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Application of Water Quality Index for Assessment of Dokan Lake Ecosystem, Kurdistan Region, Iraq

Abdul Hameed M. Jawad Alobaidy[1], Haider S. Abid[2], Bahram K. Maulood[3]
[1]*Environmental Research Center, University of Technology, Baghdad, Iraq*
[2]*Department of Biology, College of Science for Women, University of Baghdad, Baghdad, Iraq*
[3]*Twin Rivers Institute, American University of Iraq-Sulaimani, Sulaimani, Iraq*
E-mail: *jawaddhy@yahoo.co.in, haider_abid@gmail.com, Bahram.Khider@auis.org*
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Abstract

Water Quality Index (WQI) was applied in Dokan Lake, Kurdistan region, Iraq using ten water quality parameters (pH, Dissolved Oxygen, Turbidity, Conductivity, Hardness, Alkalinity, Sodium, Biochemical Oxygen Demand, Nitrate and Nitrite). The relative weight assigned to each parameter ranged from 1 to 4 based on the importance of the parameter for aquatic life. The results indicated that water quality of Dokan Lake declined from Good in the years 1978, 1979, 1980, 1999, 2000 and 2008 to Poor in 2009. The impact of various anthropogenic activities was evident on some parameters such as the EC and BOD. It is suggested that monitoring of the lake is necessary for proper management. Application of the WQI is also suggested as a very helpful tool that enables the public and decision makers to evaluate water quality of lakes in Iraq.

Keywords: Water Quality Index, Water Resources, Dokan Lake, Nature Iraq

1. Introduction

The availability of water in Iraq shows a great deal with spatial and temporal variability. The increase in population and expansion of economic activities undoubtedly leads to increasing demand of water use for various purposes. Water resources in Iraq, especially in the last two decades have also suffered of remarkable stress in terms of water quantity due to different reasons such as the dams built on Tigris and Euphrates in the riparian countries, the global climatic changes and the local severe decrease of the annual precipitation rates and improper planning of water uses inside Iraq [1-3]. Water quality is certainly affected by the quantity and quality of supplies coming from different sources. Therefore, overall national planning and resource management in respect to water with emphasis on allocation of priorities among the different uses is necessary. It is not surprising that, due to the above factors, studying water quality is so much important to be carried out in order to keep our awareness and understanding of our environment.

The term water quality was developed to give an indication of how suitable the water is for human consumption [4], and is widely used in multiple scientific publications related to the necessities of sustainable management [5]. Water quality in an aquatic ecosystem is determined by many physical, chemical and biological factors [6]. Therefore, particular problem in the case of water quality monitoring is the complexity associated with analyzing the large number of measured variables [7], and high variability due to anthropogenic and natural influences [8].

There are a number of methods to analyze water quality data that vary depending on informational goals, the type of samples, and the size of the sampling area. Research in this area has been extensive, as indicated by the number of methods proposed or developed for classification, modeling and interpretations of monitoring data [8,9]. One of the most effective ways to communicate information on water quality trends is by use of the suitable indices [10]. Indices are based on the values of various physico-chemical and biological parameters in a water sample. The use of indices in monitoring programs to assess ecosystem health has the potential to inform the general public and decision-makers about the state of the ecosystem [11,12]. This approach can also help to provide a benchmark for evaluating successes and failures of management strategies at improving water quality [13]. It will indicate what actions should be modified. Ecosystem or resource monitoring usually requires specific site(s) data while information across broader geographical regions is typically required for public policy decisions [14]. The index is a numeric expression used to transform large number of variables data into a single number, which represents the water quality level [15,16]. Water quality index (WQI) can also be used to aggregate data on water quality parameters at different times and in different places and to translate this information into a single value defining the period of time and spatial unit involved [17]. Numerous studies on water quality assessment have been made, using WQIs [18-24].

Horton [16] initially proposed the application of WQI and since then many different methods for the calculation of WQI's have been developed. The WQI developed by reference [19] was based on the professional opinion of a panel of 142 water quality experts. They selected nine parameters (dissolved oxygen, fecal coliform, pH, biochemical oxygen demand, temperature, total phosphate, nitrate, turbidity and total solids). Then, a quality value (*Q* value) from 0 to 100, based on the normal data range, was assigned for each parameter. Each *Q* value was multiplied by a weighting factor based on importance of the parameter; the summation of the weighted *Q* values yielded the WQI that defines the water as very bad, bad, medium, good and excellent.

