DEVELOPING AN INDEX FOR SURFACE WATER QUALITY ASSESSMENT +

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Abstract :

An attempt has been made to develop overall water quality index for surface water, using six water quality parameters Biochemical oxygen Demand (BOD), Total Hardness, Chloride, pH, Total Dissolved Solids (TDS) and Turbidity. The scale of the proposed index Excellent, Good, Slightly Polluted, Poor and Heavily Polluted water is proposed for surface water quality assessment. The concentration ranges for index were defined by considering the Iraqi Drinking Water Standards (IQS), World Health Organization (WHO) and other scientific studies on water pollution effects of these parameters. The value function curves are plotted for each of the parameter. The corresponding value function curves transformed the actual concentration values into individual pollution indices. The value function curve was estimated using XLSTAT software (Version 2011.3.01) to get precise calculations. The overall water quality index (OWQI) estimated based on the individual parameter indices represents the overall quality of water. A case study of Tigris River was carried out to illustrate the application of this index. The proposed index can be used as a simple tool for assessing the overall water quality status and may serve decision-makers in reporting the state of the overall surface water quality before starting the treatment, state the level of treatment required, as well as knowing the spatial and temporal variations.

Keywords: Overall Water Quality Index (OWQI), Surface Water, Tigris River, Iraqi Standards.

تطوير دليل لتقييم نوعية المياه السطحية

الحسن حيدر اسماعيل

المستخلص:

تشتمل هذه الدراسة على وضع دليل جديد يسمى دليل نوعية المياه السطحية (I□W□)، بأستخدام ستة متغيرات فيزيائية-كيميائية وهي B□D، pH، العسرة الكلية، العكورة، الكلور والمواد الذائبة الصلبة. أحتوى تصنيف الدليل المقترح لتقييم نوعية المياه السطحية على خمسة فئات وهي ممتازة، جيدة، قليلة التلوث، غير جيدة وعالية التلوث. أن نسب تراكيز المتغيرات للدليل المقترح في هذه الدراسة تم أقتراحها بالاعتماد على المحددات العراقية و WH□ وبعض الدراسات العلمية المعنية بالمتغيرات وتأثيراتها على تلوث المياه. تم رسم دالة المنحنيات لكل متغير حيث ان قيمتها المطابقة تحول تركيز القيم الفعلية الى مؤشرات التلوث لكل متغير. كما تم أستخدام برنامج XLSTAT (Version 2011.3.01) في حساب قيم دالة المنحنيات للحصول على حسابات دقيقة. حيث تم حساب دليل نوعية المياه السطحية (I□W□) بالاعتماد على مؤشرات التلوث لكل متغير والتي تمثل نوعية المياه بشكل

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شامل. جرى تطبيق الدليل المقترح في هذه الدراسة على نهر دجلة لتوضيح تطبيقات هذا الدليل. وقد وجد بأن الدليل المقترح يمكن ان يستخدم كأداة بسيطة لتقييم أداء نوعية المياه السطحية بشكل شامل كما يساعد الدليل المقترح صانعي القرار في معرفة نوعية المياه السطحية قبل البدء بمعالجتها ومعرفة مستوى المعالجة الذي تتطلبه هذه المياه بالأضافة الى تغيراتها المكانية والزمانية.

Introduction :

Water quality index (WQI) is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers [1]. It, thus, becomes an important parameter for the assessment and management of water. WQI is a single number like a grade that expresses the overall water quality at a certain area and time based on several water quality parameters. It is also defined as a rating reflects a composite influence, on overall quality of water, of a number of water quality parameters.

WQI is an arithmetical tool used to transform large quantities of water quality data into a single cumulatively derived number. It represents a certain level of water quality while eliminating the subjective assessments of such quality [2, 3, 4].

Water Quality Criteria are defined as the acceptable levels of concentrations of specific water quality parameters and may vary with the type of use such as drinking, bathing and domestic use, irrigation, recreation and industrial use. The standards indicate the suitability of water for a specific use [□]. Thus, the criteria are developed for specific individual parameters. However, if this information on water quality parameters measured individually is transformed into a single number (Index) representing the overall quality of water, it will be very useful to the public.

Numerous water quality indices have been formulated all over the world which can easily judge out the overall water quality within a particular area promptly and efficiently [6]. For example, US National Sanitation Foundation Water Quality Index (NSFWQI) [7], Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) [8], British Columbia Water Quality Index (BCWQI), and Oregon Water Quality Index (OWQI) [9, 10, 11]. These indices are based on the comparison of the water quality parameters to regulatory standards and give a single value to the water quality of a source [11, 12].

