Comparative Study of Different Approaches of Water Quality Indices

[1]Monika Pawar, [2]Anshuman Singh, [3]Prof. R. K Bhatia

[1,2]ME Environmental Engineering, [3]Associate Professor
Department of Civil Engineering, Jabalpur Engineering College, Jabalpur, Madhya Pradesh, India.

Abstract: **Water is a precious gift to all human beings. Water quality is a significant criterion in matching water demand and supply. So its rapid quality assessment becomes important in these days. The operations involved in water quality assessment are many and complex .The quality of water indices estimation endeavour single value which decrease the big quantity of parameters and represent data in a simple way which make easy interpretation of monitoring data. Several national and international agencies involved in water quality assessing and pollution control defines water quality criterion for different uses of water considering different indicator parameters. In this review paper, various WQI indices are discussed which are used for assessing surface water quality.**

Keywords**: WQI, ecology, Coliforms, DO, BOD**

INTRODUCTION

Water is the prime natural resource. Ample degree of freshwater is eminent for biological needs are a vital side of integrated environmental management and sustainable development. The surfaces water bodies like rivers, reservoir, lake, ponds etc, which are the important sources are unfortunately under severe environmental stress due to anthropogenic activities, industrialization, intense agricultural activities, urbanization, and discharge of untreated waste directly or indirectly into it [1].Water allows us to live but it could be harmful to our bodies when polluted [2]. Therefore regular water quality monitoring of the water resources are absolutely necessary to assess the quality of water for ecosystem health and hygiene, industrial use, agricultural use and domestic use [3]. Calculation of water quality index is based on number of physico-chemical and bacteriological parameters. The advantage of number of water quality indices developed is they give efficiently the overall water quality of a specific area. [3].Due to its capacity of reducing the bulk water quality information, and that is easy to understand , thus this method gains more popularity worldwide [7][8]. WQI enables us to classify the water sources according to its WQI values that indicates its quality status at a glance and helps in comparison, management, treatment etc. [7] Various scientists, agencies, experts formulated numerous of WQIs all over the world. For example weighted arithmetic water quality index, National sanitation foundation water quality index, bhargava's index, the river ganga index etc [9]. In this review paper, various water quality index are discussed and their approaches to calculate WQI value.

WATER QUALITY INDICES

The concept of WQI was firstly introduced by Horton in 1965 in United states using 10 common water quality parameters like DO, Ph, coliforms, specific conductance, alkalinity and chloride etc 1970 brown developed very similar WQI to Horton WQI based on weights to individual parameters. Further various experts and scientist came and apply different concept on WQI [11] such as The US National Sanitation Foundation Water Quality Index (NSFWQI), Florida Stream Water Quality Index (FWQI), British Columbia Water Quality Index (BCWQI), Canadian Water Quality Index (Canadian Council of Ministers of the Environment (CCME) and the Oregon Water Quality Index (OWQI) are frequently used WQI. WQI developed in India is a pioneer work of Bhargava, gives water quality in the range of 0-100 where 0 represents extremely polluted water and 100 represents unpolluted water representing the integrated impact of the parameters amplifying the pollution load [5].

Categories of WQI

In general, water quality indices are categorised into four main groups [34].

First, Public indices: These indices ignore the type of water consumption within the analysis method and used for general water quality, like National Sanitation Foundation Water Quality Index (NSFWQI) [48].

Second, specific consumption indices: The classification of water is on the premise of the type of consumption and application as drinking, industrial and ecosystem preservation etc. such as the Oregon and British Columbia indices [20].

Third, designing or planning indices: This class act as an instrument in planning water quality management projects and aiding decision making.

Fourth, statistical indices: These indices do not consider personal opinion and are based on statistical methods. Statistical approaches are used here for evaluating the data.

First three indices are also called as expert opinion (EO) approach. Due to different weights given for the same variables by various panel of experts EO becomes a subjective approach [30].

WQI APPROACH PROCEDURE

A. Variable Selections: For this monitoring of water samples is necessary for raw data generation. Once the raw data is generated variables are transformed.

