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A Comparative Study of Prevalent Water Quality Indices in Streams

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Abstract: Indian Rivers like Ganga , Godavari, Brahmputra, Krishna, Cauvery ,Tungabhadra etc. are getting heavily polluted by untreated sewage of cities,agricultural runoff infected due to excessive dose of insecticides, untreated industrial wastewater etc.(Bhargava,2007). Almost 200 million people in India do not have access to safe and clean drinking water and 90% of the country's water resources are polluted. As per an estimate by C.P.C.B. in 2011, only 29 % of wastewater generated is being treated in urban centres having population more than 50,000 in india and 71% as untreated waste water is being discharged to our rivers, streams and lakes, making them highly polluted. Even some of the our developed cities in India like Pune,Nagpur & Nashik are treating only 70 to 80 % of city sewage (report TOI.April 2013), so the sewage pollution caused by ordinary indian town & village can be imagined. This precipitates the urjent need of identifying the water quality status of our rivers ,to save the human race form water borne diseases & other associated aspects. Water quality status of the river at any place & point of time can be easily ascertained by determining it's Water Quality Index. Some water quality indices have been developed to evaluate water quality in States,Canada & other countries. These indices are based on important water quality parameters like DO,Turbidity,Coliform no. etc..They give the true status of river water quality, usually give the same result, but may have some limitations under specific cases.The present paper does, a comparative evaluation of these prevalentwater quality indices, practiced in different countries.

Keywords : Fecal Coliform; DO; BOD; WEPWQI ; NSFWQI

I. INTRODUCTION

At the present time, to safeguard freshwater resources, it is important to develop a comprehensive river water quality monitoring program all over the world. A river quality monitoring program (RQMP) could be designed on the basis of the information on the existing water quality, standards, anthropological effects and the 'use' criteria. The monitored data help the planners both at the national and international levels to develop various environmental programs. However, when a large number of samples and parameters are monitored, it becomes difficult to evaluate and present the water quality as a single unit (Chapman, 1992; Pesce and Wunderlin,2000). Traditionally, river water quality has been assessed by comparing the values with the local norms.

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However, this technique does not provide any information on the spatial and temporal trends of the overall quality (Debels et al., 2005). Thus, modern techniques such as water quality indices (WQI) and water quality modeling were developed. The advanced modeling techniques require time and extensive calibration and validation, as well as knowledge about hydraulics and other domains. Thus, applying water quality modeling for an immediate solution is not a feasible option. The models should be used mainly for assessment and management purposes (Chapman 1992; Rauch et al. 1998; Shanahan et al.1998; Somlyody et al. 1998). According to Stambuk-Giljanovic (1999), WQI is a mathematical tool which has the ability to provide a single number for the large quantities of water quality data in a comprehensive manner. Therefore, it is a simple tool for decision makers on the quality and possible uses of a given water body (Bordalo et al.,2001; Cude, 2001; Kannel et al.,2007).

II. SIGNIFICANCE OF THE ENVIRONMENTAL VARIABLES

Oxygen is the single most important gas for most aquatic organisms and for self-purification processes. DO is a measure of the amount of oxygen freely available in water. . It is commonly expressed as a concentration in terms of milligrams per liter, or as a percent saturation, which is temperature dependent.The colder the water, the more oxygen it can hold. (Ahmed Said et al., 2004). Fecal coliform are bacteria whose presence indicates that the water may have been contaminated with human or animal fecal material. If fecal coliform counts are high in a site, it is very likely that pathogenic organisms are also present, and this site is not recommended for swimming and other contact recreation.(CPCB,MINARS,2001). Phosphorus is important to all living organisms. However, excessive phosphorus causes algae blooms, which are harmful to most aquatic organisms. They may cause a decrease in the DO levels of the water, and in some cases temperature rise. This can result in a fish kill and the death of many organisms.(APHA,1998). Turbidity indicates the amount of particles suspended in water. High concentrations of particles can damage the habitats for fish and other aquatic organisms. The specific conductance represents the salinity of water. It is a measure of the ability of water to conduct an electrical current. It is highly dependent on the amount of dissolved solids in the water. An empirical relationship between total dissolved solids and conductivity can be derived for a stream (APHA 1998; BASIN 2001).