Attempts to categorize water according to its degree of purity date back to the mid-twentieth century [13, 14]. Horton (196□) selected most commonly measured water quality variables for his index including dissolved oxygen (DO), pH, coliforms, specific conductance, alkalinity, and chloride. The index weight ranged from 1 to 4 and the index score was obtained with a linear sum aggregation function. The function consisted of the weighted sum of the sub-indices divided by the sum of the weights and was multiplied by two coefficients M1 and M2, reflecting temperature and obvious pollution, respectively. Horton's pioneering effort has been followed up by several workers to formulate various WQI's and their use has been strongly advocated by agencies responsible for water supply and control of water pollution [9, 10, 11].

Dee et al. (1972, 1973) proposed a system for evaluating the environmental impact of large scale water resources projects. The system included 12 variables (such as DO pH, turbidity, and fecal coliforms), besides pesticides and toxic substances. The index was calculated with and without considering the proposed water resources project.

Steinhart et al. (1982) [1□] applied a new environmental quality index to summarize technical information on the status of, and trends in Great Lakes Ecosystem. In Canada, the water quality index was introduced by Water Quality Guidelines Task Group of the Canadian

Council of Ministers of the Environment [16]. Newly developed CCMEWQI has been employed by various provinces and Ecosystems all across Canada to assess water quality [8, 12].

In the present study, the development of overall water quality Index (OWQI) considers the important water quality indicator parameters viz. pH, turbidity, biochemical oxygen demand (BOD), total hardness, total dissolved solids (TDS) and chloride. The classification of water quality is made very general such as excellent, good, slightly polluted, poor and heavily polluted. The concentration levels of the indicator parameters are defined with due consideration to the Iraqi standards in the proposed index. Wherever, such criteria were not defined reference was made to WHO and Criteria by McKee and Wolf. A case study of the Tigris River is made to illustrate the application of this index.

Materials and method :

1.Water quality standards

1.1 - Iraqi Drinking Water Standards (IQS):

Central Organization for Quality Control and Standardization in Iraq has developed Standards for drinking water. These standards indicate maximum permissible and maximum allowable limits for various water quality indicator parameters [17]. The proposed index in this study considered the Iraqi standards to define the concentration levels of the water quality parameters.

1.2-World Health Organization (WHO) Guidelines:

WHO guidelines are indicated in terms of action levels for important organic, inorganic and bacteriological parameters; toxicity indicator parameters; and radioactive parameters such as gross alpha and beta activity [18]. The term action level indicates a higher level which is the reasons for the presence of a substance should be investigated and appropriate remedial measures be applied [19]. The use of WHO in this study is to be confined to turbidity and chloride.

1.3 -Water Quality Criteria by McKee and Wolf:

Criteria given by McKee and Wolf [20] show ranges of promulgated standards for Raw Water Sources of domestic water supply defined as excellent, good and poor where excellent needs only disinfection, good requires filtration and disinfection, and poor requires special treatment and disinfection (Table 1).

Table 1: Ranges of promulgated standards for raw water sources of water supply*

Constituent	Excellent	Good	Poor
BOD (Monthly avg.)	0.7□- 1.□	1.□- 2.□	>2.□
DO mg/L	4 - 7.□	4 - 6.□	4
pH avg.	6 - 8.□	□– 9	3.8 - 10.□
Cl max mg/L	<□0	□0 - 2□0	>2□0
Turbidity units	0 - 10	10 - 2□0	>2□0

* McKee and Wolf, 1963.

Excellent: Needs disinfection; Good: Filtration and disinfection; Poor: Special auxillary treatment and disinfection.

It is noticed that different institutions have developed standards for various uses of water and all these standards take into account the effect on human health, vegetation, as well as quality of life considerations etc. [□]. However, these institutions vary in terms of definition of terminologies for classification scheme, the criteria such as (Guide Level, Action Level, maximum permissible limits and maximum allowable limits). Therefore, define a common classification scheme in order to know the water quality status in terms of pollution effects of the parameters under consideration is of prime importance.

2.Proposed Index

Surface water quality index is proposed in the present work in Iraqi context, in which significant indicator parameters and standards already developed by other institution are referred in detail. In this paper, the scale of water quality index proposed is excellent, good, slightly polluted, poor and heavily polluted water. Excellent means water quality is pristine. Good needs only disinfection. Slightly Polluted requires filtration and disinfection. Poor requires special treatment and disinfection. Heavily Polluted water cannot be used for any purpose. These ranges have been adopted from (Sargaonkar & Deshpande, 2003) [□].

2.1 -Selection of Indicator Parameters:

The water quality parameters viz. Turbidity, pH, BOD, TDS, Hardness and Cl are considered as the significant indicator parameters of surface water quality in the present study. The concentrations (levels/ranges) of these parameters in the above classes are defined with due consideration of Iraqi standards. For parameters not included in the Iraqi standards, reference was made to the standards defined by other institution. The proposed classification along with ranges of concentrations of these parameters is given in Table 2.

