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Water quality indices: challenges and applications—an overview

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Abstract

Water quality index (WQI) is one of the most important and valuable tool used for assessing the overall water quality as it presents the final form in a single value. The concept and development of the WQI was initially developed by Horton in 1965. Since then many other transformations have occurred in the determination of WQI as proposed by different scientists and researchers. The index tends to facilitate the effective management of numerous water sources for both surface and groundwater and specifies their suitability for various uses. In general, continuous monitoring and assessments of different water quality parameters are highly complex in nature leading to generation of large voluminous datasets which are often difficult to interpret and is often uneconomical. In this context, the WQI incorporates the complex nature of different water quality parameters and helps to form a connection among these, culminating in a single value categorizing the water and this information is presented to different governmental, public agencies and regulatory authorities. The review paper presents detailed and operational descriptions along with mathematical calculations providing an insight about the development and the utility of WQIs. It has been observed that though there are many index methods available but no one single method is recognized globally to fulfill the objective of water quality management. The review also presents WQIs in an easy and streamlined manner which may be further used to have a reliable data for attaining quality of water.

Keywords Water quality index · Water quality management · Water quality · Parameters · Mathematical calculation · Decision-makers

Introduction

Water is a prime natural resource and essentially vital for all living beings. It is one of the foremost important resources utilized by living entities. Without water, there can be no life as it is totally dependent on it. Though it is a replenishable source due to the hydrological cycle, it suffers from contamination from many different sources. Of the total volume of water present in earths' hemisphere, around 75% is frozen, 3% is fresh, 10% is stored in aquifers, and only 15% is distributed unevenly across the globe (Trolard et al. 2019;Akoteyon et al. 2011;Massoud 2012; Prati et al. 1971; Khalil et al. 2011; Abdulwahid 2013; Damame et al. 2015; Phadatare and Gawande 2016; Brown et al. 1973). This uneven distribution often causes various social and economic disorders among various countries and even states within the same country. Further, increased population coupled with rising economic activities has led to an increased demand of water. Hence, the overuse of such water sources has not only led to depletion of these sources but as well as deterioration in its quality. Water sources can be in many forms like lakes, reservoirs, rivers, streams, ground water strata, glaciers, and rain water (Sahoo et al. 2015; Rosemond et al. 2009; Horton 1965; Alves et al. 2014; Dinius 1972; Dinius 1987; Akkoyunlu and Akiner 2012; Sutadian et al. 2016; Ahmad and Chaurasia 2019; Bhateria and Jain 2016). In many cities or towns, the major source of water is ground water, so they are under constant threat from various pollution sources; therefore, it is of prime importance to all these issues (Chidambaram et al. 2011). The major sources of pollution of these water resources in developing and developed countries are discharges from urban, rural, and industrial establishments containing *organic* and *inorganic impurities*. Quality of water sources is an important issue for water resource management. Besides being used for drinking purposes and domestic and residential water supplies, the numerous different sources of water also contribute majorly to the

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economy by means of agriculture, transportation, infrastructure, tourism, hydroelectricity generation, recreational activities, and various other associated human and economic uses. Therefore, adequate conservation and management of water resources is important.

Thus, it can be concluded that availability of fresh water is directly linked with the well-being of humans and their sustenance. Among various other kinds of pollution, water pollution has also become a threat to human health as well significant concern for the sustainable development (Sharma et al. 2013; Witek and Jarosiewicz 2009; Kazi et al. 2009; Brown et al. 1970).

As described in the previous paragraph, the quality of water sources is one of the foremost concerns for the management of water resources. Majorly, the quality of water can be classified in three broad categories viz., *physical*, *chemical*, and *biological characteristics*. Due to the variations of water quality parameters both spatially and temporally, it becomes difficult to interpret the quality of water. As per the latest health reports published by World Health Organization (WHO) (WHO 2019; IS 10500 2012; BIS 2019; CPCB 2017, 2019; Abbasi and Abbasi 2012), around 80% of all the diseases are caused by water contamination (Boyacioglu 2006). Once the water gets contaminated, it becomes difficult to restore its original quality. Therefore, it becomes essential to regularly monitor water quality and formulate regulatory measures for preserving it (Simeonov et al. 2002; Kannel et al. 2007; Brown et al. 1973). These consistent and systematic observations of different water quality parameters are necessary not only to evaluate its quality but also for assessment of the health of ecosystems along with the usage of these sources in various domestic, industrial and agriculture spaces. A single parameter fails to demonstrate the quality of water sources, and hence, a series of various different and unique variables in the form of physico-chemical and biological sets are used.

