Water quality indices- important tools for water quality assessment: a review

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WATER QUALITY INDICES- IMPORTANT TOOLS FOR WATER QUALITY ASSESSMENT: A REVIEW

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ABSTRACT

Water quality is a significant criterion in matching water demand and supply. Ample degree of freshwater is eminent for biological needs are a vital side of integrated environmental management and sustainable development. The quality of water indices estimation endeavour single value which decrease the big quantity of parameters and represent data in a simple way. This review includes various water quality indices (WQI) used in the surface water quality assessment. There are numerous WQI specific for any region because many National and International agencies define water quality criteria for various uses considering various parameters in water quality assessment and pollution control. Different WQI developed; their background and application area has been mentioned here.

KEY WORDS

Water Quality, index, review, water parameters, quality scale

1. INTRODUCTION

Water is the prime natural resource. Accepting this importance and short supply of means for biological needs and uphold for economic and growth activities of all kinds is a matter of highest concern.

In this modern era there is a huge decline in freshwater may be due to the population increase, urbanization, industrialization, and concentrated agricultural actions. The insufficient availability of surface water makes people dependent on ground water resources to fulfil their needs. Numerous towns and cities fulfil their demand from ground water and surface water through municipality and also from various concealed boreholes. 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. The water quality evaluation may be complicated practice in compound parameters causing numerous anxieties in general quality of water [8]. It is not easy to assess water quality for huge samples containing concentrations for many parameters [2]. The Conventional methods for evaluating quality of water are based on the comparison of experimentally determined parameter values with the existing guidelines [19]. So, water quality indices are such approaches which minimises the data volume to a great extent and simplifies the expression of water quality status. 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. Examples of different water quality indices developed worldwide are US National Sanitation

Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), British Columbia Water Quality Index (BCWQI), and Oregon Water Quality Index (OWQI) [1][35][40][63]. These indices give water quality in a single value by comparing different parameters as per the standards. In this present paper a review of different water quality indices are presented.

2. WATER QUALITY INDICES

A brief history

In the mid-twentieth century water quality was categorized by Horton in 1965 [32]. Then in 1970 Brown et al. developed a general Water quality index (WQI) [10]. In 1982 Steinhart et al. applied a novel environmental quality index to sum up technical information on the status and trends in Great Lakes ecosystem [69]. In the mid-1990s WQI was introduced in Canada by the water quality guidelines task group of CCME [23][29][53]. 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. CCME WQI, certified by the Canadian Council of Ministers of the Environment is the modified form of original BCWQI [57]. 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]. To develop cost effective pollution control strategies is the biggest challenge for developing countries. Therefore, Ongley in 1998 suggested, for such situations only few critical parameters must be used to evaluate WQI [46][47]. Many researchers has applied water quality index for representing the quality status post monitoring and analysis. Different WQI are given in **Table 1.**

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. The essential part of statistical approach is relevance bound assumptions of water quality observations. 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]. Reducing objectivity and comparability are possible because of the different ratings given by the experts. So, many alternative indexes were developed. By using statistical approaches subjectivity assumptions can be reduced in developing indices. Statistical approaches are also beneficial in identifying the significance of important parameters in water quality assessment [42].

Basic procedure of WQI development

For expert opinion approach first requirement for water quality index development is variable selections. For this monitoring of water samples is necessary for raw data generation. Once the raw data is generated variables are transformed. Different statistical approaches can be used for transformation. Various parameters have different units as well as range. By transformation process all the parameters are transformed into a common scale and sub-indices are generated. Weightage is assigned to each parameter according to their importance and potential impacts on the water quality. Expert opinion is needed to assign weights. Some indices developed by Sargaonker, Prati, aquatic toxicity index did not use weight assignment. Next step is aggregation of the sub-indices to generate a cumulative index value. And finally, assessment and classification of water quality is done [47]. The large amount of data presents challenges for the extraction of meaningful information of water quality parameters. In exploring structure and relationships in multivariate data for aggregation and transformation steps of index development various statistical approaches such as factor analysis (FA), cluster analysis (CA), discriminant analysis (DA) and principal component analysis (PCA) are widely used. Even artificial intelligence like fuzzy logic can be used in this approach [37]. Using statistical approaches reduces subjective assumptions and improves accuracy of the index.