Table 2: Proposed Water Quality Index

Parameters	**Concentration ranges**				
Classification	**Excellent**	**Good**	**Slightly Polluted**	**Poor**	**Heavily polluted**
Turbidity (NTU)	□	10	100	2□0	>2□0
pH	6.□-7.□	6-6.□and 7.□-8	□-6 and 8-9	4.□-□and 9-9.□	<4.□and >9.□
BOD□(20C^o)	1	3	6	12	24
TDS (mg/L)	□00	1□00	2000	3000	>3000
Hardness as $CaCO_3$	100	1□0	300	□00	>□00
Cl (mg/L)	1□0	2□0	600	800	>800
Class Index	**10%**	**20%**	**40%**	**70%**	**100%**

2.2- Basis for Defining the Concentration Ranges:

In case of turbidity, the Iraqi standards for drinking water and WHO guidelines specify maximum permissible level of □NTU for turbidity. This value is considered in the proposed classification scheme as (excellent water quality). While the Iraqi standards for drinking water specify maximum allowable level of 10 NTU. This value is considered in the proposed index as (good water quality). The McKee and Wolf criteria indicate 10 – 2□0 NTU as good water quality, and more than 2□0 NTU as poor water quality. Hence, accordingly the range was split into 10 –100 as (slightly polluted), 100–2□0 as (poor) and more than 2□0 as (heavily polluted).

pH range as given by the Iraqi standards for drinking water is 6.□- 8.□for maximum permissible level. pH levels in the proposed index (excellent - heavily polluted) are indicated in Table 2.

The classification for Biochemical Oxygen Demand (BOD) is reviewed as given by McKee and Wolf [20]. BOD range 0 to 1 refers excellent water quality in our proposed index. BOD classes (excellent - heavily polluted) are shown in Table 2.

The values for total dissolved solids (TDS) (maximum) □00 mg/L as Excellent water quality, between □00–1□00 as Good water quality and 1□00–2000 as slightly polluted in the proposed index take into consideration the Iraqi standards for drinking water which indicate a value of □00 mg/l as maximum permissible level and 1□00 mg/L as maximum allowable level and for Poor and Heavy Polluted Classes are therefore assigned higher values 3000 and more than 3000 mg, respectively.

Maximum permissible level for total hardness in Iraqi standards for drinking water is 100 mg/L, whereas, maximum allowable level is □00 mg/L. Accordingly, the ranges for the parameter total hardness were taken as 0–100 mg/L (excellent water quality), 100–1□0 mg/L (good water quality) and 1□0–300 mg/L (slightly polluted), 300–□00 mg/L (poor water quality) and more than □00 mg/L (heavily polluted).

The concentration level for Cl in Iraqi standards is 200 mg/L for maximum allowable level. Therefore, first class (excellent water quality) was assigned a concentration 1□0 mg/L. The action level in WHO guidelines for Cl is 2□0; a value of 2□0 mg/L was assigned to next class (good water quality). The concentration value 600 mg/L indicating slightly polluted. The Poor and heavily polluted classes were assigned concentrations more than 600 mg/L (Table 2).

3.Calculating Overall Water Quality Index (OWQI):

Different water quality parameters are measured in different units of measurement. Hence, it is necessary to bring them into the commensurate unit so that the integrated index can be obtained and used for decision making. For this purpose, an integer value is assigned to each of the scale excellent water quality, good water quality, slightly polluted, poor and heavily polluted, in percentage values i.e. 10%, 20%, 40%, 70% and 100% respectively, where, the number termed as class index indicates the level of pollution in numeric terms. This forms the basis for comparison of water quality from excellent to heavily polluted (Table 2). The value function curves, wherein, the concentration of the parameter is taken on Y-axis and index value on X-axis are plotted for each of the parameter and are shown in (Fig 1–Fig 6). These curves give the pollution index (P_i) for individual pollutants. For any particular concentration, the corresponding index can be read directly from these curves. The value function curve was estimated using XLSTAT software (version 2011.3.01) to get precise calculations. XLSTAT is a microsoft excel statistical and has been developed since