By assessing the different physico-chemical and biological parameters of water sources, it becomes not only easy to detect the levels of pollution but also helps in providing lucid and simple status regarding water quality to the regulatory authorities which further helps in framing appropriate future recommendations (Yao et al. 2010; Bhargava 1983a, b; Fatae et al. 2013; Abrahão et al. 2007). The quality of water often indicates the acceptability of water for human consumption. Various agencies like WHO and CPCB have given set standards for safe limits in drinking water. If the value of these three sets of parameters is higher than the prescribed limits, then the source of water is considered harmful for public use as well as for the environment. With the consumption of such chemically polluted water sources, the public health is at risk which can lead to immediate or prolonged health consequences. Hence, it is of extreme importance to assess the water quality parameter of different sources with aim of improving public health interventions and maintaining the water ecosystem. A few studies conducted (Singaraja et al. 2014; Thivya et al. 2013) have shown that by studying the hydrochemistry and lithology of ground water, one can easily assess the quality of ground water and its various uses for future needs. This will help in generating the ion relationship of dissolved ions and in turn leads to judicious management of supply of ground water.

One of the most important concerns in environmental management is its actual representation to the decision-makers, regulatory authorities, and the general public (Shokuhi et al. 2012; Parmar and Parmar 2010; Hamlat et al. 2014; Lumb et al. 2011a, b; Oram 2016; Kavidha and Elangovan 2014). The context of determining water quality using various techniques and parameters is complex and often fails to provide an accurate representation of water quality. The traditional method of monitoring the samples for different parameters is laborious and expensive. These methods are basically based on comparison of experimentally determined parameter values with the existing guidelines (Tiwari and Mishra 1985). Many studies have shown the difficulties faced in defining the water quality using the conventional method and its representation in simple and concise manner (Oram 2016; Kavidha and Elangovan 2014).

These traditional methods require the use of different and wide variety of water quality parameters, which are not always feasible to measure due to cost and time constraints. Further, complications arise due to the multifaceted nature of various factors affecting the quality of these water sources. In view of above, many researchers (Lumb et al. 2011a, b; Bharti and Katyal 2011; Bhargava 1985a, b; Kim and Cardone 2005; Longo et al. 2013; Cristina et al. 2011) worked with the key purpose of characterizing the state of water into a single level value giving rise to indexing form of representation of water quality namely *Water Quality Index*' (WQI).

The use of WQI is the most popular method used for assessment of water quality. It was firstly scripted by Horton in 1965 after which it has gone different transformations and variations to these indices and also the introduction of different other methodologies. WQI analysis is used with the aim to identify factors which are responsible for deteriorating the quality of water (House and Newsome 1989; Sargaonkar and Deshpande 2003;Icaga 2007; Silvert 2000; Sharma et al. 2014; Yadav et al. 2010; Ramakrishnaiah et al. 2009 ; CCME 2001; Bhargava 1983a, b; Balan et al. 2012; Shah and Joshi 2015). It helps in giving a weighted score to each variable from an index. Key purpose behind the development of WQI is that it finally represents a single numeric value developed from a wide range of parameters. This method helps in simplifying the data in a more logical form. The indexing method aids in categorizing the large environmental data into a concise form which can be easily interpreted.

The foremost objective of developing this tool is its usefulness to the decision-makers (Wagh et al. 2015; Tanushree et al. 2013; Almeida et al. 2008). WQI classifies the water parameters relative to physical, chemical, and biological characteristics of water sources which will help in defining their potential usages and handling their distributions for the intended use in future. For this methodical analysis, the different parameters must be weighted and aggregated. WQIs are reflected as water quality modeling procedures which give us the easy illustration of complex reality wherein certain variables are selected and means of weighing and aggregating are defined. The WQI is a helpful tool in summarizing a large amount of data in simple terms. It helps in managing the complex environmental issues and in turn helps in communicating about the concerns to the decision-making authorities. WQI also helps in integrating the water quality parameters so as to make it easy and understandable for public. It gathers the information from different sources and conglomerates these for developing a global status of water systems. WQI helps in providing a detailed overview of quality of water. Keeping in view of the above, the present study presents a critical review of WQI along with providing the history, concept, and their mathematical structure and then discusses its potential merits and demerits.