3. Review of different types of water quality index

I National Sanitation Foundation Water Quality Index (NSFWQI)

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.

Computing a water quality index is possible by established rating curves and associated weights, such as Additive index

$$\mathrm{WQI} = \sum_{i=1}^{n} W_i Q_i$$
$$\mathrm{I} = \sum_{i=1}^{n} I_i W_i$$

Where, $\sum_{i=1}^{n} W_i = 1$, I_i= Sub-index of each parameters, W_i= Weighting factor, Q_i = is the rating value of parameter i and n= Number of sub-indices.

II. Oregon Water Quality Index (OWQI)

The Oregon Water Quality Index, developed by the Oregon Department of Environmental Quality (ODEQ) in the late 1970s and updated several times since then is another frequently used WQI in public domain [17]. However, the original OWQI was discontinued in 1983 on account of the enormous resources required for calculating and reporting the results. With the advancements in the computer technology, enhanced tools of data display and visualization and a better understanding of water quality, the OWQI was updated in 1995 by refining the original sub-indice, adding temperature and total phosphorus sub-indice, and improving the aggregation calculation. OWQI is calculated by integrating values of eight water quality variables. It was applied for the ambient water quality of Oregon's stream but in its application in other geographic regions or water body caution should be taken. OWQI developed in the 1970's has improved markedly the science of water quality [24]. The original OWQI was modelled after the NSFWQI where the Delphi method was used for variable selection [43][18]. Delphi method was employed to develop recreational water quality index. To deal with a complex problem this technique can be used for structuring information based on group of experts to get good concord based on best available knowledge[54][39]. Both indices used logarithmic transforms to convert water quality variable results into subindex values. Index transforms make the most of the actual fact that an amendment in magnitude at lower levels of impairment incorporates a bigger impact than Associate in Nursing equal amendment in magnitude at higher levels of impairment.

1. Weighted arithmetic mean function was used in the original OWQI.
WQI = $\sum_{i=1}^{n} SI_i W_i$
2. Weighted geometric mean function was used in the NSF WQI (McClelland, 1974)
Water Quality Index = $\prod_{i=1}^{n} SI^{W_i}$

Where, SI_i= Sub-index of each parameters, W_i= Weighting factor, n= Number of sub-indices.
The weighted arithmetic mean formula can be improved by the un-weighted harmonic square mean formula to aggregate sub-index results [22]. The advantage of this WQI is that it allows the most impaired variable to impart the greatest influence on the WQI and it gives the significance of different variables on overall water quality at different times and locations. The formula is given by:

$$WQI = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{SIi^2}}}$$

III. 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:

$$WQI = \prod_{i=1}^{n} fi(Pi)^{1/n}$$

Where, n = number of of relevant variables

fi(Pi) = function of sensitivity of the i^{th} variable including the effect of weighting of the i^{th} variable

This WQI was applied to the raw data in the stretch of river Yamuna at Delhi, India [6][7].

IV. 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 value [67][68].

V. British Columbia Water quality Index (BCWQI)

In 1995, BCWQI was developed by the Canadian Ministry of Environment as increasing index for water quality evaluation. This index is 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 (discussed in section vi below).

BCWQI makes possible the classification on the basis of all existing measurement parameters. Following equation is used to calculate final index value:

$$\text{BCWQI} = 100 - \left(\sqrt{\frac{F_1{}^2+F_2{}^2+F_3\,/3^2}{1.453}}\right)$$

In the formula 1.453 is the number used to give assurance to the scale index number from 0-100. Accuracy of the British Columbia Index depends upon the repeated samplings and number of stations. Due to the use of maximum percentage of deviation the water quality trend deviates from the standard limit and it cannot determine the number of withdrawals above the maximum limit which is the major drawback of BCWQI [58].