1993 to enhance the analytical capabilities of Excel. XLSTAT relies on Excel for the input of data and the display of results, but the computations are done using autonomous software components. The use of Excel as an interface makes XLSTAT a user-friendly and highly efficient statistical and multivariate data analysis package. The quality of the computations is identical to that offered by classic scientific statistical analysis software. The software can be downloaded on http://www.xlstat.com/.
Overall water quality index (OWQI) is estimated as the average of all the pollution indices (P_i) for individual water quality parameter considered in this study and is given by the mathematical expression:

$$OWQI\,(\%) = \frac{\sum iPi}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where P_i = pollution index for ith parameter. i = 10%, 20%,……$n\%$ and n = number of parameters. The interpretation of OWQI values to determine the pollution status is done on similar lines to that for the individual parameter index defined earlier. The OWQI is simple to estimate and flexible to the addition or deletion of parameters. However, comparative assessments of water quality at different places or at different times can be made only when the parameters included in the OWQI are the same, and accordingly recommendations may be made regarding the specific use of water. The percentage estimate of OWQI corresponds to following classes:

(0–10)%: Excellent.
(10–20)%: Good.
(20–40)%: Slightly polluted.
(40–70)%: Poor.
(70–100)%: Heavily polluted.

In case of polluted and heavily polluted classes, more stringent measures for abatement of pollution are necessary to avoid any severe effects on human health, vegetation and aquatic life.

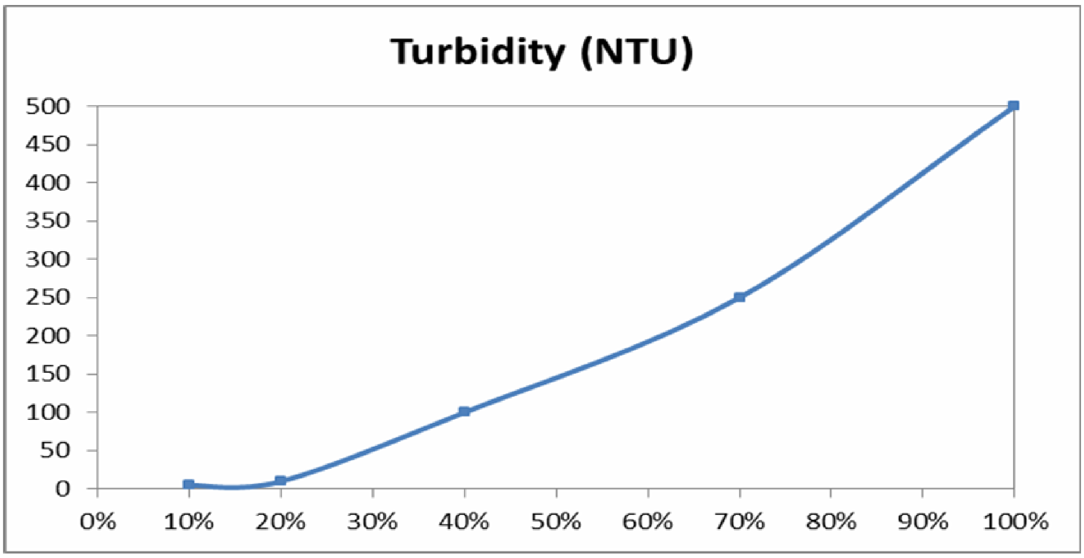

Figure 1: Value function curves for Turbidity in the proposed index.

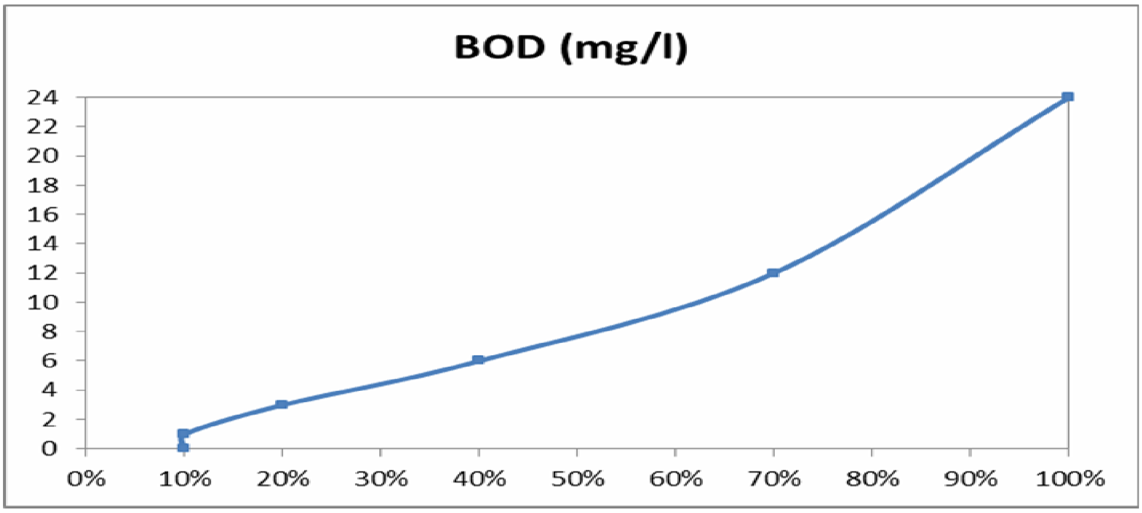

Figure 2: Value function curves for BOD in the proposed index.