History and concept of water quality index (WQI)

As per the literature, the concept of WQI was given by Horton (1965), but some evidence of this concept was mentioned in earlier studies conducted in 1800s to have some notion on water contamination. After the conceptualization of WQI, many other studies (Lumb et al. 2011a, b; Bharti and Katyal 2011; Bhargava 1985a, b; Kim and Cardone 2005; Longo et al. 2013; Cristina et al. 2011) have utilized the method for depicting the calculating of water parameters. Mainly, in most of the approaches for calculation of WQI, four common steps are being followed which include:

i. *Selection of variables*
ii. *Transformation of the variables*
iii. *Formation of sub-indices by giving weightage to each variable*
iv. *Computing an index score using aggregation of sub-indices (*Horton 1965*)*

The study conducted by Horton (1965) included10 variables for establishing an index. These included parameters like pH, dissolved oxygen (DO), chlorides, fecal coliform, specific conductance (EC), chloroform content, temperature, and alkalinity.

Horton (1965) in his study selected these parameters and gave rating scales to form sub-index ranging from 0 to 100, wherein the highest quality rating provided was 100. The weightage assigned to different parameters varied from 1 to 4 (Horton 1965). In the end, the final index score consisted of the weighted sum of all the sub-indices divided by the sum of weights and multiplied to the coefficients which depended upon the pollution level and temperature of water source respectively. The assigned weights depicted the importance of the parameter for a specific usage and higher values signified greater importance which had an impact on the final index value (Horton 1965). The indexing method projected a virtual evaluation of quality of water along with its pollution reduction strategies. It acts as a comparative tool not only to predict and evaluate the water quality but also provides an idea which parameters mostly influence the contamination (due to higher weightage) and which needs to be monitored regularly

The indexing method proposed by Horton (1965) excluded the inclusion of any toxicity parameters since any toxicity at such water sources were rendered unfit for use for consumption of human, animals, and any other activities. In general, this method utilizes a *weighted arithmetic average water quality index method* and has been extensively used to classify the water sources on the degree of purity (Horton 1965; Dinius 1972).

The WQI can be calculated using formula:

$$\mathrm{WQI} = \frac{(\Sigma Sn \times Wn \times m1 \times m2)}{\Sigma\ Wn} \quad (1)$$

where S_n is the sub-index assigned to the nth variable

W_n is the relative weight of the nth variable
m_1 is a temperature correction factor (0.5 if the temperature is below 34 °C, else1)
m_2 is a correction pollution factor (0.5 or 1)

The categorization of the water determined from the WQI s varies from 0 to 100 as per its relative impact. The detailed rating of water quality along with respective grades is given in Table 1.

Further, to this, certain modifications (Brown et al. 1970) were made to the earlier proposed method provided for water

Table 1 Rating of water quality as per Arithmetic Average Index Method (Horton 1965)

WQI range	Rating of water quality	Grade
0–25	Excellent quality	A
26–50	Good quality	B
51–75	Poor quality	C
76–100	Very poor quality	D
Above 100	Highly unsuitable	E

quality index. The study conducted (Brown et al. 1970; Brown et al. 1973) used 9 parameters to establish a new WQI. The parameters included were turbidity, temperature, DO, biochemical oxygen demand (BOD), FC, pH, nitrate, total solids, and total phosphate (Brown et al. 1970, 1973). However, this methodology was also based on weights to individual parameter and was characterized using the Delphi's technique (Brown et al. 1973). The variables were selected carefully, the development of common scale and assigning weights to variables (Brown et al. 1970; Brown et al. 1973). The weights for variables taken are as shown in Table 2.