B. Determination of quality function for each variable considered as sub-index:- various variables have different units as well as range. By transformation process all the selected parameters are transformed into common scale and sub-indices generated. Weight ages are assigned to each variable according to potential impacts. Expert opinion is needed to assign weights.

C. Aggregation Mathematical function of subindices:-Generally, arithmetic or geometric averages are considered to generate cumulative index value.

And finally, assessment and classification of water quality is done.

A REVIEW OVER DIFFERENT APPROCHES TO CALCULATE WQI

Weighted Arithmetic Water Quality Index:

Weighted Arithmetic Water Quality Index method classified the water quality according to the degree of purity by using the most commonly measured water quality variables [12].

The calculation of the WQI was done using weighted arithmetic water quality index which was originally proposed by Horton (1965) and developed by Brown et al (1972).[10][11]

The weighted arithmetic WQI method was applied to assess water suitability for drinking purpose. In this method, water quality rating scale, relative weight and overall WQI were calculated by following formulae [11]:

$$WQI = \sum^{n}_{i=1} WiQi / \sum^{n}_{i=1} Wi$$

q n values are given by the relationship.

$$qn=100\ (vn-vi) / (vs-vi)$$

vs = Standard value, vn = observed value vi = ideal value In most cases vi =0 except in certain parameters like pH, dissolved Oxygen etc,

Calculation of quality rating for pH & DO (vi ≠0) q

$$pH = 100\ (v\ pH – 7.0) / (8.5 – 1.0)\ q\ ,\ DO = 100\ (VDO – 14.6) / (5.0-14.6).$$

Calculation of unit weight: The Unit weight (Wn) to various water Quality parameters are inversely proportional to the recommended standards for the corresponding parameters

Wn = k/sn. Where, wn = unit weight for nth parameter, sn = standard permissible value for nth parameter, k = proportionality constant and can also be calculated by using the following equations:

$$k = 1/\sum 1/sn$$

Table 1: Water Quality Rating as per Weight Arithmetic Water Quality Index Method [12]

WQI Value	Rating of Water Quality Bottom
0-25	Excellent water quality
26-50	Good
51-75	Bad
76-100	Very Bad
100 & above	Unsuitable for drinking purpose .

National Sanitization Foundation Water Quality Index [13]:

A commonly-used water quality index (WQI) was developed by the National Sanitation Foundation (NSF) in 1970 (Brown and others, 1970). [11] Water quality index developed by Brown et al. using Delphi method was done by selecting parameters rigorously, developing a common scale and assigning weights to the parameters. National Sanitation Foundation (NSF) supported this index so also called as NSFWQI. It has been mentioned in many papers because it's the most comprehensive work [10][38]. Based on experts opinion rating curves are developed to attribute values for variation in the level of water quality caused by different levels of each of the selected parameters. The mathematical expression for NSF WQI is given by,

$$WQI=\sum^{n}_{i=1} WiQi$$

Where, = sub-index for ith water quality parameter; Wi= weight associated with i_{th} water quality parameter; n = number of water quality parameters.

Table 2: Water Quality Rating as per different Water Quality Index methods National Sanitation Foundation Water Quality Index (NSFWQI)[12]

WQI Value	Rating of Water Quality
91-100	Excellent water quality
71-90	Good
51-70	Medium
26-50	Bad
0-25	Very Bad

Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI):

CCMEWQI is based on a formula develop by the British Columbia Ministry of Environment, Lands and parks and modified by Alberta Environment [8][15]. The index incorporates three elements:

Scope:-the number of variables not meeting water quality objectives;

Frequency:-the number of times these objectives are not met;

Amplitude:-the amount by which the objectives are not met.

