IMPROVEMENT OF EXISTING WATER QUALITY INDEX IN SELANGOR, MALAYSIA

A.A. Mamun, S.N. Hafizah and M.Z. Alam

Bioenvironmental Engineering Research Unit (BERU), Faculty of Engineering, International Islamic University Malaysia, Jalan Gombak, 53100 Kuala Lumpur, Malaysia.
e-mail: mamun@iiu.edu.my

ABSTRACT

A reviesd and improved water quality index (WQI) is proposed for the State of Selangor in Malaysia. Analyses were conducted to develop the rating curve, find the new subindices and weighing factors for the selected parameters. The water quality parameters were grouped according their similarities. The class of water gained at 1K07 (Klang River station) using new WQI equation and existing WQI equation was Class IV and Class III respectively. However, the statuses of the water for both cases were the same, where both of them were classified as polluted water. In other case, for example at 1L02 (Langat River station), the class resulted from the new and existing WQI was the same. But, the status of the water was different, where the new WQI indicated that the water was clean, while the existing WQI indicated that the water was slightly polluted. The proposed WQI seemed to be slightly more strict compared to the existing one, which is thought to bring benefit the river environment. The outcomes of this research can be applied to protect the rivers in Selangor.

Keywords: *River Pollution and Water Quality Index (WQI).*

1. INTRODUCTION

Water is vital for all living beings. Any source of water body might be used for many different uses, e.g., drinking water, irrigation, industries, fishing, boating, swimming and many other purposes. Certainly the desired quality is different for all of these uses. Water quality may need to be maintained for other living organism too. For instance, various types of fish entail high quality water to flourish. Aquatic plants and smaller animal life have their own quality requirements and are ecologically important for the proliferation of higher-level trophic states in the food chain. Therefore, the fundamental problem in water quality is to appropriately define it in a way that reflects all of the uses and users of the water. Specific characteristics of the water need to be determined such that the quality of the water is acceptable for each use (Davis and McCuen, 2005).

In order to assess the suitability of water for diverse uses, there is a need to develop an index, which will categorize the quality of water. Ascertaining its quality is very crucial before use for domestic, agricultural, aquatic life, recreational, or industrial purposes. However, all available water bodies are not suitable for all uses. WQI is used to assess the suitability of water for a variety of uses. WQI was first proposed and demonstrated in the early 1970s but not widely used or accepted by agencies that monitor water quality (Cude *et. al* 1997). WQI is used to relate a group of variables to a common scale and combining them into a single number according to a chosen method or model. This system of rating the water quality in terms of a single number has been applied as a measure of the degree of water pollution and also as a tool in water quality classification (Fauzi and Abu Bakar, 1992).

Malaysia also follows compound WQI to evaluate overall water quality of the rivers. The existing WQI equations are proposed by the Department of Environment Malaysia. This index is being practiced in Malaysia for about 28 years. It is a set of water quality guidelines which categorise the water quality class acccording to the quality of water for public use, such as source of raw water, recreational purposes, irrigation, aquaculture and so forth. The current WQI used in Malaysia is developed based on opinion poll and questionnaire survey (Khuan *et. al,* 2002).

The WQI is not intended to replace a detailed analysis of environmental monitoring and modeling, nor should it be the sole tool for the management of water bodies. However, WQI can be used to provide a broad overview of environmental performance that can be conveyed to the public in an easily understood format (Khan *et al*., 2003). 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. Thus, it is important to develop a number of indices to summarize water quality data in an easily expressible and easily understood format for various users including general public (WSDE, 2002).

There are several water quality indices that have been developed to evaluate water quality all over the world. All of these indices use various numbers (from 6 and above) of water quality parameters. Malaysian water quality index has a few limitations, which are tried to overcome in this study. The main objectives of this study were to review the existing WQI, analyse the secondary data and develop a revised WQI for the State of Selangor.

2. EXISTING WQI

For The Malaysian water quality index is an opinion-poll formula. A panel of experts was consulted on the choice of the parameters, and the weightage to be assigned to each parameter. The parameters which have been chosen are dissolved dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solid (SS), pH value, and ammonical nitrogen (Khuan *et. al*, 2002).