To determine, the significance of the selected parameters feedback from about 142 scientists who are experts in field of water quality was selected, in turn then defined the weighting (q) for each variable. They were further classified into 5 groups (red—very poor; orange—poor; yellow—average; green—good; and blue—excellent) which categorized the quality of water sources (Brown et al. 1970, 1973; Bharti and Katyal 2011). Earlier formations of the indexing method utilized weighted average (arithmetic tools) techniques, but later with certain modifications in calculations, geometric aggregations started to be utilized. This attempt was well supported by the *National Sanitation Foundation (NSF)*; hence, it is termed as *National Sanitation Foundation Water Quality Index* (*NSF-WQI).* The mathematical expression is gives as:

$$\mathrm{WQI} = \sum_{i=1}^{n} qi\ Wi \quad (2)$$

where q_i is the quality class for the n^{th} variable

W_i is the relative weight for the n^{th} variable ($W_i = 1$)

The detailed ratings of water quality for *NSFWQI* is as explained in Table 3.

As per the principle of development of NSFWQI, many other researchers (House and Newsome 1989; Sargaonkar and Deshpande 2003; Icaga 2007; Silvert 2000; Sharma et al. 2014; Yadav et al. 2010; Ramakrishnaiah et al. 2009; CCME 2001; Bhargava 1983a, b; Balan et al. 2012; Shah and Joshi 2015) developed different indexing methodologies. One such indexing method utilized (Prati et al. 1971) 14 variables for different surface and ground water sources including DO, BOD, chemical oxygen demand (COD), pH, chloride, nitrate, permanganate, manganese, ammonium, chloroform extract, iron, benzene sulfonates, and suspended solids. In another study, House and Newsome (1989) proposed three definite water quality indices which when added gave the overall water quality index.

Table 2 Weights for variables (Brown et al. 1970, 1973)

Variables	Weight
Dissolved solids	0.07
DO	0.17
BOD	0.11
Nitrates	0.10
pH	0.11
Phosphates	0.10
Temperature	0.10
Turbidity	0.08
Fecal coliform	0.16
Total	**1.00**

Table 3 Classification of water quality by *NSFWQI* (Brown et al. 1970, 1973)

WQI range	Rating of water quality
91–100	Excellent quality
71–90	Good quality
51–70	Medium quality
26–50	Bad quality
0–25	Very bad quality

As per the specifications of water quality standards, a WQI was depicted (Prati et al. 1971), with the aim of defining the level of pollution on the basis of concentration of contaminants. The water quality was classified as per the standards given with the concentration of pollutant determined as a reference and its standard value considered as reference index. Then finally by the use of mathematical equations, the values were transformed into sub-indices. This method helped in achieving the pollution capacity. Variables utilized in WQI included pH, BOD, chemical oxygen demand (COD), DO, concentrations of permanganate, ammonium, nitrate, chloride, iron, manganese, alkyl benzene sulfonates, carbon chloroform extract, and suspended solids (SS). The index was calculated as the arithmetic mean of the 13 sub-indices for water quality parameters using the formula:

$$\mathrm{I} = \frac{1}{13} \sum_{i=1}^{13} Ii \quad (3)$$

where I_i is the index range.

Another approach (Dinius 1972; Dinius 1987), based similarly on Horton's method, was developed to evaluate the cost of remediation in case of pollution to water sources. This methodology gave decreasing category scale from 100 to 0, where 0 is assigned to very bad quality while 100 defies perfect quality of water. This method followed partially the arithmetic formulations and partially the additive version of *NSFWQI.* In all, 11 different variables were chosen. WQI was calculated using the formula:

$$\mathrm{WQI} = \frac{1}{21} \sum_{\mathrm{i}=1}^{11} Ii^{Wi} \quad (4)$$

where:

I_i is the sub-index function of the pollutant variable
W_i is the unit weight of the pollutant variable whose value ranges from 0 to 1

The weights ranged from 0.5 to 5 on a basic scale of importance, and the sum of these weights was 21, which is used as the denominator in the formula.

Certain modifications were made to the formula using the Delphi method, and different sets of parameters were introduced to determine the suitability of the water source for other associated activities like public supply, recreation, pisciculture, and agriculture activities and in industries (Dinius 1972; Dinius 1987; Brown et al. 1970, 1973). In this context, a total of 12 variables were introduced including BOD, DO, FC, E-coli, alkalinity, pH, chloride, hardness, temperature, color, nitrate, and specific conductivity (Brown et al. 1970, 1973). The weightage assigned to these parameters were as per the Delphi technique. The modified formula is given as:

$$\mathrm{WQI} = \prod_{I=1}^{12} Ii \tag{5}$$

where I_i is the sub-index of pollutant variable (between 0 and 100), W_i is the unit weight of pollutant variable (between 0 and 1), and n is the number of pollutant variables.