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

For simplifying complex and technical water quality data, a water quality index has developed by the Canadian Council of Ministers of the Environment (CCME) [12]. The CCME WQI is a science-based communication tool that tests multi-variable water quality data against specified water quality benchmarks determined by the user. The WQI mathematically combines three measures of variance (scope, frequency and magnitude) to produce a single unit less number that represents overall water quality at a site relative to the benchmark chosen (e.g., protection of aquatic life). End result is represented as single unit-less number ranging from 0-100 where 100 indicates that the variables were similar to the selected benchmarks or below the benchmark. To simplify, the CCME developed a calculator that is a pre-programmed spreadsheet with mathematical equations that helps users evaluate the condition (or health) or a water body. In the assessment of spatial and temporal changes in water quality CCME WQI is used which is based on Canadian Water Quality Guidelines [27][28]. In brief, the Canadian Water Quality Index (CWQI) equation is calculated using three factors as follows:

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

Where:

F_1 represents Scope: The percentage of variables above the guideline
F_1= [No. of variables whose objectives are not met /Total no of variables]*100;
F_2 represents Frequency: The frequency by which the objectives are not met
F_2= [No of tests whose objectives are not met /Total no of tests]*100;
F_3 represents Amplitude: The range to which the failed tests are above the guideline
(a) Range/Excursion$_i$ = [Failed test value/Objective$_j$]-1
(b) nse = $\sum_{i=1}^{n} Excursion$/No of tests
(c) F_3= [nse/0.01nse+0.01]

The constant, 1.732, is a scaling factor (square root of three) to ensure the index varies between 0 and 100.

To represent measurements of variety of variables in a single number and to combine various measurements with variety of measurements in a single metric are the advantage of the CCME WQI. The limitations of the CCME WQI include the loss of information by combining several variables to a single index value, the loss of interactions among variables, the lack of portability of the index to different ecosystem types and the sensitivity of the results to the formulation of the index [75]. The CCME WQI was not developed to replace detailed variable analysis, but rather as a tool to help water managers communicate overall quality of water in a more consistent and on-going manner.

VII. Overall Index of Pollution (OIP)

It was developed by Sargaonker et al. at National Environmental Engineering Research Institute (NEERI), Nagpur, India in order to assess the status of surface waters, specifically under Indian conditions. Based on classification schemes developed by CPCB and one proposed by Prati et al. a general classification scheme has been formulated [52]. OIP developed by Sargaonkar and Deshpande for Indian rivers is based on measurements and subsequent classification of hardness, total dissolved solids, pH, dissolved oxygen, BOD, turbidity, arsenic, fluoride and total coliforms [61]. According to BIS, WHO and European Community standards water quality observations are classified in six categories. The categories are: heavily polluted, polluted, slightly polluted, acceptable and excellent. OIP was calculated as the average of each pollution index assigned to each observation.

$$\text{OIP} = \frac{\sum_i P_i}{n}$$

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

VIII. The River Ganga Index

As the name indicates it was developed for the water quality assessment of river Ganga. It is based on NSFWQI with weighted multiplication form as set by Central Water Pollution Board, India with slight modifications in the weightages. Four important water quality parameters- dissolved oxygen (DO), biochemical oxygen demand (BOD), pH and fecal coliform were selected through Delphi. A weighted sum aggregation function was used to evaluate the overall water quality index.

$$WQI = \sum_{i=1}^{P} w_i I_i$$

where *Ii* = subindex for the *i*th water quality parameter; *wi* = weight associated with the *i*th water quality parameter; *P* = water quality parameters. This index was used for water quality assessment of river Ganga and to find out the highly polluted areas in the stretch of the river requiring immediate pollution control measures [15].

IX. 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. Additional variables causes rigidity problem when included so parameters should be carefully selected for RWQI calculation, but water quality index does not give true water quality due to the faulty aggregation function. Magnitude of aggregated index decreases with increasing water quality variables resulting in ambiguity [71].