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There are other water quality variables that affect the suitability of water for use such as pH, temperature, and nitrogen. However, the effects of these variables are reflected to a certain degree by the basic variables. For example, the temperature effect can be captured if the dissolved oxygen is measured as percent saturation. However, temperature is an important variable because there are critical temperatures for many aquatic species. Conductance is a function of water temperature and the total number of dissolved ions in water. When conductance is reported as specific conductance, it has been corrected to constant temperature of 25^0 C. The pH of the U.S. natural water is usually between 6.5 and 8.5. The capacity of the pH natural buffer helps to resist significant changes in pH (APHA 1998, BASIN 2002).

III. DEVELOPMENT OF WATER QUALITY INDICES

Categorization of water quality started in the mid-twentieth century by Horton (1965) and Landwehr (1974). Brown et al. (1970) developed a general WQI. More than 20 water quality indices being used till late 1970s were reviewed by Ott (1978) and Steinhart et al. (1981). Steinhart et al. (1982) applied a novel environmental quality index to sum up technical information on the status and trends in Great Lakes ecosystem. Water Quality Guidelines Task Group of the CCME introduced WQI in Canada, in the mid-1990s (Dunn 1995; H'ebert 1996; Rocchini and Swain 1995). Said et al. (2004) studied some frequently used WQI in public domains such as the US National Sanitation Foundation Water Quality Index, NSFWQI (Brown et al. 1970), Florida Stream Water Quality Index, FWQI (SAFE 1995), British Columbia Water Quality Index, BCWQI (Zand- bergen and Hall 1998), Oregon Water Quality Index, OWQI (Cude 2001) and the Canadian Water Quality Index (Canadian Council of Ministers of the Environment (CCME) 2001). The original BCWQI was modified into the CCME WQI, which was certified by the Canadian Council of Ministers of the Environment (CCME) 2001. In India, the pioneer work on WQI was done by Bhargava (1983), wherein the water quality is expressed as a number (ranging from 0 for highly/extremely polluted to 100 for absolutely unpolluted water) representing the integrated effect of the parameters amplifying the pollution load. The Bhargava's WQI includes the effect of weight of each variable (pollution parameter) in the sensitivity function values of the various pollution variables relevant to a particular use.

IV. DETAILS OF PREVALENT WATER QUALITY INDICES

National Sanitation Foundation Water Quality Index (NSFWQI)

U.S. National Sanitation Foundation developed an index called the NSF Water Quality Index (NSFWQI).More than 140 water quality scientists had surveyed about 35 water quality tests and were asked to consider, which tests should be included in an index (Mitchell and Stapp, 1996).Nine water quality variables are used for the NSFWQI index:DO,fecal coliform, pH, BOD temperature change, total phosphate, nitrate, turbidity and total solids.NSFWQI score are-90-100:Excellent,70-90:Good,50-70:Medium,25-50:Bad,0-25:Very Bad.To get the NSFWQI,the Q-value should be determined for each variable.Also a weighing factor is assigned to each variable (like DO:0.17,Fecal Coliform:0.16 etc.).

$$\text{NSFWQI} = \sum_{i=1}^{n} W_i Q_i$$

The NSFWQI is most commonly employed, easy to use index.Most of the states in USA has modified it to suit their requirement and standards.NSFWQI is nowadays available online & user friendly.It is an effective technique for reporting water quality data,examining trends and evaluating the effectiveness of water pollution control programmes.Another advantage of the NSFWQI is that if data of all the 9 variables are not available.then overall WQI can still be estimated by adding the results and then adjusting for the number of pollutant variables with available data.For example, if there are 2 variables with no available data,then 7 remaining subtotals are added and the 7 weighting factors are added.The former is then divided by the latter to obtain the final WQI(Basin et al.,2001).The detailed method to calculate NSFWQI has been explained in table 1(Ahmed Said et al.,2004).

