WATER QUALITY INDICES- IMPORTANT TOOLSFOR WATER QUALITY ASSESSMENT: A REVIEW

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Abstract

Water quality is a significant criterion in matching water demand and supply. Securing adequate freshwater quality for both human and ecological needs is thus an important aspect of integrated environmental management and sustainable development. To represent water quality in a lucid way different water quality indices for water quality assessment are used which aim at giving a single value to the water quality of a source reducing great amount of parameters into a simpler expression and enabling easy interpretation of monitoring data. In this review, various water quality indices (WQI) used for assessing surface water quality are discussed. As different National and International Agencies involved in water quality assessment and pollution control defines water quality criteria for different uses of water considering different indicator parameters, so there are numerous WQI specific to any region or area. An attempt to cover different water quality indices developed worldwide, their background and application area has been discussed here.

Key words*: Water Quality, index, review, water parameters, quality scale*

1. INTRODUCTION

Water is the prime natural resource. Acknowledging the vital importance of this scarce resource for human and animal life, as well as for maintaining ecological balance for economic and developmental activities of all kinds is a matter of utmost concern.In recent times, there has been a tremendous increase in demand for freshwater and water shortage in arid and semiarid regions due to population increase, urbanization, industrialization, and intense agricultural activities in many parts of world. Due to inadequate supply of surface waters, most of the people are depending mainly on groundwater resources for drinking and domestic, industrial, and irrigation uses. Innumerable large towns and many cities derive water supply from groundwater and surface water for different uses through municipality network and also from large number of private 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.Assessment of water quality can be a complex process undertaking multiple parameters capable of causing various stresses on overall water quality [8]. To evaluate water quality from a large number of samples, each containing concentrations for many parameters is difficult [2]. Traditional approaches to assessing water quality 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. Water quality index can be evaluated on the basis of various physical, chemical and bacteriological parameters. Numerous water quality indices have been formulated all over the world which can easily judge out the overall water quality within a particular area promptly and efficiently. For example, 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 are based on the comparison of the water

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quality parameters to regulatory standards and give a single value to the water quality of a source.In this present paper a review of different water quality indices are presented.

2. WATER QUALITY INDICES

A brief history:

Categorization of water quality started in the mid-twentieth century 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]. Water Quality Guidelines Task Group of the Canadian Council of Ministers of the Environment introduced WQI in Canada, in the mid-1990s [23][29][53].Some frequently used WQI in public domains are the US National Sanitation Foundation Water Quality Index, NSFWQI, Florida Stream Water Quality Index, FWQI, British Columbia Water Quality Index, BCWQI, Oregon Water Quality Index, OWQI and the Canadian Water Quality Index (Canadian Council of Ministers of the Environment (CCME). The original BCWQI was modified into the CCME WQI, which was certified by the Canadian Council of Ministers of the Environment[57]. In India, the pioneer work on WQI was done by Bhargava, 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[5]. In the developing countries, the biggest challenge has been to develop cost effective pollution control strategies with analytical cost as a limiting factor due to restricted funds. 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. Some of them are listed 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 kind of water consumption in the evaluation process and used for general water quality, such as National Sanitation Foundation Water Quality Index(NSFWQI) [48].Second, specific consumption indices: here, the classification of water is on the basis of the kind of consumption and application (drinking, industrial, ecosystem preservation, etc). The most important and applicable of these indices are the Oregon and British Columbia indices [20].Third, designing or planning indices: This category is an instrument, aiding decision making and planning in water quality management projects.
Fourth,statistical indices: In these indices statistical methods are used and personal opinions are not considered. Statistical approaches are used here for evaluating the data.Validation from a statistical point of view in regard to certain assumptions of water quality observations is another essential part in statistical approach.First three indices are also called as expert opinion (EO) approach.The EO approach is a **subjective** approach due to the different weights for the same variables given by various panels of experts [30]. Chances in lessening objectivity and comparability are still present in the different ratings given by the experts. So, many alternative indexes were developed. However, the subjectivity assumptions in developing the indices can be reduced by using statistical approaches**.**The statistical approaches can also be used to identify important parameters in determining the quality of a water body as well as the extent of their significance[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 variablesare 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 some indices, statistical approaches such as cluster analysis (CA), discriminant analysis (DA), factor analysis (FA) and principal components analysis (PCA) are widely used, to explore structure and relationships in multivariate data for transformation and aggregation steps of index development. 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.