The index gives a number between 0(worst water quality) and 100(best water quality).These number are divided into 5 descriptive categories to simplify presentation [8][15][16][17]. It is recommended that at a minimum, four calculations of index values. This index is useful tool for describing the state of the water column, sediments and aquatic life and for ranking the suitability of water for use by humans, aquatic life, wildlife etc. Once the CCME WQI value has been determined, water quality is ranked by relating it to one of the following categories [8]:

Table 3: Water Quality Grading as per CCMEWQI [12]

Grading	CCME WQI	Water Quality Status
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.
Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
Marginal	45-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
Poor	0-44	Water quality is protected almost always threatened or impaired; airment; conditions rarely depart from natural or desirable levels.

The calculation of index scores in CCME WQI method can be obtained by using the following relation:

$$WQI = [100 - (\sqrt{F_1^2 + F_2^2 + F_3^{\ 2}} /1 .732)]$$

Scope (F1) = [No. of failed variables /Total no. of variables]*100

Frequency (F2) = [No. of failed tests/Total no. of tests]*100

Amplitude (F3) (a) excursioni = [Objectivej /failed test valuei]-1

(b) Normalized sum of excursions (nse) = excursionsi /No of tests

(c) F3 = [nse/ (0.01nse+0.01]

Oregon Water quality index (OWQI):

The Oregon Water Quality Index (OWQI) is a single number that expresses water quality by integrating measurements of eight water quality variables (temperature, dissolved oxygen, biochemical oxygen demand, pH, ammonia+nitrate nitrogen, total phosphorus, total solids, and fecal coliform [9][4][12]. Its purpose is to provide a simple and concise method for expressing the ambient water quality of Oregon's streams for general recreational use, including fishing and swimming [18][19][20].

The index employs the concept of harmonic averaging. The mathematical expression of this WQI method is given by-

$$OWQI = \frac{n}{\sqrt{\sum_{i=1}^{n} \frac{1}{SI_i^2}}}$$

Where, n = number of sub indices SI = sub index of ith parameter. Furthermore, the rating scale of this OWQI has also been categorized in various classes, which are given under Table-

WQI Value	Rating of Water Quality
91-100	Excellent water quality
85-89	Good
80-84	Fair
60-79	Poor
0-59	Very Poor

British Columbia Water quality index (BCWQI):

This index is very similar to Canadian council of ministers of the environment water Quality Index (CCMEWQI) where water quality parameters are measured and their violation is determined by comparison with a predefined limit[4][9][21]. To calculate final index value the following equation is used:

$$WQI = [100 - (\sqrt{F_1^2 + F_2^2 + F_3^2} / 1.453)]$$

This number 1.453 was selected to give assurance to the scale index number from zero to 100[12].Disadvantage of this index does not indicate the water quality trend until it deviates from standard limit and due to usage of maximum percentage of deviation, it cannot determine the number of withdrawals above the maximum limit of standard.[4][9][12].

Bhargava method

Bhargava identified 4 groups of parameters. Each group contained sets of one type of parameters. Coliform organisms were included in the first group which represent the bacterial quality of drinking water. Heavy metals and toxicants were included in the second group. The third group included parameters that cause physical effects, such as odour, colour, and turbidity. Organic and inorganic substances such as sulphate and chloride, etc were included in the fourth group. The simplified model for WQI is given by

$$WQI^{n}_{i=1} = [\pi \text{ fi (pi)}]^{1/n} \times 100$$

Where, n = number of of relevant variables

fi(Pi) = function of sensitivity of the ith variable including the effect of weighting of the ith variable.

Smith's index

Index developed by Smith is hybrid of the two common index and based on expert opinion as well as water quality standards used for four water uses i.e., contact as well as non-contact. Delphi method was used for the selection of parameters for each water class, developing sub indices, and assigning weightages. Final index score was calculated using minimum operator technique:

$$I_{min} = \sum \min (I_{sub1}, I_{sub2}, \ldots\ldots I_{subn})$$

Where, I_{min} equals the lowest sub index.