Watershed Enhancement Programme Water Quality Index (WEPWQI)

Watershed Enhancement Programme (WEP) in Ohio developed a water quality index and a river index.This index is calculated in two steps: the WEPWQI, which consists of chemical,physical and biological variables and then the River Index, which consists of the 15 no. of water quality variables plus measurement of water flow and clarity.WEPWQI scores are >60:Excellent, 60-46:Good,45-31:Fair,<31: Poor. Although WEPWQI has more water quality variables,it would pick up poor conditions ,such as cases where pesticide and Polycyclic Aromatic Hydrocarbon(PAH) contamination exists (which could not be detected by NSFWQI)(WEP,1996).

CCME Water Quality Index (Conceptual Framework)

CCME water quality index have been used extensively in Canada.The CCME WQI comprises three factors and is well documented (Canadian Council of Ministers of the Environment (CCME,2001). It is based on a formula developed by the British Columbia Ministry of Environment, Lands and Parks and modified by the Alberta Environment(Ashok Lumb et al.,2006). The index is based on a combination of three factors:

Factor 1 : F_1(Scope)

Scope assesses the extent of water quality guideline non-compliance over the time period of interest, which means the number of parameters whose objective limits are not met. It has been adopted directly from the British Columbia Water Quality.

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total No.of Variables}}\right) \times 100$$

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Where, the **variables** indicate those water quality parameters whose objective values (threshold limits) are specified and observed values at the sampling sites are available for the index calculation.

Factor 2 : F_2 (Frequency)

The frequency (i.e. how many occasions the tested or observed value was off the acceptable limits) with which the objectives are not met, which represents the percentage of individual tests that do not meet the objectives ("failed tests"):

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total No.of tests}}\right) \times 100$$

The formulation of this factor is drawn directly from the British Columbia Water Quality Index

Factor 3 : $F3$ (Amplitude)

The amount by which the objectives are not met (amplitude) that represents the amount by which the failed test values do not meet their objectives, and is calculated in three steps

(i) The number of times by which an individual concentration is greater than (or less than,when the objective is a minimum) the objective is termed an "excursion" and is expressed as follows. When the test value must not exceed the objective:

$$\text{Excursion}_i = \left(\frac{\textit{failed test value}_i}{\textit{objective}}\right) - 1$$

For the cases in which the test value must not fall below the objective

$$\text{Excursion}_i = \left(\frac{\textit{objective}_i}{\textit{failed test value}_i}\right) - 1$$

(ii) The collective amount, by which the individual tests are out of compliance, is calculated summing the excursions of individual tests from their objectives and then dividing the sum by the total number of tests. This variable, referred to as the normalized sum of excursions (*nse*) is calculated as

$$\text{nse} = \left(\frac{\sum_{i=1}^{n} \textit{excursion}_i}{\textit{No. of tests}}\right)$$

(iii) F_3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a value between 0 and 100

$$F_3 = \left(\frac{nse}{0.01nse + 0.01}\right)$$

The CWQI is finally calculated as:

$$\text{CCMEWQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right)$$

The factor of 1.732 has been introduced to scale the index from 0 to 100. Since the individual index factors can range as high as 100, it means that the vector length can reach a maximum of 173.2 as shown below:

$$\sqrt{100^2 + 100^2 + 100^2} = \sqrt{30000} = 173.2$$

The above formulation produces a value between 0 and 100 and gives a numerical value to the state of water quality. Note a zero (0) value signifies very poor water quality, whereas a value close to 100 signifies excellent water quality. The assignment of CCME WQI values to different categories is somewhat subjective process and also demands expert judgment and public's expectations of water quality. The water quality is ranked in the following 5 categories

