



# A comprehensive review of water quality indices (WQIs): history, models, attempts and perspectives

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**Abstract** Water quality index (WQI) is one of the most used tools to describe water quality. It is based on physical, chemical, and biological factors that are combined into a single value that ranges from 0 to 100 and involves 4 processes: (1) parameter selection, (2) transformation of the raw data into common scale, (3) providing weights and (4) aggregation of sub-index values. The background of WQI is presented in this review study. the stages of development, the progression of the field of study, the various WQIs, the benefits and drawbacks of each approach, and the most recent attempts at WQI studies. In order to grow and elaborate the index in several ways, WQIs should be linked to scientific breakthroughs (example: ecologically). Consequently, a sophisticated WQI that takes into account statistical methods, interactions

between parameters, and scientific and technological improvement should be created in order to be used in future investigations.

**Keywords** Water quality index (WQI) · Water quality parameters · Surface water · Ground water

## 1 Introduction

Water is the vital natural resource with social and economic values for human beings (Kumar 2018). Without water, existence of man would be threatened (Zhang 2017). The most important drinking sources in the world are surface water and groundwater (Paun et al. 2016).

Currently, more than 1.1 billion people do not have access to clean drinking water and it is estimated that nearly two-thirds of all nations will experience water stress by the year 2025 (Kumar 2018).

With the extensive social and economic growth, such as human factors, climate and hydrology may lead to accumulation of pollutants in the surface water that may result in gradual change of the water source quality (Shan 2011).

The optimal quantity and acceptable quality of water is one of the essential needs to survive as mentioned earlier, but the maintenance of an acceptable quality of water is a challenge in the sector of water resources management (Mukate et al. 2019). Accordingly, the water quality of water bodies can be tested

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through changes in physical, chemical and biological characteristics related to anthropogenic or natural phenomena (Britto et al. 2018).

Therefore, water quality of any specific water body can be tested using physical, chemical and biological parameters also called variables, by collecting samples and obtaining data at specific locations (Britto et al. 2018; Tyagi et al. 2013).

To that end, the suitability of water sources for human consumption has been described in terms of Water Quality Index (WQI), which is one of the most effective ways to describe the quality of water, by reducing the bulk of information into a single value ranging between 0 and 100 (Tyagi et al. 2013).

Hence, the objective of the study is to review the WQI concept by listing some of the important water quality indices used worldwide for water quality assessment, listing the advantages and disadvantages of the selected indices and finally reviewing some water quality studies worldwide.

## 2 Water quality index

### 2.1 History of water quality concept

In the last decade of the twentieth century, many organizations involved in water control, used the water quality indices for water quality assessment (Paun et al. 2016). In the 1960's, the water quality indices was introduced to assess the water quality in rivers (Hamlat et al. 2017).

Horton (1965), initially developed a system for rating water quality through index numbers, offering a tool for water pollution abatement, since the terms “water quality” and “pollution” are related. The first step to develop an index is to select a list of 10 variables for the index's construction, which are: sewage treatment, dissolved oxygen (DO), pH, coliforms, electroconductivity (EC), carbon chloroform extract (CCE), alkalinity, chloride, temperature and obvious pollution. The next step is to assign a scale value between zero and 100 for each variable depending on the quality or concentration. The last step, is to designate to each variable is a relative weighting factor to show their importance and influence on the quality index (the higher the assigned weight, the more impact it has on the water quality index, consequently it is more important) (Horton 1965).

Later on, Brown et al. (1970) established a new water quality index (WQI) with nine variables: DO, coliforms, pH, temperature, biochemical oxygen demand (BOD), total phosphate, nitrate concentrations, turbidity and solid content based on a basic arithmetic weighting using arithmetic mean to calculate the rating of each variable. These rates are then converted not temporary weights. Finally, each temporary weight is divided by the sum of all the temporary weights in order to get the final weight of each variable (Kachroud et al. 2019a; Shah and Joshi 2017). In 1973, Brown et al., considered that a geometric aggregation (a way to aggregate variables, and being more sensitive when a variable exceeds the norm) is better than an arithmetic one. The National Sanitation Foundation (NSF) supported this effort (Kachroud et al. 2019a; Shah and Joshi 2017).

Steinhart et al. (1982) developed a novel environmental quality index (EQI) for the Great Lakes ecosystem in North America. Nine variables were selected for this index: biological, physical, chemical and toxic. These variables were: specific conductance or electroconductivity, chloride, total phosphorus, fecal Coliforms, chlorophyll *a*, suspended solids, obvious pollution (aesthetic state), toxic inorganic contaminants, and toxic organic contaminants. Raw data were converted to subindex and each subindex was multiplied by a weighting factor (a value of 0.1 for chemical, physical and biological factors but 0.15 for toxic substances). The final score ranged between 0 (poor quality) and 100 (best quality) (Lumb et al. 2011a; Tirkey et al. 2015).