Nature Iraq has paid great attention to the principle of seeding and introducing the idea of water quality indices to the Iraqi scientists throughout workshop held in Sulaimaniyah, Iraq in July 2008. This was followed by a project that applied several models of (WQI) and Indices of Biological Integrity (IBI) on data collected by Nature Iraq and others. Because of the necessities of national planning and resources management, this project may be regarded as one of the aspects of the key ecological investigation tools in this respect. The objective of the present work is to apply the WQI tool to evaluate the historical changes in the water quality of Dokan Lake during the period from 1978 to 2009. It must be mentioned that the lake's water is one of the main water sources for Sulaimaniyah Governorate which has a population of about 1 million.

2. Materials and Methods

2.1. Description of the Study Sites

Three sites were studied in Dokan Lake which lies in the northwestern part of Sulaimaniyah, about 76 Km from the city center (**Figure 1**). The lake has a full–pool operating altitude of 515 m above mean sea level and its boundaries extend between a latitude of 34º17´- 36º33´N and a longitude of 43º17´- 46º24´E. It was formed during 1954-1959 by Damez-Bullot Dam on the Lesser Zab valley near Dokan gorge. The major outlet establishes the Lesser Zab River with its Mahor tributaries (Karfin and Shahrawan) and other waters in addition to rainfall and snow fall/snow melt water [25]. Morphometric features of Dokan Lake are as follow: the volume of the lake is 6.8 billion cubic meters with a surface area of about 270 km^2 and 48 km^2 at high and low level period, respectively. The drainage area is covering about 11690 km^2 of which 1080 km^2 are located within Qala-Diza and Raniya plains [26-28].

The area passed through different socio-economical activities such as migration and reduction in agricultural activities throughout years 1980-1991, when after that a strong re-inhabitation and village building took place. Ultimately, strong agricultural activities arose, including application of pesticides and fertilizers that drained directly or indirectly to the lake. However, two successive drought years (2008 and 2009) faced the area. Besides that, the population increased and quite different industrial activities took place.

2.2. Sample Collection and Analysis

Historical water quality data related to Dokan Lake were collected in the years 1978-1979 [25], 1979-1980 [29]

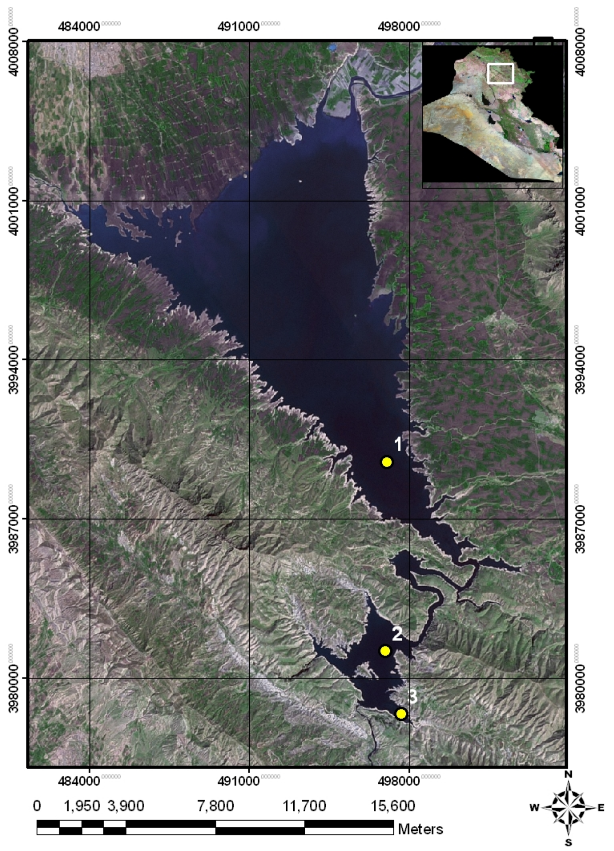

Figure 1. Dokan Lake basin showing sampling stations.

and for 1999-2000 [30]. Also, monthly water samples were collected from the Lake during June 2008 to April 2009 and analyzed following methods outlined in the Standard Method for Examination of Water and Wastewater [31]. Water samples were collected in stopper fitted polyethylene bottles and refrigerated at 4˚C in order to be analyzed as soon as possible. Conductivity and pH were measured in situ using portable measuring devices.