The River Ganga Index:

Water Quality of ganga river was evaluated using this Index of Ved Prakash et al. The four important water quality parameters-dissolved oxygen (DO), Biochemical Oxygen Demand (BOD), pH and fecal coliforms[13]. This WQI is based on the weighted multiplication form and is given by the equation:

$$WQI = \sum^{p}_{i=1} \text{Wi li=1}$$

Where, I i = subindex for the ith quality parameters; Wi = weight associated with the ith water quality parameters; P= number of water quality parameters. The developed index was employed to evaluate the water quality profile of river Ganga in its entire stretch and to identify area requiring urgent pollution control measures [14]. Where, Pi=pollution index for ith a parameters.

Overall Index of Pollution Index (OIP):

This index was developed in order to assess the status of surface waters in Indian conditions specifically by Sargoanker et al. at NEERI Nagpur, India[4][9]. Sargaonkar and Deshpande developed OIP for Indian rivers based on measurements and subsequent classification of pH, turbidity, dissolved oxygen, BOD, hardness, total dissolved solids, total coliforms, arsenic, and fluoride [26][27]. According to WQI value classified the water Excellent, Acceptable, Slightly polluted and heavily Polluted, according to Indian Guidelines/WHO standards /Eupropean standards. The mathematical Expression:

$$OIP = \sum Pi / n$$

Where, Pi = pollution index for ith parameters, n= number of parameters.

Dinius's Water Quality Index (1972):

This index broke new ground in the sense that through it an attempt was made to design to rudimentary social accounting which would measure the costs and impacts of pollution control efforts [4][9]. Dinius's examined the water quality described by various authorities to different levels of pollution variables, and from this information generated 11 sub index equations [27]. The index was calculated as the weighted sum of the subindices, like Horton's index and the additive version of the NSFWQI:

$$IWQ = \sum_{i=1}^{n} I_i^{W_i}$$

The weights ranged from 0.5 to 5 on a basic scale of importance. On this scale, 1,2,3,4 and 5 denote, respectively, very little, little, average, great and very great importance. The sum of the weights was 21 which is the denominator in the index equation. The index was applied in several streams Albama, USA by Dinius [4][9][27].

Mcduffie and Haney's River Pollution Index:

It is relatively simple water quality index in which eight pollutant variables are included [9][28]. Most subindices are of the general linear form:

IA Proposed River Pollution Index =*X*/ Xn

Where,

Ii is the subindices of the ith pollutant variable. X is the observed value of the pollutant variable. Xn is the natural level of the pollutant variable.

Six out of eight subindices described by Mcduffie and Haney were explicit linear functions, and two (coliform count and temperature) were explicit nonlinear functions [9]. The index does not include Ph and toxic substances [28]. The overall index is computed as the sum of n subindices times a scaling factor 10/n+1:

$$RPI = \frac{10}{n+1}\left(TF + \sum_{i=1}^{n} 10 \times I_i\right)$$

Here, TF is the temperature factor and n is the number of parameters other than temperature.

Stoner's Index:

This index, aimed for use in public water supply and irrigation, employed a single aggregation function which selects from 2 sets of recommended limits and subindex equations [4][9][29]. Two types of water quality parameters are used in the stoner's index:

Type I parameters normally considered toxic at low concentrations (eg. Lead, Radium-226). Type II which affects aesthetic and health characteristics (e.g, Chlorides, sulphur, odour, taste). The type I pollutant variables were treated in a dichotomous manner, giving subindex step functions. Each value of Type 1 assigned value Zero if the concentration is less than or equal to the recommended limit and the value 100 if the recommended limit is exceeded [9]. The Type II pollutant variables are represented by explicit mathematical function. The overall index was computed by combining the unweighted type I subindices with the weighted type 2 subindices[13]:

$$WQI=\sum_{i=1}^{m} Ii + \sum_{j=1}^{n} Wj Ij$$

Where,

Ii is the subindex for the i_{th} type I pollutant variable, Wj is the weight for j_{th} type II pollutant variable, Ij is the subindex for j_{th} type II pollutant variable.