The WQI (Eqn. 1) approved by the DOE is calculated based on the above six parameters. Among them DO carries maximum weighing factor of 0.22 and pH carries the minimum of 0.12 in the WQI equation. The WQI equation eventually consists of the sub-indices, which are calculated according to the best-fit relations (Mamun *et. al.*, 2007).

$$WQI = 0.22SIDO+0.19SIBOD+0.16SICOD+0.16SISS+0.15SIAN+0.12SI\,pH \qquad (1)$$

Where, WQI = Water quality index; SIDO = Sub-index of DO; SIBOD = Sub-index of BOD; SICOD = Sub-index of COD; SIAN = Sub-index of AN; SISS = Sub-index of TSS; SIpH = Sub-index of pH.

However, a few limitations were identified while reviewing the Malaysian water quality index procedure and the long term data recorded in various river basins in Malaysia. The main drawbacks are given below (Mamun *et al.*, 2007):

a. pH is not a problem for Most of the Malaysian rivers and thus can be eliminated from the existing WQI equations. However, pH should be monitored to assess the suitability of water for other usages as required by the Interim National Water Quality Standards (INWQS);
b. No nutrient (phosphorus, nitrogen, etc.) is considered in the existing WQI equation;
c. Ammoniacal Nitrogen (AN) is identified as one of the main pollutants to render many of the rivers polluted but there is no limit in the effluent discharge standard for this parameter. However, it plays a significant role in determining the Class of water;

3. METHODOLOGY

The secondary data from 2002 until 2006 was collected from the Department of Environmental (DOE) Malaysia. The data included the value for colour, DO saturation, DO, BOD, COD, SS, pH, NH_3-NL, temperature, conductivity, salinity, turbidity, dissolved solids, total solids, NO_3, Cl, PO_4, As, Hg, Cd, Cr, Pb, Zn, Ca, Fe, K, Mg, Na, OG, MBAS, E. coli, coliform, the existing DO sub-index, BOD sub-index, COD sub-index, AN sub-index, SS sub-index, pH sub-index and WQI.

3.1 Selection of Parameters

Parameters for each water usage were selected by following the steps.

- The percentiles for each parameter were calculated. The values for percentile calculated were compared with the guidelines for each use. The guidelines used for raw water, recreational and irrigation purposes were class III, class IIB, and IV respectively. The guidelines were according to INWQS limits and other international sources.
- The parameters that exceeded the limits mentioned in guidelines were selected as the major pollutants for each river and were used to develop new WQI.
- However, certain critical parameters also had been selected by taking into consideration its importance based on the water usages and its adverse effect to human health.
- The parameters selected were then grouped based on their properties, whether physical, oxygen demand, nutrients, heavy metals, microbial, ion toxicity or specific ion.

3.2 Development of Rating Curve

- This The percentile values varying 5 percentiles using the 5 years data from three river basins were calculated. It was followed by the calculation of average concentration for each parameter from the three rivers according to percentile.
- The graph of the average concentration of each parameter versus the percentile was plotted.
- Based on the guidelines from INWQS, the class V value was the target for each parameter. The values that were equal or almost equal to the value in class V were assigned as 0 percentile. Other percentiles were calculated using correlation equations between the old percentiles with the new one. The new percentiles were developed from this method.
- The graph of the average concentration of each parameter versus the new percentile was plotted. The best-fit curve was plotted from this curve.
- In order to find the sub-index for each parameter, the graph was plotted inversely from the graph developed in step 4 (above) where the new graph had the sub-index at the y-axis and average concentration at the x-axis. The best-fit curve was plotted from this curve. This curve became the rating curve for each parameter.

3.3 Determination of Group Sub-index

- The individual sub-index for each parameter was determined using the equation developed for each of them. The individual sub-index was then used to determine the value for group sub-index.
- Based on the group of parameter selected before, the group sub-index was determined using formula of harmonic mean below (Eqn 2):

$$\text{Harmonic Mean} = \sum_{i=1}^{n} \frac{n}{\frac{1}{x_i}} \qquad (2)$$

3.4 Selection of Weighing Factor

- The existing WQI weighing factor for each parameter was used as a guide to develop the new weighing factor in this study. The existing WQI used for the selection of weighing factor were Malaysian WQI, Universal WQI and NSF WQI.
- Weighing factor for each parameter, in this study, was determined from the evaluation of the group of parameter that already being considered. The evaluation was done by giving the priority value to each group based on the guideline. The highest value of 5 was given to the critical group of parameter, while the least important group of parameter had been assigned to the value of 1.
- The fraction obtained for each group of parameter became the weighing factor.