Dinius (1987), developed a WQI based on multiplicative aggregation having a scale expressed with values as percentage, where 100% expressed a perfect water quality (Shah and Joshi 2017).

In the mid 90's, a new WQI was introduced to Canada by the province of British Columbia, and used as an increasing index to evaluate water quality (Lumb et al. 2011b; Shah and Joshi 2017). A while after, the Water Quality Guidelines Task Group of the Canadian Council of Ministers of the Environment (CCME) modified the original British Columbia Water Quality Index (BCWQI) and endorsed it as the CCME WQI in 2001 (Bharti and Katyal 2011; Lumb et al. 2011b).

In 1996, the Watershed Enhancement Program (WEPWQI) was established in Dayton Ohio, including water quality variables, flow measurements and

water clarity or turbidity. Taking into consideration pesticide and Polycyclic Aromatic Hydrocarbon (PAH) contamination, is what distinguished this index from the NSFQI (Kachroud et al. 2019a, b).

Liou et al. (2003) established a WQI in Taiwan on the Keya River. The index employed thirteen variables: Fecal coliforms, DO, ammonia nitrogen, BOD, suspended solids, turbidity, temperature, pH, toxicity, cadmium (Cd), lead (Pb), copper (Cu) and zinc (Zn). These variables were downsized to nine based on environmental and health significance: Fecal coliforms, DO, ammonia nitrogen, BOD, suspended solids, turbidity, temperature, pH and toxicity. Each variable was converted into an actual value ranging on a scale from 0 to 100 (worst to highest). This index is based on the geometric means (an aggregation function that could eliminate the ambiguity caused from smaller weightings) of the standardized values (Akhtar et al. 2021; Liou et al. 2004; Uddin et al. 2021).

Said et al. (2004) implemented a new WQI using the logarithmic aggregation applied in streams waterbodies in Florida (USA), based on only 5 variables: DO, total phosphate, turbidity, fecal coliforms and specific conductance. The main idea was to decrease the number of variables and change the aggregation method using the logarithmic aggregation (this function does not require any sub-indices and any standardization of the variables). This index ranged from 0 to 3, the latter being the ideal value (Akhtar et al. 2021; Kachroud et al. 2019a, b; Said et al. 2004; Uddin et al. 2021).

The Malaysian WQI (MWQI) was carried out in 2007, including six variables: DO, BOD, Chemical Oxygen Demand (COD), Ammonia Nitrogen, suspended solids and pH. For each variable, a curve was established to transform the actual value of the variable into a non-dimensional sub-index value.

The next step is to determine the weighting of the variables by considering the experts panel opinions. The final score is determined using the additive aggregation formula (where sub-indices values and their weightings are summed), extending from 0 (polluted) to 100 (clean) (Uddin et al. 2021).

The Hanh and Almeida indices were established respectively in 2010 on surface water in Vietnam and 2012 on the Potrero de los Funes in Argentina, based on 8 (color, suspended solids, DO, BOD, COD, chloride, total coliforms and orthophosphate) and 10

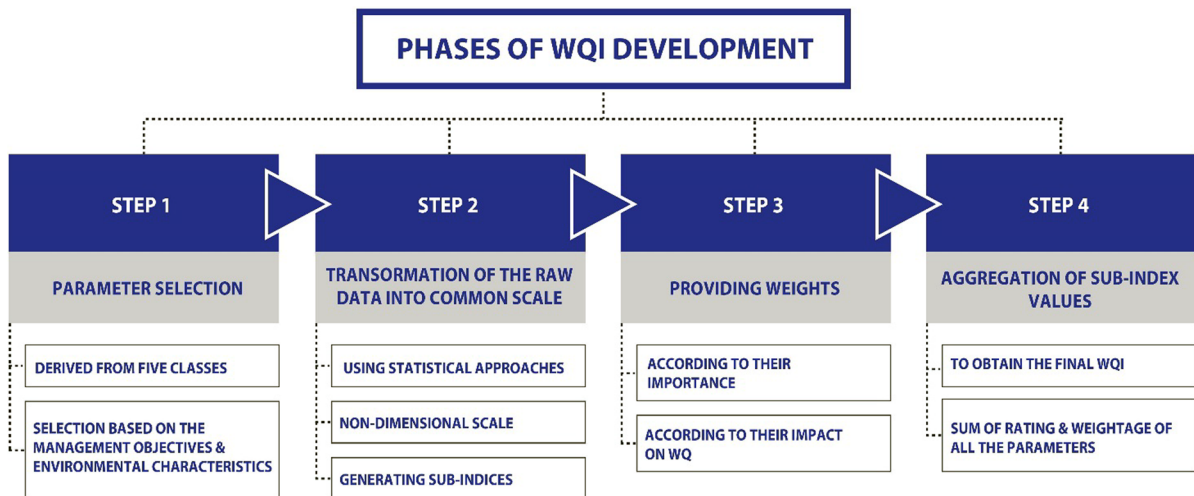
(color, pH, COD, fecal coliforms, total coliforms, total phosphate, nitrates, detergent, enterococci and *Escherichia coli.*) water quality variables. Both indices were based on rating curve-based sum-indexing system (Uddin et al. 2021).