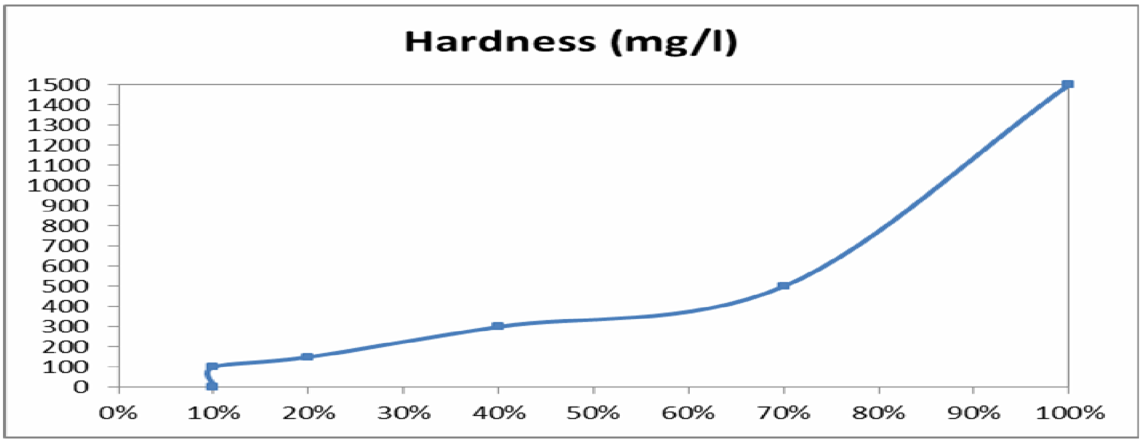

Figure 3: Value function curves for hardness in the proposed index.

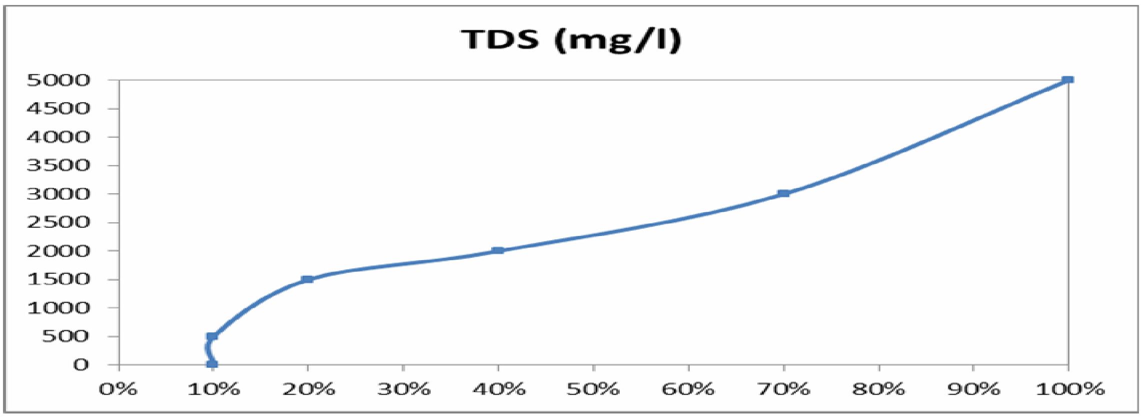

Figure 4: Value function curves for TDS in the proposed index.