2.3. Application of the WQI

This study is an attempt to evaluate the historical changes in water quality of Dokan Lake. For this purpose, ten water quality parameters have been selected which are: pH, Dissolved Oxygen, Turbidity, Conductivity, Hardness, Alkalinity, Sodium, Biochemical Oxygen Demand, Nitrate and Nitrite. Values used for each parameter are the mean value of the three sites under this investigation.

In the formulation of WQI, the importance of various parameters depends on the intended use of water; here, water quality parameters are studied from the point of view of suitability for human consumption. The 'standards' (permissible values of various parameters) for the drinking water used in this study are those recommended by the WHO [32]. When the WHO standards were not available, the Iraqi drinking water standards [33] were applied.

The calculation and formulation of the WQI involved the following steps:

1) In the first step, each of the ten parameters has been assigned a weight (AW_i) ranging from 1 to 4 depending on the collective expert opinions taken from different previous studies. The mean values for the weights of each parameter along with the references used are shown in **Table 1**. However, a relative weight of 1 was considered as the least significant and 4 as the most significant.

2) In the second step, the relative weight (*RW*) was calculated by using the following equation:

$$RW = \frac{AW_i}{\sum_{i=1}^{n} AW_i} \quad (1)$$

where, *RW* = the relative weight, *AW* = the assigned weight of each parameter, n = the number of parameters. The calculated relative weight (*RW*) values of each parameter are given in **Table 2**.

3) In the third step, a quality rating scale (Q_i) for all the parameter except pH and DO was assigned by dividing its concentration in each water sample by its respective standard according to the drinking water guideline recommended by the [32], or the Iraqi drinking water standards [33], the result was then multiplied by 100.

Table 1. Assigned weight values adopted from the literature.

Parameters	References number								Mean Value
	10	23	34	35	36	37	38	39	
pH (pH unit)	4	1	4	1	1	1	4	1	2.1
DO (mg/L)	4	4	4	4	4	4	4	4	4.0
Turbidity (NTU)	2	2	2	-	-	4	-	2	2.4
Conductivity (μS/cm)	2	4	2	-	1	4	4	2	2.7
Hardness (mg/L)	1	1	1	-	1	1	2	1	1.1
Alkalinity (mg/L)	1	-	1	-	-	-	3	-	1.6
Na (mg/L)	-	-	-	-	-	1	-	-	1.0
BOD (mg/L)	3	3	3	2	3	3	4	3	3.0
NO_3 (μg/L)	-	2	-	3	2	2	-	2	2.2
NO_2 (μg/L)	-	2	-	-	2	2	-	2	2.0

Table 2. Relative weight of the water quality parameters.

Parameters	Water quality standard	Assigned weight (AW)	Relative weight (RW)
pH (pH unit)	6.5-8.5 (8.0)	2.1	0.095023
DO (mg/L)	5.0	4.0	0.180995
Turbidity (NTU)	5.0	2.4	0.108597
Conductivity (μS/cm)	250.0	2.7	0.122172
Hardness (mg/L)	100.0	1.1	0.049774
Alkalinity (mg/L)	100.0	1.6	0.072398
Na (mg/L)	200.0	1.0	0.045249
BOD (mg/L)	5.0	3.0	0.135747
NO_3 (μg/L)	50.0	2.2	0.099548
NO_2 (μg/L)	3.0	2.0	0.090498
Total		22.1	1.0

$$Q_i = \left[\frac{C_i}{S_i}\right] \times 100 \quad (2)$$

While, the quality rating for pH or DO ($Q_{pH,\ DO}$) was calculated on the basis of,

$$Q_{pH,DO} = \left[\frac{C_i - V_i}{S_i - V_i}\right] \times 100 \quad (3)$$

where, Q_i = the quality rating, C_i = value of the water quality parameter obtained from the laboratory analysis, S_i = value of the water quality parameter obtained from recommended WHO or Iraqi standard of corresponding parameter, V_i = the ideal value which is considered as 7.0 for pH and 14.6 for DO.