The most recent developed WQI model in the literature was carried out in 2017. This index tried to reduce uncertainty present in other water quality indices. The West Java Water Quality Index (WJWQI) applied in the Java Sea in Indonesia was based on thirteen crucial water quality variables: temperature, suspended solids, COD, DO, nitrite, total phosphate, detergent, phenol, chloride, Zn, Pb, mercury (Hg) and fecal coliforms. Using two screening steps (based on statistical assessment), parameter (variable) redundancy was determined to only 9: temperature, suspended solids, COD, DO, nitrite, total phosphate, detergent, phenol and chloride. Sub-indices were obtained for those nine variables and weights were allocated based on expert opinions, using the same multiplicative aggregation as the NSFQI. The WJWQI suggested 5 quality classes ranging from poor (5–25) to excellent (90–100) (Uddin et al. 2021).

## 2.2 Phases of WQI development

Mainly, WQI concept is based on many factors as displayed in Fig. 1 and described in the following steps:

1. Parameter selection for measurement of water quality (Shah and Joshi 2017):  
The selection is carried out based on the management objectives and the environmental characteristics of the research area (Yan et al. 2015). Many variables are recommended, since they have a considerable impact on water quality and derive from 5 classes namely, oxygen level, eutrophication, health aspects, physical characteristics and dissolved substances (Tyagi et al. 2013).
2. Transformation of the raw data parameter into a common scale (Paun et al. 2016):  
Different statistical approach can be used for transformation, all parameters are transformed from raw data that have different dimensions and units (ppm, saturation, percentage etc.) into a common scale, a non-dimensional scale and sub-indices are generated (Poonam et al. 2013; Tirkey et al. 2015).



**Fig. 1** Phases of WQI development

3. Providing weights to the parameters (Tripathi and Singal 2019):

Weights are assigned to each parameter according to their importance and their impact on water quality, expert opinion is needed to assign weights (Tirkey et al. 2015). Weightage depends on the permissible limits assigned by International and National agencies in water drinking (Shah and Joshi 2017).

4. Aggregation of sub-index values to obtain the final WQI:

WQI is the sum of rating and weightage of all the parameters (Tripathi and Singal 2019).

It is important to note that in some indices, statistical approaches are commonly used such as factor analysis (FA), principal component analysis (PCA), discriminant analysis (DA) and cluster analysis (CA). Using these statistical approaches improves accuracy of the index and reduce subjective assumptions (Tirkey et al. 2015).

## 2.3 Evolution of WQI research

### 2.3.1 Per year

According to Scopus (2022), the yearly evolution of WQI's research is illustrated in Fig. 2 (from 1978 till 2022).

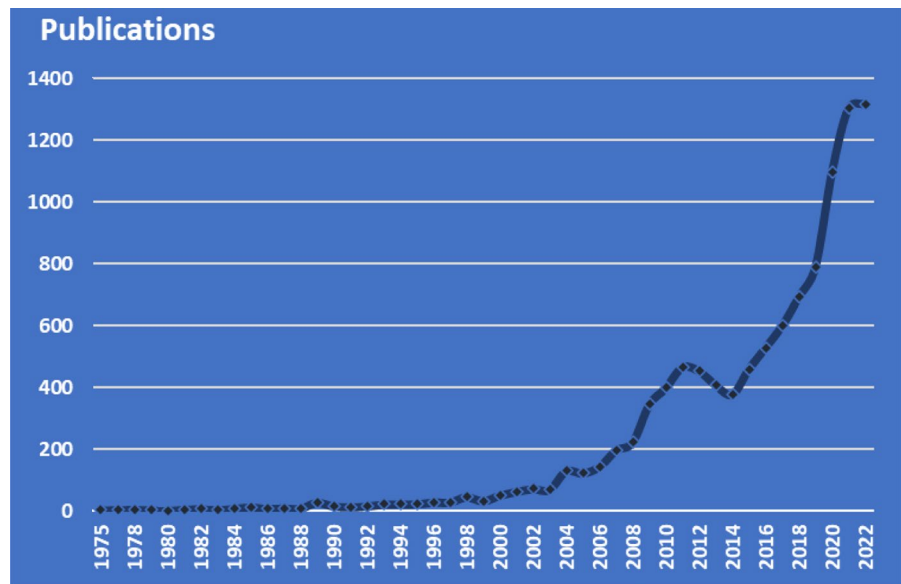
Overall, it is clear that the number of research has grown over time, especially in the most recent years. The number of studies remained shy between 1975 and 1988 (ranging from 1 to 13 research). In 1998, the number improved to 46 studies and increased gradually to 466 publications in 2011. The WQI's studies have grown significantly over the past decade, demonstrating that the WQI has become a significant research topic with the goal of reaching its maximum in 2022 (1316 studies) (Scopus, 2022).