3.5 Selection of Limits for Class and Parameter

- The values obtained from the percentiles were used to construct the limits for each class and parameter.
- The ranges of percentile values were divided into five main sections.
- The concentration of the parameter at each section was calculated using the rating curve equation. The concentration obtained turned out to be the limits for each class and parameter.

3.6 Calculation of WQI

- The data obtained from DOE Malaysia was employed to calculate the new WQI. The individual sub-index was determined using the rating curve equation for each parameter.
- The group sub-index of the parameters was calculated by applying individual sub-index obtained into the Equation 3.1.
- The calculated sub-index of the group of parameter was multiplied with the weighing factor attained.
- The summation of the index obtained for each group of parameter turned out to be the value of new Water Quality Index (WQI).

3.7 Classification of Water

- The river water quality was classified into five main classes.
- Class II, III, and IV were further sub-divided into three classes, where each class had the range value of 10.
- The classifications of water were depending on the WQI values obtained and according to the classes developed.

4. RESULTS AND DISCUSSIONS

4.1 Calculation and Comparison of Percentile Value

The 50-percentile value (median value) for each parameter was calculated and compared with the INWQS limits of class III (for raw water), class IIB (for recreation), and IV (for irrigation), where each class were corresponded to the limits for raw water, recreational and irrigation purposes respectively (Table 4.1). The values that exceeded the limits in INWQS were considered as the important parameters and included in the new WQI equations developed.

Table 1: Comparison of 50-percentile values with the limits in INWQS class for raw water, recreational and irrigation purposes

Parameters	50-percentile Values			INWQS Class III*	INWQS Class IIB*	INWQS Class IV*
	Klang River	Langat River	Selangor River			
DO (% saturation)	41.4	72.4	93.3	-	-	-
DO (mg/L)	3.19	5.57	7.26	3-5	5-7	<3
BOD (mg/L)	8	4	2	6	3	12
COD (mg/L)	44	33	22	50	25	100
SS (mg/L)	58	123	59	150	50	300
pH	7.24	7.02	7.135	5-9	6-9	5-9
NH_3-N (mg/L)	4.59	1.48	0.15	0.9	0.3	2.7
Conductivity (μmhos/cm)	274	139.5	47.5	-	-	6000
Salinity	0.13	0.06	0.02	-	-	2
Turbidity (NTU)	58.45	112.6	72.1	-	50	-
DS (mg/L)	152	61	23	-	-	4000
TS (mg/L)	218	211	75	-	50	-
NO_3 (mg/L)	0.23	0.64	0.41	-	7	5
Cl (mg/L)	13	7	2	-	200	80
PO_4 (mg/L)	0.27	0.06	0.05	-	-	-
As (mg/L)	0.0238	0.004	0.003	0.05	0.05	0.1
Hg (mg/L)	0.000291	0.000384	0.000259	0.004	0.001	0.002
Cd (mg/L)	0.001	0.001	0.001	0.01	0.01	0.01
Cr (mg/L)	0.005	0.003	0.00142	0.05	0.05	0.1
Pb (mg/L)	0.01	0.01	0.01	0.02	0.05	5
Zn (mg/L)	0.03445	0.03585	0.0366	0.4	5	2
Fe (mg/L)	0.22	0.31	0.678	1	0.03	5
Na (mg/L)	17.3	9.425	3.1	-	-	3 SAR
E-coli (Counts/100ml)	54000	13550	2000	-	-	-
Coliform (Counts/100ml)	123000	50500	18000	50000	5000	50000

* Source: DOE Malaysia, 2005.

4.2 Selected Parameters

Based on the comparisons shown in the Table 4.1, several parameters were selected to be included in the new WQI equation. However, during the selection of parameters, additional parameters were chosen eventhough the parameters did not exceed the limits of INWQS. Those were selected because of their adverse effects on human and crops. The selected parameters were then grouped according to the types of parameters. Table 2 shows the selected parameters with their groups.