Ground Water Quality Index of Soltan (1999):

Soltan proposed a WQI based a WQI based on 9 water quality parameters including heavy metals to assess the water quality from artesian wells located near Dkhala oasis, Egypt [9][30]. The indices for individual parameters were calculated as follows-

$$WQI= \sum^{n}_{i=1} (q_n)$$

Where, qi= 100 X Vi/ Si

The average water quality index for n parameters was calculated using the expression

$$AWQI= \sum^{n}_{i=1} (q_n)/n$$

Where, n is the parameters and qi is quality rating of ith parameters. $V\ i$ is the observed value of the ith parameters And Si is the water quality standard for the ith parameters. The permissible or critical pollution index value was set at 100. The AWQI has a value of 0 when all pollutants reach their permissible limits. AWQI values exceeding 100 indicate that the water sample may suffer from serious pollution problems [9][30].

Recreational Water Quality Index (RWQI)

Ideally, recreational water quality indicators are microorganisms or chemical substances whose concentrations can be quantitatively related to swimming and associated to health hazards. Selection of parameters has great importance to RWQI calculation because rigidity problems exist when additional variables are included in the index to address specific water quality concerns, but the faulty aggregation function might artificially reduce the value of the water quality index so that it does not accurately reflect the true water quality. As the number of water quality variables increases, the magnitude of the aggregated index decreases raising the issue of ambiguity again [35][9]. Numerical scales related to the degree of quality were established for each variable to assess variation in quality water and to convey findings in a comprehensive manner to others. These rating curves are, in fact, the essence of the development of this index. Rating curves have the ability to reproduce the relationship between swimming-associated illness and water quality indicator. The success or failure of the application of the quality index developed will depend on rating curves.

Once rating curves were established, various computing methods to water quality index are possible. The calculation of the proposed RWQI is (1):

$$RWQI = \prod_{i=1}^{n} . Qi^{Wi}$$

Where,

Qi is the rating value of parameter i and Wi is the weighting factors (ΣWi=1). Therefore, each analytical value is transformed in a non-dimensional value or quality level (Qi) through a mathematical equation or through its corresponding graphic representation. Wi is the influence of each parameter in the total value of the index. To calculate each of them, their individual weight must be considered. Wi is calculated as (2):

$$W_i = \frac{\frac{1}{ai}}{\sum \frac{1}{ai}}$$

The ai coefficient values vary from 1 (very important parameter) to 4 (less significant parameter) according to the importance assigned to each parameter involved in the index. In this way, the RWQI is calculated by the multiplication of all of the products of the parameter weights and sub index values (QiWi) (Eq. 1). RWQI is a number among 0 to 100, where values close to 100 represent the best quality [4][9][35]. This formulation avoids the problems of ambiguity and eclipsing to the number of water quality variables required to be aggregated in a given index. If the value of a sub-index is zero, RWQI has become zero automatically. Furthermore, weight factor of parameter allows obtain large changes to little variations for each one of different parameters. Besides, this formulation has great sensitivity to small parameter variations giving greater protection to people [35].

Comparison:-

Method	**Developed by**	**WQI**	**Purpose**	**Method of Aggregation**
Weighted Arithmetic Water Quality Index	proposed by Horton (1965) and developed by Brown et al (1972).[	$WQI = \sum^{n}_{i=1} WiQi / \sum^{n}_{i=1} Wi$	WQI method was applied to assess water suitability for drinking purpose	Additive aggregation(the subindices are combined through summation)
National Sanitization Foundation Water Quality Index	by the National Sanitation Foundation (NSF) in 1970 (Brown and others, 1970	$WQI=\sum^{n}_{i=1} WiQi$	Based on experts opinion rating curves are developed to attribute values for variation in the level of water quality.	Weighted Product