Equations (2) and (3) ensures that Q_i = 0 when a pollutant is totally absent in the water sample and Q_i = 100 when the value of this parameter is just equal to its permissible value. Thus the higher the value of Q_i is, the more polluted is the water [40].

4) Finally, for computing the WQI, the sub indices (SI_i) were first calculated for each parameter, and then used to compute the WQI as in the following equations:

$$SI_i = RW \times Q_i \quad (4)$$

$$WQI = \sum_{i=1}^{n} SI_i \quad (5)$$

The computed WQI values could be classified as <50 = Excellent; 50-100 = Good; 100-200 = Poor; 200-300 = Very poor; >300 = Unsuitable [41].

3. Results and Discussion

The WQI was used to aggregate diverse parameters and their dimensions into a single score, displaying a picture of the historical water quality of Dokan Lake. It was observed from the computed annual WQI that the values ranged from 53.18 during 2000 to 101.26 during 2009 and therefore can be categorized into "Good water" during 1978, 1979, 1980, 1999, 2000, 2008 to "Poor water" during 2009 (**Figure 2**). However, it was generally observed that 14%, 80.50%, and 5.50% of all monthly computed WQI values from 1978 to 2009 have fallen under "Excellent", "Good", "Poor", water quality respectively.

Descriptive statistics for all water quality parameters examined are shown in **Table 3**, while the correlation coefficients between WQI and water quality parameters are shown in **Table 4**. In order to reach a better view on the causes of deteriorated water quality in the Dokan lake water, selected results from the determination of water quality parameters are discussed below.

The results of pH varied from 6.45 to 8.20, indicating that the water samples are almost neutral to sub-alkaline in nature. pH is an important factor that determines the suitability of water for various purposes [42]. The observed values show a relative agreement with pH values of surface water which lie within the range of 6.5 to 8.5 [32]. However, the values come also in accordance with the known values of Iraqi inland waters [43].

The mean values of DO and BOD have never reached critical values in the most times of the study period, indicating good water quality conditions. The observed average DO concentration level of 8.12 mg/L complies

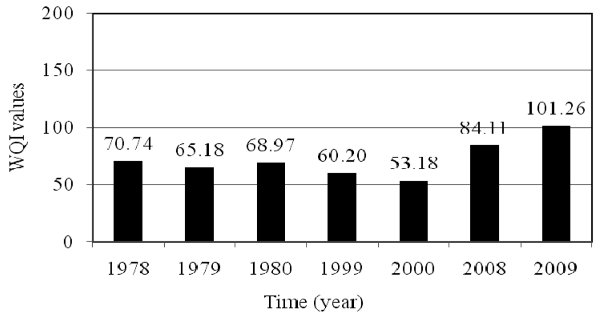

Figure 2. Historical changes in the computed water quality index in Dokan Lake.

Table 3. Statistical summary of Dokan Lake water quality data.

Parameters	Min.	Max.	Mean	Standard Deviation
pH (pH unit)	6.45	8.20	7.63	±0.39
DO (mg/L)	3.55	12.30	8.12	±1.68
Turbidity (NTU)	0.33	15.05	5.50	±3.97
Conductivity (µS/cm)	189.33	540.00	280.91	±57.63
Hardness (mg/L)	23.66	219.96	127.70	±60.28
Alkalinity (mg/L)	64.83	240.00	139.88	±44.72
Na (mg/L)	2.45	6.45	4.51	±0.97
BOD (mg/L)	2.07	6.60	3.20	±1.04
NO_3 (µg/L)	14.83	122.41	53.23	±27.31
NO_2 (µg/L)	0.12	2.57	0.77	±0.55