Table 2: Summary of selected parameters for raw water

Physical	Oxygen Demand	Nutrients	Metals	Microbial
Total suspended solids (TSS)	COD	Total Nitrogen	Arsenic	Total coliform
-	DO (% saturation)	Total Phosphorus	Mercury	-
-	-	-	Chromium	-
-	-	-	Iron	-

4.3 Rating Curves for Subindices

The percentile values varying 5 percentiles using the 5 years data from three river basins were calculated. It was followed by the calculation of average concentration for each parameter from the three rivers according to percentile. Then, the graph of the average concentration of each parameter versus the percentile was plotted. Based on the guidelines from INWQS, the class V value was the target for each parameter. The values that were equal or almost equal to the value in class V were assigned as 0 percentile and other percentiles were calculated using correlation equations between the old percentiles with the new one. The graphs of the average concentration of each parameter versus the new percentile were plotted.

The rating curves developed are shown in Figure 1. Each curve might have one or two equations to represent the curve for differnet conditions. The equations were then used to calculate the sub-index for each parameter. Table 3 shows the equations obtained for each parameter. The individual sub-index was calculated using those equations.

Table 3: The equations obtained for each parameter for raw water supply

Parameter	Equations	Conditions
TSS	$y = -4E\text{-}06x^3 + 0.0031x^2 - 0.9261^x + 100$	Range as in the graph
COD	$y = 0.0101x^2 - 2.0161x + 100$	Range as in the graph
DO (% saturation)	$y = -1E\text{-}07x^4 - 0.0004x^3 + 0.0948x^2 - 5.2578x + 100$	57-100
	$y = -8E\text{-}06x^4 + 0.0011x^3 - 0.0267x^2 + 0.177$	<57
Total Nitrogen	$y = -0.0345x^4 + 0.6895x^3 - 2.8852x^2 - 15.645x + 100$	Range as in the graph
Total Phosphorus	$y = 47576x^4 - 40197x^3 + 12305x^2 - 1699.7x + 102.65$	Range as in the graph
Arsenic	$y = -898348x^3 + 129826x^2 - 6217.8x + 100$	Range as in the graph
Mercury	$y = 5E+07x^2 - 140140x + 100$	0-0.0014mg/L
	$y = -2E+06x^2 + 1000x + 4.6667$	>0.0014mg/L
Chromium	$y = -145976x^3 + 37415x^2 - 3284.2x + 100$	Range as in the graph
Iron	$y = 56.613x^2 - 160.8x + 100$	Range as in the graph
Total Coliform	$y = -1E\text{-}12x^3 + 9E\text{-}08x^2 - 0.004x + 100$	Range as in the graph