Canadian Council of Ministers of the Environment Water Quality Index	Canadian Council of Ministers of the Environment	$WQI = [100 -(\sqrt{F_1^2 + F_2^2 + F_3^2} /1.732)]$	This index is useful tool for describing the state of the water column, sediments and aquatic life and for ranking the suitability of water for use by humans, aquatic life, wildlife etc.	Arithematic aggregation
Oregon Water quality index	by the Oregon Department of Environmental Quality (ODEQ)	$OWQI = \frac{n}{\sqrt{\sum_{i=1}^{n} \frac{1}{SI_i^2}}}$	Its purpose is to provide a simple and concise method for expressing the ambient water quality of Oregon's streams for general recreational use, including fishing and swimming	Weighted product.
British Columbia Water quality index	develop by the British Columbia Ministry of Environment, Lands and parks and modified by Alberta Environment	$WQI = [100 - (\sqrt{F_1^2 + F_2^2 + F_3^2} /1.453)]$	water quality parameters are measured and their violation is determined by comparison with a predefined limit	Arithematic aggregation
Bhargava method	Bhargava	$WQI^{n}_{i=1} = [\pi \text{ fi (pi)}]^{1/n} \text{ x } 100$	Identified 4 groups of parameters	Multiplicative aggregation(the subindices are combined through Product operation)
The River Ganga Index	Ved Prakash	$WQI = \sum^{p}_{i=1} Wi \; li=1$	based on the weighted multiplication form	Multiplicative aggregation(the subindices are combined through Product operation)
Overall Index of Pollution Index	Sargaonkar and Deshpande	$OIP = \sum Pi/n$	to assess the status of surface waters in Indian conditions	Multiplicative aggregation(the subindices are combined through Product operation)
Dinius's Water Quality Index	Dinius's	$IWQ = \sum_{i=1}^{n} I_i^{W_i}$	examined the water quality described by various authorities to different levels of pollution variables	Additive aggregation(the subindices are combined through summation)
Mcduffie and Haney's River Pollution Index	Mcduffie and Haney's	$RPI = \frac{10}{n+1}\left(TF + \sum_{i=1}^{n} 10 \times I_i\right)$	The RPI was applied on a test basis using data from Newyork State's water	Linear indices with weighted sum aggregation.

			quality surveillance network and other sources.	
Stoner's Index	Stoner	$WQI=\sum_{i=1}^{m} Ii + \sum_{j=1}^{n} Wjlj$	Water use in public water supply and irrigation	Non linear indices with Weighted sum
Ground Water Quality Index of Soltan	Proposed by Soltan (1999)	$WQI= \sum^{n}_{i=1} (q_n)$	based on 9 water quality parameters including heavy metals to assess the water quality from artesian wells	Additive aggregation(the subindices are combined through summation)
Smith Index	Proposed by Smith	$I_{min} = \sum min (I_{sub1}, I_{sub2}, \ldots\ldots I_{subn})$	based on expert opinion as well as water quality standards used for four water uses i.e., contact as well as non-contact	Logical aggregation(the subindices are combined through logical operation)

CONCLUSION:

The water quality varies according to the type of use. Drinking water standards varies with the region; time and prevailing condition thus affect WQI value. WQI are necessary for reducing large, multiple water quality data into single numeric value that makes easy to report to managers, and public. WQI value indicates its quality in simple and understandable manner. This, in turn, is essential for comparing water quality of different sources and helps in monitoring the changes in the water quality of a given source as a function of time and other influencing factors. The water quality and Index value significantly influenced with time of sampling. There is no universal WQI which can be applied on every water body of Earth. So, different agencies, scientists, experts give their own WQI based on regional condition, standards, purpose, parameters. So, the selection of WQI should be selected according to purpose like drinking purpose, aquatic life, bathing, industrial purpose, agricultural purpose etc and also according to resources like groundwater, river, aquifer etc. In all the water quality indices cited in literatures organic pollutants are not considered, because analysis of organics is too expensive. Otherwise most of the important water quality parameters are taken into account. There should be regular monitoring of water quality in order to detect changes in physicochemical parameters concentration and convey to the public. So these indices are useful tools to represent water quality in a simple and understandable manner.