Numerical scales related to the degree of quality were established for each variable to assess variation in quality of 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. A quality index developed is how much successful is dependent 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):

$$\text{RWQI} - \prod_{i=1}^{n} Q_i^{W_i} \qquad (1)$$

Where, Q_i is the rating value of parameter i and W_i is the weighting factors ($\Sigma W_i=1$). Therefore, each analytical value is transformed in a non-dimensional value or quality level (Q_i) through a mathematical equation or through its corresponding graphic representation.

In the total value of the index W_i is the affect of each parameter. To calculate each of them, their individual weight must be considered.

W_i is calculated as (2):

$$W_i = \frac{\frac{1}{a_i}}{\Sigma\frac{1}{a_i}} \qquad (2)$$

The a_i 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 ($Q_i^{W_i}$) (Eq. 1). RWQI is a number among 0 to 100, where values close to 100 represent the best quality.

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.

X. Water quality index

According to Couillard and Lefebre, a WQI is an algorithm that expresses a measure of the qualitative state of the water. This may be obtained by either deductive or inductive method [69]. The final result can be a symbol or a simple combination of numeric and alphanumeric variables.

Water Quality Index (WQI):

Assigning weight to parameters - w_i (i)

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad \text{(ii)}$$

Where, W_i = relative weight

n = number of parameters

$$q_i = \frac{C_i}{S_i} \times 100 \qquad \text{(iii)}$$

Where, $q_i =$ is the quality rating

$C_i =$ is the concentration of each chemical parameter in each water sample in milligrams per litre

$S_i =$ is the standard for each chemical parameter in in milligrams per litre

$$SI_i = W_i \times q_i \quad \text{(iv)}$$

Where, $SI_i =$ is the sub-index of ith parameter

$$\text{WQI} = \sum SI_i \quad \text{(v)}$$

Classification of water quality index is done as excellent (index range >80-100), good (index range >60-80), moderate (index range >40-60), bad (index range >20-60) and very bad (index range >0-20) [70][71].

The weighted individual values of the parameters measured in the field or laboratory as physical, chemical or biological are included in the global value for water conditions provided by the WQI developed by Bascaran in 1979. While this assessment may be carried out with the physical–chemical components from a normal water analysis (major ions, pH, temperature and electrical conductivity), the greater the amount of elements, the better the accuracy of the estimation. For the estimate, a weight and percent value were assigned according to the concentrations, or values, in question and the following relationship [13]:

$$\text{ICA} = K\frac{\sum C_i P_i}{\sum P_i}$$

Where

C_i percent value function assigned to the parameters
P_i weight assigned to each parameter
K is a constant whose values are 1.0 for clear waters with no apparent contamination, 0.75 Waters with slight colour, scum, apparent non-natural turbidity, 0.50 for Water with polluted appearance and strong odour, 0.25 for black waters that present fermentations and odours.

For each sample assessed, the sum of the weighted parameters being considered is calculated and multiplied by a constant related to the sample's sensitivity features, such as appearance and water odour. The parameters frequently used are: major ions, biochemical oxygen demand (BOD), dissolved solids or those in suspension, nitrogen compounds, phosphorous sulphur, pH, hardness, turbidity, electrical conductivity and toxic and pathogenic elements. The major ions were used for assessing WQIs in the Mexico Basin. The ICA indices range from 0 to 100, and quality scales are 90-100 (Excellent), 80-90 (Acceptable), 70-80 (Slightly polluted), 50-70 (Polluted), 40-50 (Strongly polluted), and 0-40 (Excessively polluted).