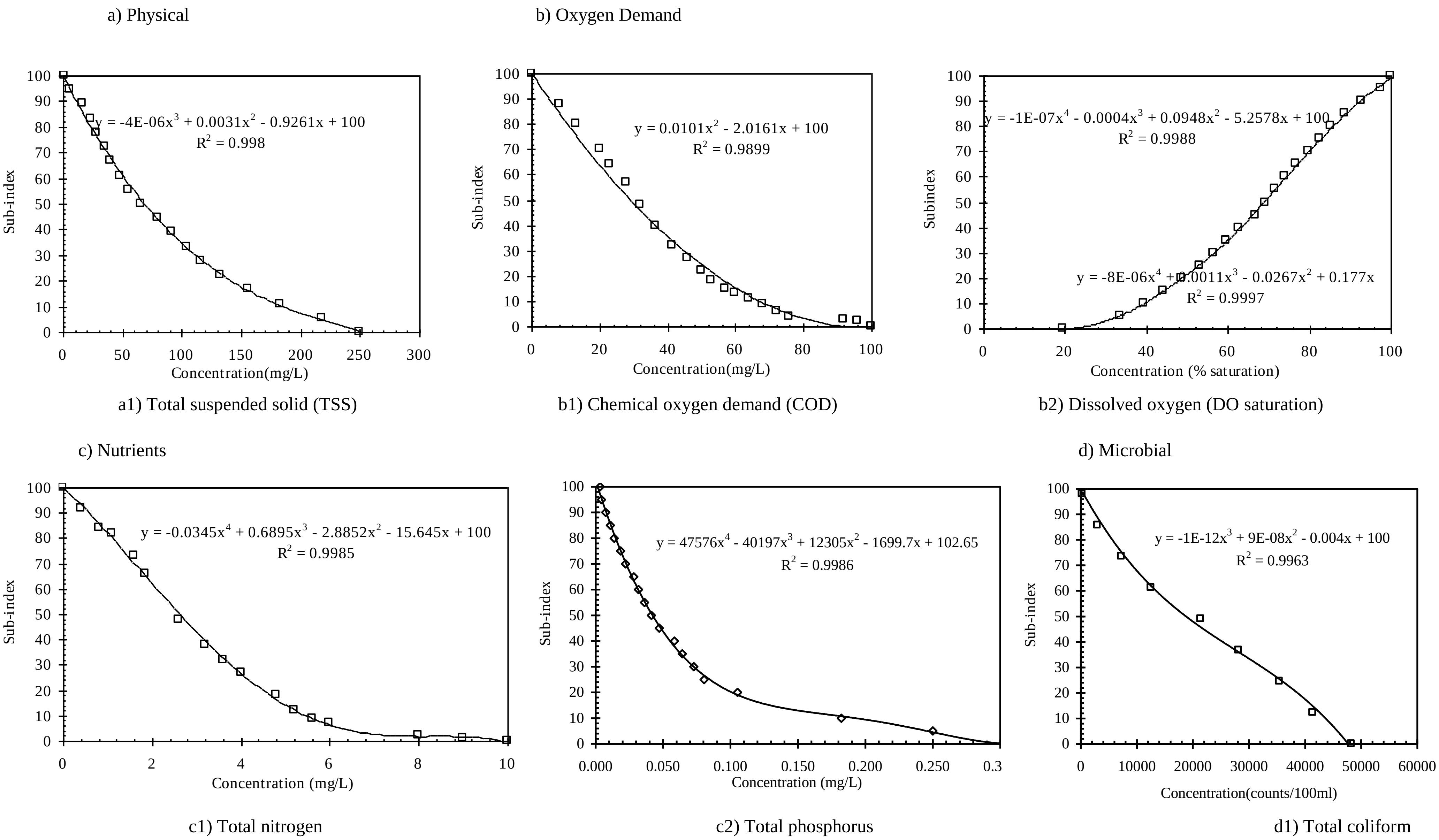

Figure 1: Sample rating curves for raw water parameters

4.4 Weighing Factors for each Group

Weighing factor for each parameter in this study was determined by giving the priority value to each group based on the guideline. The highest value of 5 was given to the critical group of parameter, while the least important group of parameter was assigned the value of 1. Then, the calculated fraction for each group of parameter was identified as the weighing factor. Table 4 shows the weighing factor for each water use.

Table 4: Determination of weighing factor for raw water

Group	Priority value	Proposed weighing factor
Physical	1	0.067
O_2 demand	2	0.133
Nutrients	4	0.267
Microbial	3	0.200
Heavy metals	5	0.333
Total	15	1.000

4.5 Weighing Factors for each Group

The WQI was divided into five main classes that are Class I, Class II, Class III, Class IV, and Class V. Class II, Class III, and Class IV were then further divided into three sub-sections with the range value of 10 for each sub-section to make the classifications become more specific. Each section was assigned certain range of WQI values, varied from 0 to 100. The threshold values for parameters were determined using the equation of rating curve obtained. The summaries of selected limits for each class and parameter are given in the Table 5.

4.6 The WQI Equation

The equation obtained to determine the quality of the source of raw water intake is:

Raw water WQI =
$$\begin{aligned} &0.067\times(\mathrm{P})+0.133\times(\mathrm{OD})+0.267\times(\mathrm{N}) \\ &+0.200\times(\mathrm{M})+0.333\times(\mathrm{HMet}) \end{aligned} \quad (3)$$

where,

P = Sub-index of physical group
OD = Sub-index of oxygen demand group
N = Sub-index of nutrient group
M = Sub-index of microbial group
HMet = Sub-index of heavy metal group

Using the data obtained from DOE Malaysia, raw water quality of the rivers in Selangor was calculated using this new WQI equation. The results on the new classes of WQI gained for each river were compared with the existing classes of WQI.