1. Excellent: (CCME WQI values 95–100)
2. Good: (CCME WQI values 80–94)
3. Fair: (CCME WQI values 60–79)
4. Marginal: (CCME WQI values 45–59).
5. Poor: (CCME WQI values 0–44)

The CCME has prepared software in Visual Basic, which is implemented in Microsoft Excel for computing the WQI. The macro is quite flexible in that it can take a large number of data sets on the large number of water quality variables for computing the indices. The choice of variables, depending on the availability of data, can be manipulated easily. The detailed instructions on the implementation of the macro are well described in the Calculator Version 1.0 (CCME, 2001). The output is available in the form of a table displaying the values of F_1, F_2, F_3, WQI, number of samples, number of variables tested, total number of variables, total tests, failed tests, passed tests and tests below detection level. It also gives a frequency histogram of F_1,F_2 and F_3 . The macro is user-friendly but requires input data in a given tabular format.It should be noted that F_2 essentially is the ratio of number of failed tests divided by the total number of tests expressed as percentage. However Indian scientists have also started using it and validated the results.

The New WQI Index

The New WQI equation was developed by Ahmed Said,David Stevens & Gerald Shelke,USA in 2004 in two steps (Ahmed Said et al.,2004). The first was ranking water quality variables according to their significance. The variables included in the new WQI are DO, total phosphates, fecal coliform, turbidity and specific conductivity. Second, several forms were tested to give DO the highest weight followed by fecal coliform and total phosphorus. The percent saturation refects the temperature effect. Turbidity and specific conductance were given the least influence. A final form was selected that keeps the index in a simple equation and a reasonable numerical range. The logarithm was used to give small numbers that are easily used by the management decision-makers, the stake- holders, and general public as well. A sensitivity analysis was performed to test the performance and to verify that appropriate influences were given for the water quality variables as shown in Figure 1

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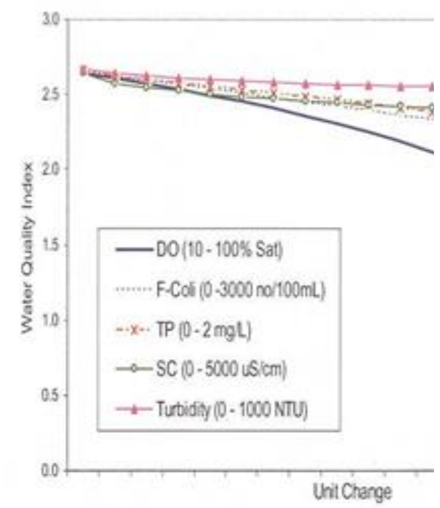

Figure 1.Water Quality Index (WQI) for the unit change of water quality variables. The slope of the lines defines the behavior of the variables. The dissolved oxygen (DO) has the maximum slope and the most rapid effect on WQI followed by fecal coliform

In the final form, the powers of the variables were chosen for the WQI based on the effect of each variable on water conditions. For example, higher values of fecal coliform and total phosphorus will be very harmful for health and aquatic life. The forms of the fecal coliform and total phosphorus in the index formula were chosen to give strong responses to these effects On the other hand, turbidity and specific conductance have linear effects, which are less sensitive for changing the values of the variables, in the index formula. This is because, for example, turbidity would not be very dangerous unless it is associated with a higher level of disease-causing microorganisms that will make fecal coliform higher as well in the formula.