REFERENCES:

1. K Yogendra and E T Puttaiah, Determination of water quality index and suitability of a urban waterbody in Shimoga Town, Karnataka, Sengupta, M and Dalwani, R.(Editors). 2008 Proceeding Taal2007: The 12th world lake Conference: 342-346.
2. Drinking water "2008".
3. Neerja Kalra*3, Rajesh Kumar1, S. S. Yadav2 and R. T. Singh3, Water quality index assessment of ground water in Koilwar block of Bhojpur (Bihar), Journal of Chemical and pharmaceutical Research, 2012, 4(3):1782-1786.
4. Tirkey Poonam, Bhattacharya Tanushree*, Chakraborty Sukalyan, water quality indices- important tools for water quality assessment: a review, international journal of advances in chemistry (ijac) vol.1, no.1, november 2015.
5. Ratna Kumar Srivastava and Deepti Pandey, Physico-chemical and Microbiological Quality Evaluation of Groundwater for Human Domestic Consumption in Adjoining Area of Omti Nallah, Jabalpur (M. P.), India, INTERNATIONAL JOURNAL OF ENVIRONMENTAL SCIENCES Volume 3, No 3, 2012.
6. Katyal, "Water Quality Indices Used for Surface Water Vulnerability Assessment," Int. J. Environ. Sci., vol. 2, no. 1, 2011.
7. Sourav Ray, 2 S. H. Bari, 3 S. D. Shuvro, Assessment of Water Quality of Goalichara: A Water Quality Index Based Approach, ARPN Journal of Science and Technology, VOL. 5, NO. 7, July 2015.
8. CCME WATER QUALITY INDEXES 1.0 User's Manual, In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg. © Canadian Council of Ministers of the Environment 2001 Excerpt from Publication No. 1299; ISBN 1-896997-34-1
9. Abbasi, Tasneem, and Shahid A. Abbasi. Water quality indices. Elsevier, 2012.
10. R. K. Horton, "An index numb er system for rating water quality," J. Water Pollut. Control Fed., vol. 37, no. 3, pp. 300–306, 1965.
11. R. M. Brown, N. I. McClelland, R. A. Deininger, and R. G. Tozer, "A WATER QUALITY INDEX DO WE DARE," Water Sew. Works, vol. 117, no. 10, pp. 339–343, 1970.