XI. Contamination index (CI)

The CI represents the sum of the individual factors of those components that exceed permissible values, as established by the EPA. This method makes possible to assess and map the degree of groundwater contamination. It takes into account ion elements and species that exceed permissible limits for human health, according to Environmental Protection Agency guidelines.
Assessment of the CI was carried out as follows:

$$C_d = \sum_{i=1}^{n} C_{fi}$$

$$\text{Where,} \quad C_{fi} = \frac{C_{Ai}}{C_{Ni}} - 1$$

C_{fi} is the contamination factor for the N^{th} component, N
=total number of parameters
C_{Ai} is the analytical value of the N^{th} component
C_{Ni} is the permissible superior concentration of the N^{th} component

This method uses the ion elements and species contained in the groundwater, as previously determined by chemical sample analysis done in the laboratory, and that exceed maximum limits permissible for human water consumption. Determination of CI is based on the sum of the individual factors of the components exceeding the permissible values according to the Official Mexican Standard NOM- 127-SSA1-1994, ‘‘Environmental health, water for human use and consumption—quality permissible limits regarding quality and treatment to which water must be submitted for its drinkability’’. It is worth pointing out that the NOM-127-SSA1-1994 does not consider a large number of physical–chemical parameters, or guidelines, to be employed for the estimation of a more detailed CI. Therefore, in order to use the majority of the analytical results obtained from the wells (DGCOH 1998), it was considered necessary to enrich the work by applying guidelines for human water consumption from the Ecological Water Quality Criteria (Mexico), the World Health Organization (WHO) and the European Economic Community (CEE); hence, it was possible to perform contamination mapping with a greater degree of sensitivity. The negative values obtained were not considered for the CI map. They are related to the main recharge zones (which do not have apparent contamination); only values greater than zero were considered [4].

XII. Aquatic Toxicity Index (ATI)

It was developed by Wepener et al. to assess the health of aquatic ecosystems. Since extensive toxicity database are available for fishes, the toxic effects of different water quality to fishes have been employed as health indicators of the aquatic ecosystem [73]. The physical water quality parameters employed were pH, dissolved oxygen and turbidity while the chemical determinant included ammonium, total dissolved salts, fluoride, potassium and orthophosphates and the potentially hazardous metals chosen were total zinc, manganese, chromium, copper, lead and nickel concentrations. An ATI scale, similar to the WQI scale proposed by Smith for salmonid spawning was used. The Solway modified un-weighted additive aggregation function was initially employed to aggregate the values obtained from the rating curves [33].

$$I = \frac{1}{100} \cdot \left(\frac{1}{n} \sum_{i=1}^{n} q_i \right)^2$$

Where *I* is the final index score, *qi* is the quality of the *i*th parameter (a value between 0–100) and *n* is the number of determinants in the indexing system. Wepener et al. didn't employ the weighted sum system, as too little information is available about the importance of one determinant compared to another under different local conditions and the inherent chemistry of the system as a whole.

XIII. Dinius Water Quality Index (DWQI)

It is a multiplicative water quality index developed by Dinius for six categories of water uses: public water supply, recreation, fish, shellfish, agriculture and industry. He employed the liberal use of Delphi for decision making. The index included 12 parameters: dissolved oxygen, 5-day BOD, coliform count, E-coli count, pH, alkalinity, hardness, chloride, specific conductivity, temperature, colour and nitrate. The weightage of each parameter was assigned based on the evaluation of importance by the Delphi panel members [21]. The individual sub-index functions were combined with the help of a multiplicative aggregation function as follows

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

Where, IWQ is the Dinius water quality index whose value ranges from 0–100, *Ii* is the sub-index function of the pollutant parameter, *Wi* is the unit weight of the pollutant parameter whose value ranges from, 0–1 and n is the number of pollutant parameters.

4. CONCLUSION

The water quality varies according to the type of use. Acceptable water quality criterion depends upon the prevailing conditions and it varies from time to time and region to region. For resolving large multi-parameter water analysis data into single digit scores, water quality indices are necessary. Thus, water quality index plays a major role in water quality assessment of a given source as a function of time and other influencing factors. Time of the sampling also significantly influences water quality parameters and hence the index value. However, it is extremely difficult to develop a universally acceptable general water quality index. But researchers may develop region and source specific water quality index. Most of the developed water quality indices are surface water specific and there is ample scope to develop groundwater quality index. NSF WQI, CCME WQI and WQI are water quality indices which are frequently used for water quality assessment. CCME and BCWQI are most efficient for low parameter values. General WQI is an efficient one but parameters should be carefully selected depending on the source and time. Smith's index gives a better aggregation of datasets. The main drawback of NSFQI is the eclipsing effect. Due to this affect one or more parameters which have values above permissible limit are masked if rest of the parameters are within the limits. 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 is need for regular monitoring of water quality in order to detect changes in physiochemical parameters concentration and convey it to the public. So these indices are very helpful tool to represent water quality in a simple and understandable manner.