To calculate this index, there is no need to standardize the variables. The calculations are further simplified through the elimination of sub-indices (percent of ideal situation of each variable). The proposed index is:

$$\text{New WQI}=\log\left[\frac{(DO)^{1.5}}{(3.8)^{TP}\ (Turb)^{0.15}\ (15)^{FCol/10000}+0.14\ (SC)^{0.5}}\right] \quad (1)$$

Where, DO is the dissolved oxygen (% oxygen saturation),Turb is the Turbidity (Nephelometric turbidity units [NTU] TP is the total phosphates (mg/L) FCol is the fecal coliform bacteria (counts/100 mL)SC is the specific conductivity in (MS/cm at 25^{0}C)

The index was designed to range from 0 to 3.The maximum or ideal value of this index is 3.In very good waters that have 100% dissolved oxygen, no TP, no fecal coliform, turbidity less than 1 NTU and specific conductance less than 5 MS/cm, the value of this index will be 3. From 3 to 2, the water is acceptable, and less than 2 is marginal and remediation, likely in the form of TMDLs, is needed.If one or two variables have deteriorated, the value of this index will be less than 2. If most of the variables have deteriorated, the index is less than 1, which means that water quality is poor.

Table 1. An example of the National Sanitation Foundation Water Quality Index (NSFWQI) calculation and the New WQI (A.Said)

Variable	Result	Unit	Q-Value	Weight factor	Subtotal
DO	82	% saturation	90	0.17	15.3
Fecal coliform	12	#/100 ml	72	0.16	11.52
pH	7.67		92	0.11	10.12
BOD	2	mg/L	80	0.11	8.8
Change in temp.	5	^{0}C	72	0.10	7.2
Total phosphate (PO_4)	0.5	mg/L	60	0.10	6.0
Nitrates	5	mg/L NO_3	67	0.10	6.7
Turbidity	5	NTU	85	0.08	6.8
TS	150	mg/L	78	0.07	5.46
NSFWQI					**77.9**
New WQI (A.Said)					**2.22(from equation no1)**

NSFWQI:90-100:Excellent,70-90:Good,50-70:Medium,25-50: Bad,0-25:Very Bad

New WQI(A.Said):3-2:Good,2-1:Need total maximum daily loads(TMDL),1-0:Need TMDL and best management practices.

Reference: http://bcn.boulder.co.us/basin/watershed/wqi nsf.html

Table 1 shows a sample calculation using NSFWQI (Mitchell and Stapp 1996) and the new WQI. The NSFWQI value is 77.9, which lies on the good water classification region, so the water is considered good.To get the NSFWQI, the Q-value should be determined for each variable. Also, a weighting factor is assigned to each variable. The NSFWQI includes nine water quality variables (DO, fecal coliform, pH, BOD, temperature TP, nitrate, turbidity, and TS). The new WQI gives a value of 2.22, which indicates that the water is good in just one simple step

V. CONCLUSIONS

The NSFWQI is most commonly employed, easy to use index.Most of the states in USA has modified it to suit their requirement and standards.NSFWQI is nowadays available online & user friendly.It is an effective technique for reporting water quality data,examining trends and evaluating the effectiveness of water pollution control programmes.Another advantage of the NSFWQI is that if data of all the 9 variables are not available.then overall WQI can still be estimated by adding the results and then adjusting for the number of pollutant variables with available data.For example, if there are 2 variables with no available data,then 7 remaining subtotals are added and the 7 weighting factors are added.The former is then divided by the latter to obtain the final WQI. CCME water quality index have been used extensively in Canada. However Indian scientists have also started using it and validated the results.

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While New WQI suggested by Said,Stevens & Sehlke in 2004 is based on only 5 variables like DO, F-coli, TP, SC & turbidity and is more sensitive to the elevated values of phosphorus and Turbidity or decreased value of DO. New WQI developed by A.Said et.al. has some advantages over the others. It is very simple, fast, does not need to standardize the water quality variables or to calculate subindices, and it decreases the number of water quality variables that are needed to evaluate the water quality situation. This index contains five variables compared to eight variables for other indices. However, the measurements should not be performed downstream of a wastewater treatment plant or in areas where large amounts of animal or untreated human waste is deposited into the stream. This index gives results very similar to those calculated using NSF and WEP methods while using fewer variables.However ,New WQI is still to be utilized & validated for Indian conditions.

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