most failed tests	Variables with highest nse
St.1	5	16	Pb, Fe, turbidity, NO_3, temperature	Pb
St. 2	5	18	Pb, Fe, turbidity, NO_3, temperature	Pb
St. 3	6	18	Pb, Fe,Zn turbidity, NO_3, temperature	Pb

The pH of an aquatic ecosystem is important because it is closely linked to biological productivity. Although the tolerance of individual species varies, pH values between 6.5 and 8.5 usually indicate good water quality and this range is typical of most major drainage basins of the world. pH values in this study ranged between 7.1-8.4 indicating that the water sampler are almost neutral to sub-alkaline in nature [23] and agree with Iraqi published data [24,25]. The hydrogen ions entering a drainage basin in rainwater are neutralized by carbonate and silicate minerals as water percolates through soils. This neutralization capacity in soils determines whether or not acid precipitation will cause water quality impacts in receiving water bodies. The ability of rocks and soils in any given drainage basin to buffer the acidity of rainwater is related to the residence time of water in the soil as well as the levels of calcium carbonate, bicarbonate, and silicate minerals [26, 27].

Temperature affects the speed of chemical reactions, the rate at which algae and aquatic plants photosynthesize, the metabolic rate of other organisms, as well as how pollutants, parasites, and other pathogens interact with aquatic residents. Temperature is important in aquatic systems because it can cause mortality and it can influence the solubility of dissolved oxygen (DO) and other materials in the water column (e.g., ammonia). In this study temperature show great fluctuation which return to fluctuate naturally both daily and seasonally [28]. Aquatic organisms often have narrow temperature tolerances. Thus, although water bodies have the ability to buffer against atmospheric temperature extremes, even moderate changes in water temperatures can have serious impacts on aquatic life, including bacteria, algae, invertebrates and fish. Thermal pollution comes in the form of direct impacts, such as the discharge of industrial cooling water into aquatic receiving bodies, or indirectly through human activities such as the removal of shading stream bank vegetation or the construction of impoundments [29].

Oxygen that is dissolved in the water column is one of the most important components of aquatic systems. Oxygen is required for the metabolism of aerobic organisms, and it influences inorganic chemical reactions. Oxygen is often used as an indicator of water quality, such that high concentrations of oxygen usually indicate good water quality [29]. No stagnation for dissolved oxygen was observed at any station throughout the study period, the recorded values were always above 6.3 mg/l, the high levels recorded during the winter months through out Tigris River whereas the high value reached 8.2 mg/l in station 3 during February. Oxygen enters the water by photosynthesis of aquatic biota and by the transfer of oxygen across the air-water interface. The amount of oxygen that can be held by the water depends on the water temperature, salinity, and pressure. Gas solubility increases with decreasing temperature (colder water holds more oxygen) and salinity (freshwater holds more oxygen than does saltwater) [30].

Compounds of nitrogen (N) and phosphorus (P) are major cellular components of organisms. Since the availability of these elements is often less than biological demand, environmental sources can regulate or limit the

productivity of organisms in aquatic ecosystems. The results show that phosphate was not exceeding the limited value, lack of phosphates in water is due to consumption by aquatic organisms (e.g. aquatic plant, algae) [31]. Phosphorus is present in natural waters primarily as phosphates, which can be separated into inorganic and organic phosphates. Phosphates can enter aquatic environments from the natural weathering of minerals in the drainage basin, from biological decomposition, and as runoff from human activities in urban and agricultural areas. Inorganic phosphorus, as orthophosphate (PO_4), is biologically available to primary producers that rely on phosphorus for production and has been demonstrated to be an important nutrient limiting maximum biomass of these organisms in many inland systems [32]. In this study observed high value of Nitrate which exceed the CCME guideline during February in all stations, and station 2 through June, as a result of human activities (cultural eutrophication) through factors such as runoff from agricultural lands and the discharge of municipal waste into rivers. Nitrogen occurs in water in a variety of inorganic and organic forms and the concentration of each form is primarily mediated by biological activity. Nitrogen-fixation, performed by cyanobacteria (blue-green algae) and certain bacteria, converts dissolved molecular N_2 to ammonium (NH_4). Aerobic bacteria convert NH4 to nitrate (NO_3) and nitrite (NO_2) through nitrification, and anaerobic and facultative bacteria convert NO_3 and NO_2 to N_2 gas through denitrification [33]. Primary producers assimilate inorganic N as NH4 and NO_3, and organic N is returned to the inorganic nutrient pool through bacterial decomposition and excretion of NH_4^+ and amino acids by living organisms [34].

Conclusions

The Canadian Council of Ministries of the Environment (CCME) Water quality Index (WQI) used for rating of water quality in Tigris River indicated that the quality of water is marginal to poor. It was almost always endangered or deteriorated. The condition in it usually deviated from normal levels and the water is not capable to protect or support ample aquatic life. Lead, Iron, and Turbidity were the main factors responsible for determination of the River water quality. These parameters need to be modified to maintain the quality of water for further use. The CCME-WQI served an important evidential in monitoring poor quality of aquatic system.

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الخلاصة

في الدراسة الحالية تم مراقبة مجموعة من العوامل الفيزيائية والكيميائية في نهر دجلة في مدينة بغداد لتحديد نوعية المياه خلال سنة ٢٠١٠. تم حساب دليل نوعية المياه لإغراض حماية الإحياء المائية باستعمال الدليل الكندي. تم اختيار ١٢ عامل لتحديد نوعية المياه: الرصاص و الحديد والزنك والمنغنيز والكدرة والأس الهيدروجيني والأوكسجين ودرجة الحرارة المياه والفوسفات والامونيا والنترات والنتريت. وقد أشارت الدراسة الى ان المحطة الثالثة أكثر تلوثاً من باقي المحطات. اذ تراوحت نتائج الدليل بين حافيّة في المحطة الأولى والثانية الى رديئة في المحطة الثالثة. في الدراسة الحالية وان أكثر العوامل التي انحرفت عن القيم المثالية هي الرصاص والحديد والكدرة.