Table 4. **Correlation coefficient between WQI and water quality parameters.**

	WQI	pH	DO	Turbidity	Conductivity	Hardness	Alkalinity	Na	BOD	NO_3	NO_2
WQI	1.0										
pH	0.20	1.0									
DO	**-0.41**	-0.05	1.0								
Turbidity	**0.62**	-0.25	-0.16	1.0							
Conductivity	**0.75**	0.10	-0.15	0.23	1.0						
Hardness	0.35	0.22	-0.32	-0.46	**0.50**	1.0					
Alkalinity	**0.83**	0.21	-0.31	0.19	**0.79**	**0.70**	1.0				
Na	0.17	0.16	0.40	0.42	-0.36	-0.31	-0.09	1.0			
BOD	**0.55**	0.37	0.16	0.19	0.18	-0.07	0.24	0.49	1.0		
NO_3	**-0.41**	0.14	**0.47**	-0.42	0.02	-0.11	-0.20	-0.38	0.03	1.0	
NO_2	-0.02	-0.08	-0.20	0.32	0.05	**-0.64**	-0.30	-0.02	0.27	-0.08	1.0

In bold correlation is significant at the 0.01 level (2-taoled).

with WHO standards and is considered good to sufficient for human consumption and most aquatic biota [44]. The results of DO in Dokan Lake are consistent with those of unpolluted water bodies in other parts of Iraq [43]. Unpolluted waters are likely to have a BOD value of < 3 mg/L, while values above 5.0 mg/L recorded in Dokan lake (only in April 1980) indicate possible pollution. The correlation coefficient between WQI and BOD (r = 0.55) in the present study has shown a significant positive relationship ($P < 0.01$). BOD values indicate a possibility of organic pollution effect on water in this area. Therefore, a continuous monitoring is needed.

Turbidity is widely concerned as an important parameter for drinking water. However, the observed values were still within the permissible level recommended by the WHO for drinking water. The correlation coefficient between WQI and turbidity (r = 0.62) showed a significant positive relationship ($P < 0.01$).

The importance of Electrical Conductivity (EC) is due to its measure of cations which greatly affects the taste and thus has significant impact on the user acceptance of the water as potable [32,45]. It is an indirect measure of total dissolved salts. High conductivity may arise through natural weathering of certain sedimentary rocks or may have an anthropogenic source, e.g. industrial and sewage effluent [32]. The results showed that EC values were slightly higher than the permissible level recommended by the WHO for drinking water. The correlation coefficient between WQI and conductivity (r = 0.75) demonstrated a rather positive relationship ($P < 0.01$).

The Total Hardness (TH) is also an important parameter of water quality whether to be used for domestic, industrial or agricultural purposes. The results obtained by water surveys conducted in this investigation showed that TH values were often higher than the minimal permissible level recommended by the WHO for drinking water. Still, no significant correlation with WQI was observed.

The observed values of alkalinity were slightly higher than the permissible level recommended by the WHO for drinking water. The correlation coefficient between WQI and alkalinity (r = 0.83) demonstrated a significant positive relationship ($P < 0.01$).

Nitrate was the most abundant form of nitrogen compounds (53.23 μg/L) during the present study, but still complies with the WHO recommendations, while nitrite was found in small amounts (0.77 μg/L). The possible sources of nitrate and nitrite in the surface water of Dokan Lake are mainly from the atmosphere, surface runoff, sewage discharges, agricultural fertilizers and organic wastes [32]. The correlation between WQI and Nitrate (r = –0.41) display a significant negative relationship ($P < 0.01$).

From correlation coefficient values between WQI and water quality parameters, it is evident that Dissolved oxygen, Turbidity, Conductivity, Alkalinity, BOD and Nitrate were the most affecting factors for the computed WQI values of Dokan Lake in the study period (**Table 4**).

During the last decade, Dokan Lake has been subjected to rapid decline in water quality status which is possibly due to the increase in the population and human activities. The effect was quite evident from the results; **Figure 2** shows that the values of WQI increased from less than 75 to almost 84 then to more than 100 during 1978-2000, 2008 and 2009 respectively. Finally, it can be implied that the preventative measures taken by the local authorities are still not sufficient; it is clear that the domestic discharge and agricultural activities in addition to the last two years of drought are the major threats to Dokan Lake's water quality.

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