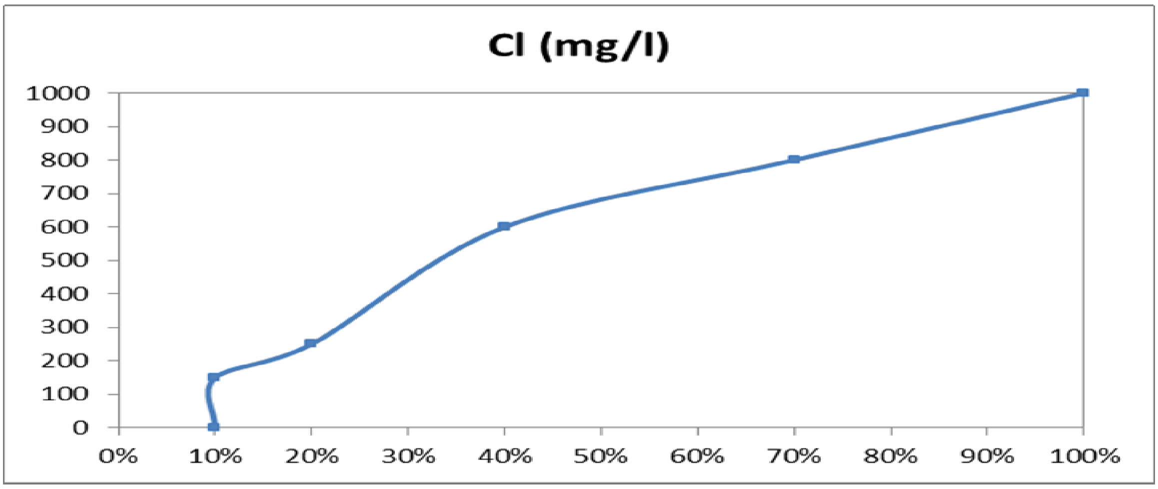

Figure 5: Value function curves for chloride in the proposed index.

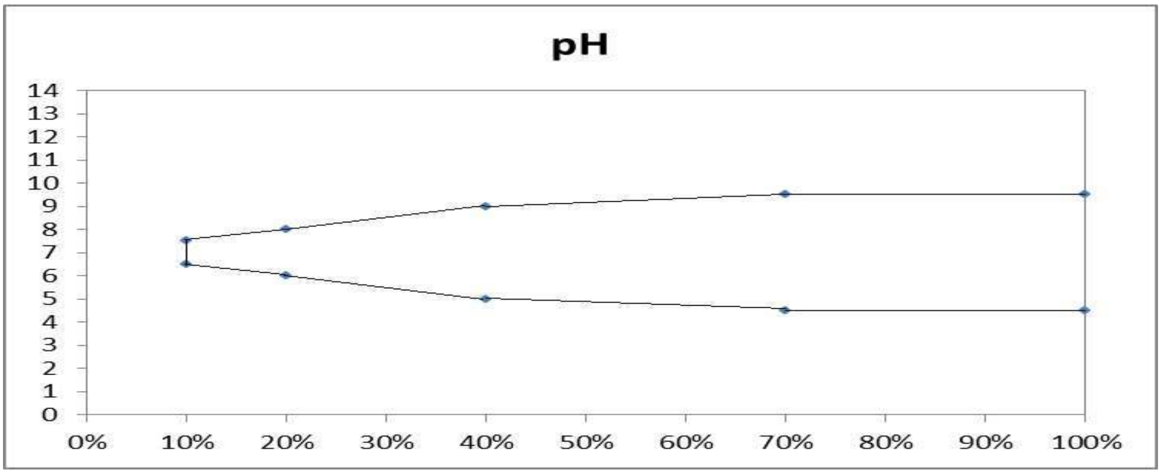

Figure 6: Value function curves for pH in the proposed index.

Application of OWQI for Tigris River (Baghdad stretch):

The proposed index of water quality classification and the methodology presented for estimation of OWQI was applied to assess the water quality status at a few sampling stations on the Tigris River. Water samples were collected in one liter polypropylene bottles at bimonthly intervals from sampling sites between October 2009 and March 2010 from the mid at 0.3 meters of the depth. Before the sample collection, all bottles were washed with dilute acid followed by distilled water and were dried in an oven. At each sampling location, water samples were collected in two polypropylene bottles. Before taking final water samples, the bottles were rinsed three times with the water to be collected. Water samples for BOD estimation were collected in BOD bottles (non-reactive borosilicate glass bottles of 300 ml capacity). Analysis of water samples was started as soon as possible after collection to avoid unpredictable changes. Four sampling stations were selected on Tigris river namely Al-Rashdia which the river enter Baghdad city, Almasbah near oil vegetables factory, Saeda near tanning and leather factory and Altwetha after its confluence with Dyalla river south of Baghdad. Grab sampling procedure was adopted for the analysis of various water quality parameters as recommended by standard methods [21].

The results of water quality in the months of (October – March) at four stations were considered for estimation of OWQI. The results are given in Table 3. Pollution indices for each of the water quality parameter measured at these stations were estimated using value function curves for each parameter (Table 4). It was done by using XLSTAT software (Version 2011.3.01). The OWQI was calculated by taking the average of all the pollution indices for individual water quality parameters. The results show that in Oct-09, the overall water quality was in the range Good to slightly polluted water quality (Fig. 7). In Nov-09 and Jan-10, the overall water quality was slightly polluted in Al-Rashdia, Almasbah and Altwetha but Poor in Saeda. In Dec-09 and Feb-10, the overall water quality was always slightly polluted. The water quality status in Mar-10 was Good in all the stations except Almasbah and Altwetha. No Excellent class was detected in the Tigris River in our study. This is obvious because of wastewater discharge along the river in Baghdad stretch [22]. Same trend were noticed in the results of WQI of (Alobaidy et al. 2010) for the year 2004. The scale of water quality index used in the study of (Alobaidy et al. 2010) is, water is excellent if the range of WQI between (0-2□), good (26-□0), poor (□1-7□), very poor (76-100) and unsuitable if WQI > 100. Their results were range from (Poor to Very Poor). Very poor class noticed at Al-Karama WTP, Al-Wathba WTP, Al-Qadisiya WTP, Al-Doura WTP and Al-Rasheed WTP [24].