Review of different types of water quality index:

National Sanitation Foundation Water Quality Index (NSFWQI):

Brown et al. developed a water quality index paying great rigor in selecting parameters, developing a common scale, and assigning weights for which elaborate Delphic exercises were performed. This effort was supported by the National Sanitation Foundation (NSF) and that is why also referred as NSFWQI. This work seems to be the most comprehensive and has been discussed in various papers [10][38]. Rating curves were developed by asking the experts to attribute values for variation in the level of water quality caused by different levels of each of the selected parameters.

Having established the rating curves and associated weights, various methods of computing a water quality index are possible, like

Additive index- WQI = $\sum_{i=1}^{n} W_i Q_i$

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.

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 expresses water quality by integrating measurements of eight water quality variables. It provided the ambient water quality of Oregon's streams for general recreational use and its application to other geographic regions or water body types should be approached with caution. The science of water quality has improved markedly since the introduction of the OWQI in the 1970s[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. This technique can be characterised as a method for structuring information derived from a group of experts, so that consensus can be developed on the best available knowledge to deal with a complex problem [54][39]. Both indices used logarithmic transforms to convert water quality variable results into subindex values. Logarithmic transforms take advantage of the fact that a change in magnitude at lower levels of impairment has a greater impact than an equal change in magnitude at higher levels of impairment.

1. The original OWQI used a weighted arithmetic mean function.

$$\mathrm{WQI} = \sum_{i=1}^{n} SI_i W_i$$

3. The NSF WQI (McClelland, 1974) used a weighted geometric mean function

$$\mathrm{WQI} = \prod_{i=1}^{n} SI^{W_i}$$

Where, SI_i= Sub-index of each parameters, W_i= Weighting factor, n= Number of sub-indices.
The unweighted harmonic square mean formula, as a method to aggregate sub-index results, has been suggested as an improvement over both the weighted arithmetic mean geometric mean formula [22]. This formula allows the most impaired variable to impart the greatest influence on the water quality index and acknowledges that different water quality variables will pose differing significance to overall water quality at different times and locations. The formula is given by:

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

Bhargava method:

Bhargava identified 4 groups of parameters. Each group contained sets of one type of parameters. The first group included the concentrations of coliform organisms to represent the bacterial quality of drinking water. The second group included toxicants, heavy metals, etc. The third group included parameters that cause physical effects, such as odour, colour, and turbidity. The fourth group included the inorganic and organic nontoxic substances such as chloride, sulphate, etc. The sub-indices were worked out and the simplified model for WQI for a beneficial use is given by:

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

Where n is the number of variables considered more relevant to the use and fi(Pi) is the sensitivity function of the i^{th} variable which includes the effect of weighting of the i^{th} variable in the use. The index was applied to the raw water quality data at the upstream and downstream of river Yamuna at Delhi, India [6][7].

Smith's index:

Smith developed an index for four water uses i.e., contact as well as non-contact. It is a hybrid of the two common index types and is based on expert opinion as well as water quality standards. The selection of parameters for each water class, developing sub indices, and assigning weightages were all done using Delphi. The minimum operator technique was used to obtain the final index score:

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

Where, I_{min} equals the lowest sub index value [67][68].

British Columbia Water quality Index (BCWQI):

British Columbia water quality index was developed by the Canadian Ministry of Environment in 1995 as increasing index to evaluate water quality. 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). It provides possibility to make a classification on the basis of all existing measurement parameters.
To calculate final index value the following equation is used:

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

The number 1.453 was selected to give assurance to the scale index number from zero to 100.It is important to note that repeated samplings and increasing stations increase the accuracy of British Columbia index. Disadvantages of this method are that this index does not indicate the water quality trend until it deviates from the standard limit and due to usage of maximum percentage of deviation, it cannot determine the number of withdrawals above the maximum limit of standard [58].