Many Indian studies (Dinius 1972; Dinius 1987; Yao et al. 2010; Bhargava 1983a, b; Fatae et al. 2013; Abrahão et al. 2007) have also introduced few other variations to the determination of WQI by making various combinations which highlighted the pollution levels specifically. One such study conducted (Bhargava 1983a, b; Bhargava 1985a, b) had defined the variables and introduced the specified WQI formula as per the usage and utilization of the water sources. Number of variables used in this study was limited to 14, and each collection was confined to a setting of a single type. In this method, parameters like coliform and heavy metals were included to represent the bacteriological and toxicity status of the source. Additional parameters like turbidity, odor, color, other organic and inorganic substances like sulfate and chlorides, and other such associated parameters were also included. The study also used the maximum allowable contaminants (C_{MCL}) for each variable based on observations reported by US Environmental Protection Agency (Sargaonkar and Deshpande 2003;Icaga 2007; Silvert 2000; Sharma et al. 2014; Yadav et al. 2010; Ramakrishnaiah et al. 2009; CCME 2001). The mathematical expression is as follows:

$$\mathrm{WQI} = \left[\prod_{i=1}^{n} \mathrm{fi}\right]\left(\frac{1}{n}\right) \times 100 \tag{6}$$

where f_i is the value of the sensitivity function of the i-th variable including the effect of the concentration and weight of the variable (i) varying from 0 to 1 and (n) is the number of variables taken into account.

Other such study (Tiwari and Mishra 1985) utilized the basic principles of Horton (1965) only with the slight modification in weighting method. Instead of using the methodologies given earlier, this study introduced normative values of the major variables of the sources of water. This method utilized logarithmic and antilogarithmic for mathematical calculations. The formula used for depicting WQI is as follows:

$$\mathrm{WQI} = \mathrm{Antilog} \sum \mathrm{Wn}\ \mathrm{logqn} \tag{7}$$

where:

q_n is the quality class for the nth variable
W_n is the relative weight of the nth variable

The value of q_n can be computed using the following formulas:

$$qn = \frac{Vn - \mathrm{Videal}}{Sn - \mathrm{Videal}} \times 100 \tag{8}$$

$$qn = \frac{Vn}{Vs} \times 100 \tag{9}$$

where

V_n is the value of variable in sample n
S_n is the value of variable recommended by guidelines
V_{ideal} is the ideal value which is considered by some researchers; Eq. (8) is used for calculating pH and DO, while for calculating rest of the other parameters, Eq. (9) is used.

The relative weight (W_n) is calculated using the following equation:

$$Wn = \frac{K}{Sn} \tag{10}$$

where:
K is proportionality constant given by:

$$\mathrm{K} = \frac{1}{\sum_{i=1}^{n} 1/\mathrm{Si}} \tag{11}$$

For this method, the quality of water is classification is given in Table 4.

A very important study (Trolard et al. 2019; CCME 2001; Sharma et al. 2013) in the context of WQI was formulated and

Table 4 Classification of water quality (Tiwari and Mishra 1985)

WQI	Quality range
< 26	Excellent
26–50	Good
51–75	Medium
76–100	Poor
> 100	Unsuitable

conducted under The Canadian Council of Ministers and Environment (CCME) wherein the WQI was based on the principles as per the instruction provided by the water quality task group, and which was inspired by the British Colombia Water Quality Index (BCWQI). It was based on the frequency of sampling and measurement. This scheme could be used by various countries with slight modifications conforming to the water quality standards of those nations. This method was developed for identifying community significant actions as well as for evaluation of aquatic life in surface waters.