Based on the results obtained it was observed that the class of water between the new WQI and the existing WQI experienced a small difference, where most of them differed within one class only. For example, the class of water gained at 1K07 (Klang River station) using new WQI equation and existing WQI equation was Class IV and Class III respectively. However, the statuses of the water for both cases were the same, where both of them were classified as polluted water. In other case, for example at 1L02 (Langat River station), the class resulted from the new and existing WQI was the same. But, the status of the water was different, where the new WQI indicated that the water was clean, while the existing WQI indicated that the water was slightly polluted. This situation happened since the division of class of the new WQI was making narrower than the existing one, which has a wider range of class of water. The water status was classified as slightly polluted for the existing WQI if the value of WQI was between 59-80. However, using the new WQI classification of water status, if the WQI value was between 59-80, the water was categorized as between fair and clean (Table 4.9), depending on the WQI value obtained.

The small difference of class of water between the new WQI and existing WQI wd oumade it easy for the authority and public to accept the river water condition, since there was no abrupt change in the quality of water. Generally, dramatic changes in any situation will make people tend to resist the changes rather than to accept it.

Table 5: Classes for Raw Water Quality

Parameter	Unit	Classes										
		Very Clean	Clean			Fair			Polluted			Very Polluted
		I	II-A	II-B	II-C	III-A	III-B	III-C	IV-A	IV-B	IV-C	V
WQI	-	<94	94-85	84-75	74-65	64-55	54-45	44-35	34-25	24-15	14-5	<5
TSS	mg/L	<7	7-17	18-30	31-44	45-60	61-78	79-99	100-126	127-161	162-214	>214
DO	% Sat.	>88	88-84	83-79	78-74	73-69	68-64	63-58	57-47	46-41	40-30	<30
COD	mg/L	<3	3-8	9-13	14-19	20-25	26-33	34-40	41-49	50-61	62-77	>77
TN	mg/L	<0.34	0.34-0.87	0.88-1.38	1.39-1.88	1.89-2.38	2.39-2.91	2.92-3.48	3.49-4.14	4.15-4.98	4.99-6.42	>6.42
TP	mg/L	<0.006	0.006-0.011	0.012-0.019	0.020-0.027	0.028-0.037	0.038-0.049	0.050-0.064	0.065-0.086	0.087-0.134	0.135-0.250	>2.50
Hg	mg/L	<0.00004	0.00004-0.00011	0.00012-0.00019	0.00020-0.00028	0.00029-0.00037	0.00038-0.00047	0.00048-0.00059	0.00060-0.00072	0.00073-0.00089	0.00090-0.00117	>0.00117
As	mg/L	<0.0010	0.0010-0.0026	0.0027-0.0045	0.0046-0.0065	0.0066-0.0088	0.0089-0.0114	0.0115-0.0144	0.0145-0.0181	0.0182-0.0231	0.0232-0.0321	>0.0321
Cr	mg/L	0.002	0.002-0.004	0.005-0.008	0.009-0.012	0.013-0.016	0.017-0.021	0.022-0.027	0.028-0.035	0.036-0.045	0.046-0.065	>0.065
Fe	mg/L	<0.035	0.035-0.100	0.102-0.168	0.169-0.241	0.242-0.319	0.320-0.402	0.403-0.493	0.494-0.594	0.595-0.709	0.710-0.846	>0.846
Total Coliform	MPN/100mL	<1432	1433-4280	4281-7567	7568-11470	11471-16265	16266-22314	22315-29657	29658-37077	37078-43252	43253-48140	>48140

4.7 Application of WQI

The users can assess the river water quality using the new WQI equations developed by following the steps:

1. Collect the data of the parameters for the river desired.
2. Select the data of parameters to be used.
3. Determine the individual sub-index using the rating curve equations given in Table 3.
4. Determine the group sub-index using the formula of Harmonic Mean as given in the Equation 2.
5. Apply the value of group sub-index obtained to the new equation by multiplying the value with the weighing factor to get the value of new WQI.
6. Compare the value of new WQI with the classification of WQI in Table 5.
7. The final results obtained will be the value new of WQI, the class of river water, and the status of the river water.

5. CONCLUSIONS

The proposed WQI eqautions are more technically sound compared to the exsiting equations which were developed formulated based on the questionaire survey of the water quality experts. The rating curves and limits for the parameters considered in the new WQI were developed based on the scientific method. The range of classification also was narrowed down compared to the existing one, so that the quality of the water becomes more specific and controllable. The WQI of raw water was compared with the existing values. The class and status of the water determined using this new WQI for raw water quality did not give so much difference with the existing conditions determined using the existing WQI.

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