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

The Canadian Council of Ministers of the Environment(CCME) has developed a Water QualityIndex (WQI) to simplify the reporting of complexand technical water quality data [12].The CCME WQI is a science-based communicationtool that tests multi-variable water qualitydata against specified water quality benchmarksdetermined by the user. TheWQI mathematicallycombines three measures of variance (scope, frequencyand magnitude) to produce a single unitlessnumber that represents overall water qualityat a site relative to the benchmark chosen (e.g.,protection of aquatic life). The end result is asingle unit-less number from 0 to 100, where ascore of 100 indicates that all variables were at orbelow the selected benchmarks during all monitoringtimes. To simplify, the CCME developed acalculator that is a pre-programmed spreadsheetwith mathematical equations that helps users evaluatethe condition (or health) or a water body.Canadian Water Quality Guidelines have been applied to the CCME WQI calculator to assess spatial and temporal changes in water quality[27][28]. In brief, theCanadian Water Quality Index (CWQI) equationis calculated using three factors as follows:

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

Where:
F_1 represents Scope: The percentage of variablesthat exceed the guideline or the number of variables whose objectives are not met
F_1= [No. of failed variables /Total no of variables]*100;
F_2 represents Frequency: The percentage of individualtests within each variable that exceededthe guideline or the frequency by which the objectives are not met
F_2= [No of failed tests/Total no of tests]*100;
F_3 represents Amplitude: The extent (excursion)to which the failed test exceeds the guideline or the amount by which the objectives are not met
(a) $excursion_i$ = [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 indexvaries between 0 and 100.

The advantages of the CCME WQI are its ability to represent measurements of a variety of variables in a single number and the ability to combine various measurements with a variety of measurement units in a single metric.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.

Overall Index of Pollution (OIP):

It was developed by Sargaonkeret al. at National Environmental Engineering Research Institute (NEERI), Nagpur, India in order to assess the status of surface waters, specifically under Indian conditions. A general classification scheme has been formulated based on a concept similar to the one proposed by Pratiet al.and giving due consideration to the classification scheme developed by CPCB [52]. 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 [61]. Each water quality observation was scored as Excellent, Acceptable, Slightly Polluted, Polluted, and Heavily Polluted, according to Indian standards and/or other accepted guidelines and standards such as World Health Organization and European Community Standards. Once categorized, each observation was assigned a pollution index value and the OIP was calculated as the average of each index value given by the mathematical expression:

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

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

The River Ganga Index:

The index was developed to evaluate the water quality profile of river Ganga in its entire stretch. The index had the weighted multiplication form and was based on the NSFWQI, with slight modifications in terms of weightages to confirm to the water quality criteria for different categories of uses as set by Central Water Pollution Board, India.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 ith water quality parameter; wi= weight associated with the ith water quality parameter; 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 areas requiring urgent pollution control measures [15].

Recreational water quality index (RWQI):

Ideally, recreational water quality indicators are microorganismsor chemical substances whose concentrations can be quantitativelyrelated to swimming and associated to health hazards.Selection of parameters has great importance to RWQI calculationbecause rigidity problems exist when additional variablesare included in the index to address specific water qualityconcerns, but the faulty aggregation function might artificiallyreduce the value of the water quality index so that it does notaccurately reflect the true water quality. As the number of waterquality variables increases, the magnitude of the aggregatedindex decreases raising the issue of ambiguity again [71].

Numerical scales related to the degree of quality were establishedfor each variable to assess variation in quality water and toconvey findings in a comprehensive manner to others. Theserating curves are, in fact, the essence of the development of thisindex. Rating curves have the ability to reproduce the relationshipbetween swimming-associated illness and water qualityindicator. The success or failure of the application of the qualityindex developed will depend on rating curves.

Once rating curves were established, various computingmethods to water quality index are possible. The calculationof the proposed RWQI is (1):

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

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

W_i is the influence of each parameter in the total value ofthe index. To calculate each of them, their individual weightmust be considered.

W_i is calculated as (2):

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

The a_i coefficient values vary from 1 (very important parameter)to 4 (less significant parameter) according to the importanceassigned to each parameter involved in the index. In thisway, the RWQI is calculated by the multiplication of all of theproducts of the parameter weights and sub-index values ($Q_i^{W_i}$)(Eq. 1). RWQI is a number among 0 to 100, where valuesclose to 100 represent the best quality.