The concept of CCMEWQI was dependent on the various factors used in CCME grouped as F_1, $F_{2,}$ and F_3. These groups of parameters (F_1, F_2, F_3) signify the scope and extent for evaluating the non-compliance with water quality during the test period, mean frequency along with number of samples used for the test conducted, and standard deviations occurred or non-availability of values during test period respectively (CCME 2001; Trolard et al. 2019; Sharma et al. 2013). The calculation for WQI is given as:

$$\text{CCMEWQI} = 100 - \sqrt{F1^2 + F2^2 + F3^2/1.732} \quad (12)$$

where:

F_1 (Number of failed variables ÷ Total number of variables) × 100
F_2 (Number of failed tests ÷ Total number of tests) × 100
F_3 (nse ÷ [0.01nse +0.01]); nse is expressed as nse = departure/number of tests

The categories for water qualities as per CCMEWQI are given in Table 5.

Another important development in the determination of WQI was the indexing system developed by the Oregon Department of Environmental Quality (ODEQ) which is the most common and widely known as Oregon Water Quality Index. This method since its development has undergone several modifications. In its earliest format, it utilized large voluminous datasets which unnecessarily complicated the index calculation. Further improvements to the model involved similar design principles used for development of NSFWQI wherein Delphi technique was followed for selection of variables. This methodology gives the score for evaluation of quality of water. The parameters used were temperature, DO, BOD, pH, ammonia, nitrate nitrogen, total phosphate, total solids, and FC. The mathematical expression is given:

$$\text{OWQI} = \sqrt{\frac{n}{\sum_{i=1}^{n} 1/\text{SI}^2}} \quad (13)$$

where:

n number of sub-indices
SI sub index of i^{th} parameter

The detailed rating of ranges and various categories are given in Table 6.

Few other research studies considering WQI (Icaga 2007; Silvert 2000; Sharma et al. 2014; Yadav et al. 2010; Ramakrishnaiah et al. 2009) encompassed the physical, chemical, and biological variables along with flow measurements and turbidity of water sources for determination of pollution load. The indices were expressed in three categories of good, fair, and poor. Few of the studies (Shokuhi et al. 2012; Parmar and Parmar 2010; Hamlat et al. 2014; Lumb et al. 2011a, b; Oram 2016; Kavidha and Elangovan 2014) utilized logarithmic aggregation methods where mainly the idea was just to reduce the lengthy data while maintaining the accuracy. It helped in the development of a data bank. Many new indices have been developed by simplifying the existing formulas. These help in assessing and defining the overall index for classification of pollution. Few researchers (Kanownik et al. 2019; Vasistha and Ganguly 2020) have also used methods to determine the nutrient content in the form of indices for calculating ammonium nitrogen, total phosphorous, total nitrogen, phosphate, and nitrate nitrogen depending on the requirement of the selection of these parameters for study. The selection of nutrients in assessment of WQI is particularly when considering agricultural source or lake surface water body wherein nutrients are important parameters for determining water quality.

Instead of using the manual calculation method, different softwares are also used to calculate WQI. Many times, it becomes practically difficult in setting up WQI with definite pollutants in many cases. Therefore, software's are needed which can be of great help to the experts in presenting their own indexes. Studies (Sarkar and Abbasi 2006; Nabizadeh

Table 5 Classification of water quality as per CCMEWQI (CCME 2001)

WQI	Quality class
< 44	Poor
45–64	Bad
65–79	Marginal
80–94	Good
95–100	Excellent

Table 6 Classification of water quality as per OWQI

WQI	Quality class
95–100	Excellent
80–94	Good
60–79	Fair
45–59	Marginal
0–44	Poor

et al. 2013; Soumaila et al. 2019; RadFard et al. 2019) have shown that with the use of software, the missing values in the data sets can be presented for efficient use of water quality parameters. One such initially developed tool is computer automated QUALIDEX (Sarkar and Abbasi 2006). The software helped in generating an index of own and also compared the performance its performance with the already developed indexes. The major application of the software was to analyze the variations in quality of water at different sites at different times. The software was coded in visual C++ and integrated with MS Access databases. The development of such tools has led to the fulfillment of urgent need for diagnostic for overall assessment of quality of water. Few other types of software were also developed with certain modifications to depict WQI. One such software is named Iranian Water Quality Index Software (IWQIS) which was developed to address the issue of variation in water quality parameters. The software was based on the concept of dynamic weight allocation for making the computational process easier and simpler (Nabizadeh et al. 2013). IWQIS can also be used to determine the sensitivity analysis of weights attributed to the parameters when the allocation of definite weight factors to some parameters is controversial. Software called Artificial Neural Network (ANIS) and Arc-Gis was also developed to estimate the quality of water. They also followed the pattern of the other software's along with the application of neural fuzzy systems (RadFard et al. 2019).