Thus, based on the estimated values of OWQI, the sampling stations where pollution control measures are required can be identified. The detailed about the specific parameters responsible for pollution can be obtained by referring to the concentration ranges and the level of treatment required to make the water suitable for designed use at that location can be decided. As a case study, the OWQI values estimated at a few sampling stations on the Tigris River, are useful to ascertain the suitability of water for designated best use at a particular location [23, 24, 2□].

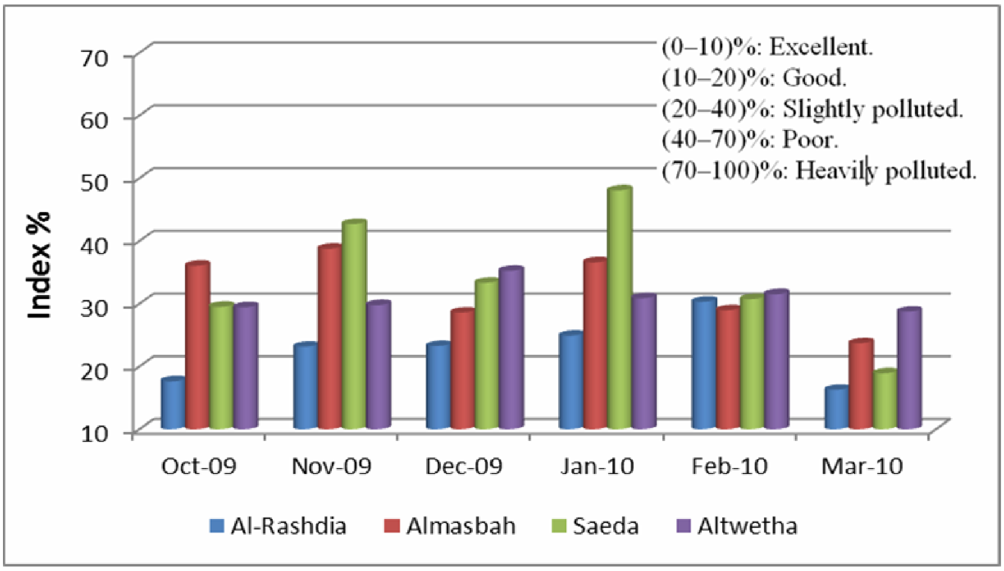

Figure 7: Overall Water Quality Index for Tigris River (Baghdad stretch)

Table 3: Observed water quality data in Tigris River.

Parameters	Stations			
Oct 2009	**Al-Rashdia**	**Almasbah**	**Saeda**	**Altwetha**
pH	7.1	7.3	7.1	7.2
Turbidity (NTU)	17	40	23	84
BOD (mg/l)	1.3	7.1	4.3	6.4
TDS (mg/l)	623	73□	194□	66□
Cl (mg/l)	133	334	140	160
Hardness (mg/l)	302	1374	460	400
Nov 2009				
pH	7.2	7.1	7.7	7.6
Turbidity (NTU)	24	34	31	86
BOD (mg/l)	2.□	6.1	□3	6
TDS (mg/l)	690	1□72	1160	□3□
Cl (mg/l)	110	□4□	760	134
Hardness (mg/l)	430	2100	1800	□00
Dec 2009				
pH	7.6	6.9	7.7	8
Turbidity (NTU)	22	3□	2□	74
BOD (mg/l)	3.4	7	4.4	7.6
TDS (mg/l)	820	1140	2110	8□□
Cl (mg/l)	123	120	244	223
Hardness (mg/l)	3□□	400	□20	666
Jan 2010				
pH	7.2	7.2	6.9	7.4
Turbidity (NTU)	28	23	33	37
BOD (mg/l)	4.4	□3	□.□	□7
TDS (mg/l)	720	1220	2230	1□□□
Cl (mg/l)	123	□□4	7□□	14□
Hardness (mg/l)	400	1823	2244	□00
Feb 2010				
pH	7.3	6.7	7.9	8.1
Turbidity (NTU)	41	30	31	24
BOD (mg/l)	□9	□2	2.2	7
TDS (mg/l)	□70	610	730	720
Cl (mg/l)	230	200	□44	166
Hardness (mg/l)	634	667	769	□33
Mar 2010				
pH	7.2	6.8	7.7	7.6
Turbidity (NTU)	□9	87	37	94
BOD (mg/l)	1.1	3.2	2.8	7.3
TDS (mg/l)	□20	□30	□60	□30
Cl (mg/l)	112	13□	86	102
Hardness (mg/l)	187	344	266	342

Table 4: Index for individual parameter at four sampling stations on Tigris River.