This formulation avoids the problems of ambiguity andeclipsing to the number of water quality variables requiredto be aggregated in a given index. If the value of a sub-indexis zero, RWQI has become zero automatically.Furthermore, weight factor of parameter allows obtain largechanges to little variations for each one of different parameters.

Besides, this formulation has great sensitivity to smallparameter variations giving greater protection to people.

Water quality index:

According to Couillard and Lefebre, a WQI is analgorithm that expresses a measure of the qualitative stateof the water. This may be obtained by either deductive orinductive method [69]. The final result can be a symbol or asimple combination of numeric and alphanumericvariables.

Water Quality Index (WQI):

Assigning weight to parameters - w_i **(i)**

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

Where, W_i = relative weight

n = number of parameters

$$q_i = \frac{C_i}{S_i} \times 100 \quad \textbf{(iii)}$$

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

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

Where, $SI_i =$ is the sub-index of ithparameter
WQI = $\sum SI_i$(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 WQI developed by Bascaran in 1979 provides a global value for water conditions andincorporates weighted individual values from a series ofphysical, chemical, or biological parameters measured inthe field or laboratory.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 ofthe estimation.For the estimate, a weight and percent value wereassigned according to the concentrations, or values, inquestion and the following relationship[13]:

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

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, scums, apparent non-natural turbidity, 0.50 for Water with polluted appearanceand strong odour, 0.25 for black waters that present fermentations and odours.

For each sample assessed, the sum of the weightedparameters being considered is calculated and multipliedby a constant related to the sample's sensitivity features,such as appearance and water odour.The parameters frequently used are: major ions, biochemicaloxygen demand (BOD), dissolved solids or thosein suspension, nitrogen compounds, phosphorous sulphur,pH, hardness, turbidity, electrical conductivity and toxicand pathogenic elements. The major ions were used forassessing WQIs in the Mexico Basin. TheICA 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).

Contamination index (CI):

The CI represents the sum of theindividual factors of those components that exceed permissiblevalues, as established by the EPA. This method makes possible to assess and map thedegree of groundwater contamination. It takes into accountion elements and species that exceed permissible limits forhuman health, according to Environmental Protection Agency guidelines.
Assessment of the CI was carried out as follows:

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

C_{fi} contamination factor for the N^{th}component
C_{Ai} analytical value of the N^{th} component
C_{Ni} permissible superior concentration of the N^{th}component (N means normative value).
This method uses the ion elements and species containedin the groundwater, as previously determined by chemicalsample analysis done in the laboratory, and that exceedmaximum limits permissible for human water consumption.Determination of CI is based on the sum of the individualfactors of the components exceeding the permissiblevalues according to the Official Mexican Standard NOM-127-SSA1-1994, ''Environmental health, water for humanuse and consumption—quality permissible limits regardingquality and treatment to which water must be submitted forits drinkability''.It is worth pointing out that the NOM-127-SSA1-1994does not

consider a large number of physical–chemicalparameters, or guidelines, to be employed for the estimationof a more detailed CI. Therefore, in order to use the majorityof the analytical results obtained from the wells (DGCOH1998), it was considered necessary to enrich the work byapplying guidelines for human water consumption from theEcological Water Quality Criteria (Mexico), the WorldHealth Organization (WHO) and the European EconomicCommunity (CEE); hence, it was possible to perform contaminationmapping with a greater degree of sensitivity.The negative values obtained were not considered forthe CI map. They are related to the main recharge zones (which do not have apparent contamination); only valuesgreater than zero were considered [4].

Aquatic Toxicity Index (ATI):

It was developed by Wepeneret 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. Wepeneret 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.

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

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

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.

CONCLUSION

The water quality varies according to the type of use. Furthermore, the criterion of an 'acceptable water quality' varies from region to region and from time to time depending upon the prevailing conditions. Water quality indices are necessary for resolving lengthy, multi-parameter, water analysis reports into single digit scores. This, in turn, is essential for comparing the water quality of different sources and in monitoring the changes in the water quality 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.

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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
SubbaRao[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 using DO
Khan et al.[36]	2005	On water quality for five pristine watersheds in Newfoundland and Labrador	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 KienGiang 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