The most recent work in the field of WQI is based on the use of fuzzy logic methodology. This method works on the principle in expressing the partial truth between false and true by taking numbers between 0 and 1 (Icaga 2007; Silvert 2000; Sharma et al. 2014). It is like a converse of Boolean logic where truth values of variables lay between the integer values of 0 and 1 (Icaga 2007; Silvert 2000). In the fuzzy logic method, a subjective variable like odor can also be taken as input which the advantage of this method is as earlier mathematical models did not take such parameters into account as they were considered to be inadequate while measuring. The concept of acceptability is considered as fuzzy (Shokuhi et al. 2012; Parmar and Parmar 2010; Hamlat et al. 2014; Lumb et al. 2011a, b; Oram 2016; Kavidha and Elangovan 2014). The valuation provided by this method is established on a numerical scale representing the various quality standards of different water sources. It also helps in providing aggregating water quality variables in order to present a complete environmental quality of waters.

In order to develop fuzzy logic index, the following 6 steps were followed: (i) determination of quality classes for the measured variables, (ii) arranging the variables according to their groups, (iii) application of membership functions (m_f) which help in standardization of natural measurements scales of quality variables, (iv) applying successive rules to the variables, (v) applying fuzzy logic algorithm by grouping the variables, and (vi) defuzzification of the inference for obtaining the index whose values ranges from 0 to100.

Challenges in application of water quality index (WQI)

The foremost objective of WQI is simple representation of the water quality of the source by aggregating and weighing various parameters measured. Due to the considerable number and variability of the selected parameters, the process of aggregation is used to reduce the sub-indices to a single scale. A panel of well-versed experts helped in selection of variables and assigning the weights for aggregation. Nevertheless, it has been observed from the literature that a number of indices have been developed which has made the situation complex. It is also important to note that with so vast datasets related to various types of WQI, these tools have undergone two types of advancements. While one shows a normative progress, which is based on the prescribed guidelines and standards (Trolard et al. 2019), the other is related to the progression of digital processing which impacted the aggregation methods (Trolard et al. 2019; Sargaonkar and Deshpande 2003). A study conducted (Tiwari and Mishra 1985) revealed that at least 30 different water quality indices are of use around the world. With the presence of so many different WQIs, possible disagreements arise while using these WQIs due to usage of same WQI which might have different limits or using different WQIs based on same variables but different classifications and sometimes applying different WQIs on the basis of different types and number of variables. A study (Witek and Jarosiewicz 2009; Kazi et al. 2009) has shown that while using two scales for the similar index for evaluation of a surface water body at various locations has shown that such approaches help in classification of the variables. While one indexing method has shown good classification for the variable and for the same variable, the other indexing method has shown poor quality. Hence, it can be surmised that there exists no universal or best WQI method. The suitability of the use of the WQI entirely depends on the sources, the parameters measures, the weightage assigned, their classification scale, and their final interpretation of the obtained WQI.

Studies (Fetoshi et al. 2020; Trolard et al. 2019; Sharma et al. 2014) have shown that the use of same parameters used for determining WQI using different methods leads to different classification. A research evaluating water quality in 8 water sources showed a significant difference between the classes of the water quality in the same site but with different indices. The results are highlighted in Table 7.

Many similar such studies (Trolard et al. 2019; Akoteyon et al. 2011;Massoud 2012; Prati et al. 1971; Khalil et al. 2011; Abdulwahid 2013; Damame et al. 2015; Phadatare and Gawande 2016; Brown et al. 1973) conducted have utilized

Table 7 Comparison of different water quality indices (Trolard et al. 2019)

Site	WQI score and quality					
	CCMEWQI	Quality	OWQI	Quality	NSFWQI	Quality
1	34	Poor	13	Very Poor	52	Medium
2	45	Marginal	24	Very Poor	70	Medium
3	49	Marginal	26	Very Poor	74	Medium
4	73	Fair	60	Poor	78	Good
5	40	Poor	19	Very Poor	69	Medium
6	58	Marginal	60	Poor	77	Good
7	70	Fair	60	Poor	77	Good
8	35	Poor	13	Very Poor	57	Medium

two or more indexes to compute different sets of data on different number of variables and compared the results. The results have shown the possibility of both agreement or disagreement of categorization of the water source based on the different indexing system. The differences in classification of water using the different indices system may be attributed to mode of aggregation of variables and parameters used in calculation of each index