12. Shweta Tyagi1, Bhavtosh Sharma2,*, Prashant Singh1, Rajendra Dobhal2,3, Water Quality Assessment in Terms of Water Quality Index, American Journal of Water Resources, 2013, Vol. 1, No. 3, 34-38.
13. BASIN: The National Sanitation Foundation Water Quality Index, http://bcn.boulder.co.us/basin/ watershed/wqi_nsf.html.
14. Pradyusa Samantray*1, 2, Basanta K. Mishra3, Chitta R. Panda2 and Swoyam P. Rout1, Assessment of Water Quality Index in Mahanadi and Atharabanki Rivers and Taldanda Canal in Paradip Area, India, J Hum Ecol, 26(3): 153-161 (2009).
15. Landwehr J. M. &Deininger R. A., (1976) "A comparison of several water qualityindexes", J. Water Pollut. Control Fed.,Vol. 48, No. 5,pp 954.
16. Lakshmi. E1, Dr. G. Madhu2, An Assessment of Water Quality in River Periyar, Kerala, South India Using Water Quality Index , IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT).Volume 8, Issue 8 Ver. II (Aug. 2014), PP 11-16.
17. G. M. Munna1, M. M. I. Chowdhury2, A. A. Masrur Ahmed3*, Sadia Chowdhury1 and M. M. Alom1, A Canadian Water Quality GuidelineWater Quality Index (CCME-WQI) based assessment study of water quality in Surma River, Journal of Civil Engineering and Construction Technology Vol. 4(3), pp. 81-89, March 2013 Available online at http:// www.academicjournals.org/JCECT.
18. Dunnette D. A., (1979) "A Geographically Variable Water Quality Index Used in Oregon"J.Water Pollut. Control Fed., Vol.51, No.1, pp53-61.
19. Cude, C.G., "Oregon water quality index: a tool for evaluating water quality management effectiveness", J. American Water Resou. Assoc., 37(1). 125-137. 2001.
20. Hubler, S., Miller, S., Merrick, L., Leferink, R. and Borisenko, A., "High level indicators of Oregon's forested streams", Lab. Environ. Assess. Div., Hillsboro, Oregon. 2009
21. Salim N. A. A., Wood, A. K., Yusof, A. M., Hamzah, M. S.,Elias, M. S., and Rahman, S.A.,(2009) "A study of arsenic and chromium contamination in sediments of freshwater bodies".Fresenius Env.Bul.Vol.18, No. 9, pp1618-1623.
22. Bhargava D.S., (1983)"Use of water quality index for river classification and zoning of Ganga River", Environ. Pollut. Ser. B., England Vol.6, No. 1, pp51–67.
23. Bhargava D.S., (1983)"A light- penetration model for the rivers Ganga and Yamuna",Int.J. Dev. echnol.,Vol.1, No. 3, pp199–205.
24. Smith D. G., (1987) "Water Quality Indexes for Use in New Zealand's Rivers and Streams", Water Quality Centre Publication No. 12, Water Quality Centre, Ministry of Works and Development, Hamilton, New Zealand.
25. Smith D. G., (1990)"A better water quality indexing system for rivers and streams",Water Res., Vol.24, No.10, pp1237–1244.
26. CPCB,(2000).Water quality status of Yamuna River, Central Pollution Control Board, New Delhi, series ADSORBS/32/1999–2000.
27. Deeksha Katyal*, Ahmed Qader, Ali Hayder Ismail and Kiranmay Sarma, Water quality assessment of Yamuna River in Delhi region using index mapping Interdisciplinary Environmental Review, Vol. 13, Nos. 2/3, 2012
28. Ashok Lumb · T.C. Sharma · Jean-François Bibeault, A Review of Genesis and Evolution of Water Quality Index (WQI) and Some Future Directions
29. Tanja Srebotnjaka,⁎, Genevieve Carr b, Alexander de Sherbininc, Carrie Rickwoodd, A global Water Quality Index and hot-deck imputation of missing data, ELSEVIER journal homepage: www.elsevier.com /locate/ecolind 2011
30. Gopal Krishan, Surjeet Singh, Suman Gurjar, Kumar CP and Ghosh NC, Water Quality Assessment in Terms of Water Quality Index (WQI) Using GIS in Ballia District, Uttar Pradesh, India, Journal of Environmental & Analytical Toxicology, April 08, 2016, Volume 6 • Issue 3• 1000366
31. House M. A. and Ellis J. B., (1980) "Water quality indices: An additional management tool?" Progress. Water Tech.Vol.13, pp 336–344.
32. WATER QUALITY INDICES MARGARET. A. HOUSE Middlesex Polytechnic, Queensway, Enfield. 1986.
33. M.j. Pawari. Prof. Sagar gawande, Ground Water Pollution & Its Consequences, International Journal of Engineering Research and General Science Volume 3, Issue 4, July-August, 2015 ISSN 2091-2730.
34. Wepener V., Euler N., Van Vuren J. H. J., Du Preez H. H. and Kohler A., (1992) "The development of an aquatic toxicity index as a tool in the operational management of water quality in the Olifants River (Kruger National Park)", KoedoeVol.35, No.2, pp1–9.
35. Swamee P.K. and Tyagi A., (2007) "Improved method for aggregation of water quality subindices". J. Environ. Eng., Vol.133, pp220– 225.
36. APHA (2005) Standard methods for examination of water and wastewater, 21st edn. American Public Health Association, Washington.
37. BIS 2012 – Drinking water specification IS No. 10500. Bureau of Indian Standards.
38. Abhilasha Mehra1, Prof. R. K Bhatia2, Prof. Dr. Shailza Verma3, A Review of Different Approaches of Water Quality Indices, International Journal of Engineering Technology and Computer Research (IJETCR).