Table 1: List Of Selected Studies Carried Out Worldwide Using Water Quality Indices

Workers	**Year of publication**	**Type of Work**	**Index used**
Tiwari and Mishra[72]	1985	Water quality index of major Indian rivers	Water Quality index
Singh[66]	1992	Water quality index of some major rivers of Pune, Maharashtra	WQI
Wills and Irvine[74]	1996	Water quality assessment in Cazenovia creek New York in watershed management project	NSFWQI
Subba Rao[70]	1997	Water quality index in hard rock terrain of Guntur district, Andhra Pradesh, India	WQI
Zanderbergen et al.[76]	1998	Water quality of two small water shed in Greater Vancouver area	BCWQI
Pesce and Wunderlin[51]	2000	Water quality of the Suquia River (Argentina)	WQI
Mishra and Patel[44]	2001	Pollution load in the drinking water of Rairangpur, A small tribal dominated town of North Orissa	WQI
Naik and Purohit[45]	2001	Water quality of river Brahmani in Sundargarh district, Orissa	WQI
Rudolf et al.[55]	2002	Effect of industrial and municipal effluents on the waters of San Vicente Bay (Chile) by using DO content as an index of water quality	WQI
Sargaonkar et al.[61]	2003	Water pollution load of Yamuna river	Overall index of pollution
Said et al.[57]	2004	Big Lost River Watershed in Idaho	Innovative WQI

Khan et al.[36]	2005	On water quality for five pristine watersheds in Newfoundland and Labrador	using DO Modified site-specific WQI
Sanchez et al.[60]	2006	DO deficit was used as the environmental indicator to assess the WQI in the watersheds of Las Rozas, Madrid (Spain)	Modified WQI
Lumb et al.[40]	2006	Water quality of Mackenzie River basin, Canada	CCMEWQI
Kannel et al.[35]	2007	Spatial and temporal changes of the water quality in the Bagmati River Basin (Nepal)	Modified WQI
Hop et al.[31]	2007	Water quality of Huong, Thach Han and Kien Giang rivers	Bhargava WQI
Sedeño-Díaz and López-López[62]	2007	Spatial and long temporal variations in water quality over the last 25 years in the Río Lerma basin, Mexico	WQI
Avvannavar and Shrihari[3]	2008	Water quality index for drinking purposes for river Netravathi, Mangalore, South India	WQI
Sahu and Sikdar[56]	2008	Hydrochemical framework of the aquifer in and around East Kolkata wetlands, West Bengal	WQI
Samantray et al.[59]	2009	Assessment of Water Quality Index in Mahanadi and Atharabanki Rivers and Taldanda Canal in Paradip Area, India	NSFWQI
Parmar et al.[50]	2010	Evaluation of water quality index for drinking purposes of river Subernarekha	Bhargava WQI
Cristina Roşu et al.[16]	2011	Assessment of ground water quality in Tureni Village, Cluj County	WQI
Sharma et al.[64]	2011	Water quality analysis of River Yamuna in the national capital territory (2000-2009), India	CCMEWQI
Shokuhi et al.[65]	2012	Evaluation of Aydughmush Dam ReservoirWater Quality	NSFWQI
Bhattacharya et al.[9]	2012	Groundwater quality of Anand district, Gujarat, India	Modified WQI
Mangukya et al.[41]	2012	Ground water quality of Surat city, Gujarat, India	Modified WQI
Fataei et al.[25]	2013	Water Quality Assessment in Balikhlou River, Iran	WQI and CWQI
Jena et al.[34]	2013	Assessment Of Water Quality Of Industrial Area(Bhilai Steel Plant industrial area, India) Surface Water Samples	BSI-WQI

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