Few researchers (Shokuhi et al. 2012; Parmar and Parmar 2010; Hamlat et al. 2014; Lumb et al. 2011a, b; Oram 2016; Kavidha and Elangovan 2014) have also highlighted the differences among the spatial-temporal classification of water sources by using different WQIs. Various logarithmic and arithmetic indexes have also been used in this context for calculations. The results have described that in majority of cases, the indices succeed in accurately representing the water quality classifications. Though it is possible that the indices characterize equally, it is imperative to keep a continuous check on difference of classification among various methods as well as standards (Trolard et al. 2019; Akoteyon et al. 2011;Massoud 2012; Prati et al. 1971; Khalil et al. 2011; Abdulwahid 2013; Damame et al. 2015). The depth of analysis from various methods of WQI also help to detect that such approach helps in classification of the variables based on different calculations. Such cases can also lead to generation of more accurate results with the applications of WQIs.

It has been observed that the common points in conception of WQI methodologies include the choice of parameter, weighting methods, and aggregation methods. Quality of any source of water is dependent on the spatial-temporal dimensions of its path taken during its life cycle along with its different associated usages. This helps in determining the choice of water quality variable, sampling period, and analytical techniques. The quality of water cannot be defined by a single specific variable as it is the combination of many different variables. These combined variables express the water quality in a single appropriate value which forms the relationship with the water managing objectives (Wagh et al. 2015; Tanushree et al. 2013). One such common method used for selection of variables is the Delphi technique which is dependent upon the expert opinion. However, with the introduction of different techniques including multivariate statistical analysis, it has become easier and more accurate to select the variables representing the changing nature of water sources and provide insights to its future quality and which are highly robust. Hence, it becomes extremely important in choosing the number and nature of parameters carefully. The weightage assigned to these parameters generally follow two methods—one being dependent on the expert's opinion and the other on the prescribed standards. Both these methods affect the final index value obtained and can significantly influence the category of the source and thereby change the water quality objectives. Finally, the aggregation methods provided to the variables will depict whether they are weighted arithmetically, geometrically, harmonic mean square average, or logarithmically functioned or fuzzy logic. Initially, arithmetic averages were used which was later replaced with the geometric averages, though the geometric method had a distinct disadvantage of not giving accurate results if the concentration values of the selected variables were low. However, the advantage associated with the geometric method of weighing was the results were less influenced if extreme values were used in comparison to the average values obtained from arithmetic method. The use of harmonic mean for assigning weightage to the selected parameters was also considered to be an improvement over both arithmetic and geometric depending upon the different conditions.

Consequently, very strong irregularities could be measured on certain variables during monitoring the water quality that could be observed in the final WQI. Presently, with the simplification of computer use, the aggregations have taken another form like use of logarithmic approach functions and recent use of fuzzy logic. However, a review of the latest scientific literature still suggests the use of WQI based on arithmetic or geometric aggregations.

Conclusion

The first WQI was developed by Horton in the year 1965 after which more approaches were established to determine it. The main aim of all the techniques used for determination of WQI were to reduce the complex monitoring data into a single value helpful in determining the quality of water and to fulfill the objectives of water quality. Further, the development of WQI has seen several methods including the use of weighted or non-weighted aggregations. The review study conducted showed that indices developed by different scientists revealed that often during the formulations, the regulatory framework was not considered, and objectives of water management were not well-defined which affected the weightage assigned to different parameters. Hence, the method of assigning weightage must be provided considering those parameters which are good estimates in providing the present and future use of any water body. The review conducted on all of the existing methodologies WQI have shown the susceptibility of the different indices during their formulations. It is also observed that the indices employ a combination of different physico-chemical and biological parameters for determining WQI which is helpful to the different government and regulatory agencies and experts globally. In spite of all the struggles and discussed different indices being used globally, no single index has been universally accepted, and search for more useful and universal water quality index is still in progress, and hence, the water agencies, users, and water managers in different countries may use and accept it with little changes.

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