Parameters	Stations			
Oct 2009	**Al-Rashdia**	**Almasbah**	**Saeda**	**Altwetha**
pH	10%	10%	10%	10%
Turbidity (NTU)	22.1%	27%	23.8%	36.9%
BOD (mg/l)	12%	46.4%	28%	42.2%
TDS (mg/l)	11.2%	12.3%	37.8%	11.7%
Cl (mg/l)	10%	24.1%	10%	11.4%
Hardness (mg/l)	40.□%	96.□%	67.□%	64.4%
OWQI%	**17.63%**	**36.05%**	**29.5%**	**29.43%**
Nov 2009				
pH	10%	10%	13.8%	11.□%
Turbidity (NTU)	23.9%	2□6%	2□%	37%
BOD (mg/l)	17%	40.□%	3□%	40%
TDS (mg/l)	11.9%	21.9%	1□4%	10.2%
Cl (mg/l)	10%	34.6%	67%	10%
Hardness (mg/l)	66%	100%	100%	70%
OWQI%	**23.13%**	**38.76%**	**42.7%**	**29.78%**
Dec 2009				
pH	11.□%	10%	13.8%	20%
Turbidity (NTU)	23.7%	2□7%	24%	32.1%
BOD (mg/l)	22.1%	46.2%	28.7%	□0.8%
TDS (mg/l)	12.7%	1□2%	42.1%	13.1%
Cl (mg/l)	10%	10%	19.3%	18.1%
Hardness (mg/l)	□9.□%	64.4%	72%	77.3%
OWQI%	**23.25%**	**28.58%**	**33.32%**	**35.23%**
Jan 2010				
pH	10%	10%	10%	10%
Turbidity (NTU)	24.2%	23.8%	2□3%	26%
BOD (mg/l)	28.7%	34.9%	36.6%	48%
TDS (mg/l)	12.1%	16.1%	49.1%	21.3%
Cl (mg/l)	10%	34.8%	67.4%	10%
Hardness (mg/l)	64.4%	100%	100%	70%
OWQI%	**24.9%**	**36.6%**	**48.06%**	**30.88%**
Feb 2010				
pH	10%	10%	18%	22%
Turbidity (NTU)	27.1%	24.6%	2□%	23.9%
BOD (mg/l)	39.6%	33.9%	1□4%	46.2%
TDS (mg/l)	10.4%	11%	12.2%	12.1%
Cl (mg/l)	18.6%	16%	34.7%	11.9%
Hardness (mg/l)	76.2%	78.3%	79.2%	73.1%
OWQI%	**30.31%**	**28.96%**	**30.75%**	**31.53%**
Mar 2010				
pH	10%	10%	13.8%	11.□%
Turbidity (NTU)	30.8%	37.2%	26%	38.1%
BOD (mg/l)	10.2%	20.□%	19.1%	48.□%
TDS (mg/l)	10.1%	10.2%	10.3%	10.2%
Cl (mg/l)	10%	10%	10%	10%
Hardness (mg/l)	26.4%	□4.3%	34.3%	□4.1%
OWQI%	**16.25%**	**23.7%**	**18.91%**	**28.73%**

Conclusion:

Surface water quality index is proposed in this study. Six water quality parameters considered in the present study were pH, Turbidity, BOD, Cl, TDS and Hardness. The concentration ranges for these classes were defined by considering the Iraqi Drinking Water Standards (IQS) and other reported scientific information on pollution effects of these parameters. The value function curves are plotted for each of the parameters. The corresponding value function curves transformed the actual concentration values into individual pollution indices and it was estimated by using XLSTAT software (Version 2011.3.01) for clear output. The OWQI estimated based on the individual parameter indices represents the overall quality of water.

This study used the proposed WQI to assess the status of water quality and the suitability of surface water for different uses. The level of treatment required for such surface water expressed in term of OWQI. As a case study, the OWQI values estimated on the Tigris River, are useful to achieve the suitability of water for designated best use at a particular location and to determine the level of treatment required for the individual parameter by referring to the concentration ranges defined in the proposed index. Thus, the Overall Water Quality Index is useful to the public for assessment of surface water quality status and can be used as a powerful tool in formulating the pollution control strategies in terms of treatment required at different levels. Extensive studies are required to consider more water quality parameters in this index which responsible for deteriorate the surface water quality.

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