### 2.3.2 Per country

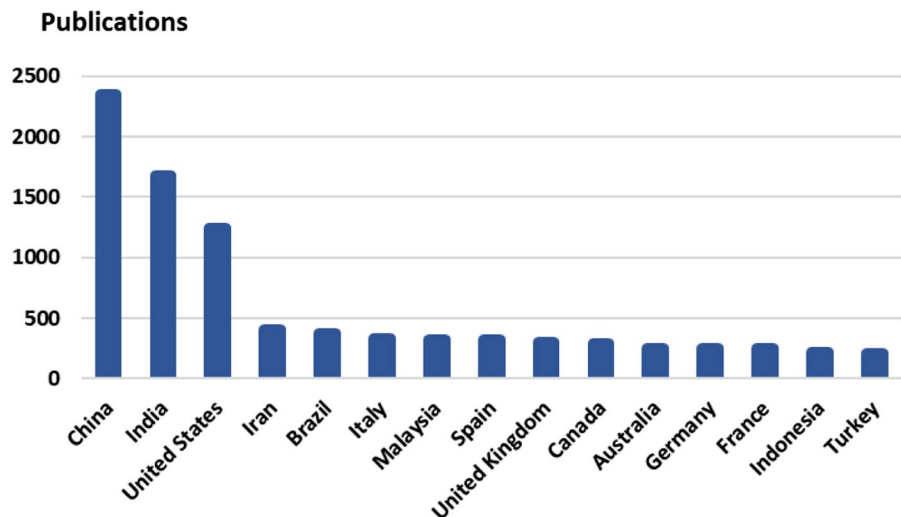
In Fig. 3, the development of WQI research is depicted visually per country from 1975 to 2022.

According to Scopus (2022), the top three countries were China, India and the United States, with 2356, 1678 and 1241 studies, respectively. Iran, Brazil, and Italy occupy the fourth, fifth, and sixth spots, respectively (409, 375 and 336 study). Malaysia and Spain have approximately the same number of studies, respectively 321 and 320 study. The studies in the remaining countries decrease gradually from 303 document in Spain to 210 documents in Turkey. This demonstrates that developing nations, like India, place a high value on the development of water quality protection even though they lack strong economic power, cutting-edge technology, and a top-notch scientific research team. This is because water quality is

**Fig. 2** Evolution of WQI research per year (Scopus 2022)



**Fig. 3** Evolution of WQI research per country (Scopus 2022)



crucial to the long-term social and economic development of those nations (Zhang 2019).

#### 2.4 Different methods for WQI determination

Water quality indices are tools to determine water quality. Those indices demand basic concepts and knowledge about water issues (Singh et al. 2013). There are many water quality indices such as the: National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of Environment Water Quality Index (CCMEWQI), Oregon

Water Quality Index (OWQI), and Weight Arithmetic Water Quality Index (WAWQI) (Paun et al. 2016).

These water quality indices are applied in particular areas, based on many parameters compared to specific regional standards. Moreover, they are used to illustrate annual cycles, spatio-temporal variations and trends in water quality (Paun et al. 2016). That is to say that, these indices reflect the rank of water quality in lakes, streams, rivers, and reservoirs (Kizar 2018).

Accordingly, in this section a general review of available worldwide used indices is presented.

### 2.4.1 National sanitation foundation (NSFWQI)

The NSFWQI was developed in 1970 by the National Sanitation Foundation (NSF) of the United States (Hamlat et al. 2017; Samadi et al. 2015). This WQI has been widely field tested and is used to calculate and evaluate the WQI of many water bodies (Hamlat et al. 2017). However, this index belongs to the public indices group. It represents a general water quality and does not take into account the water's use capacities, furthermore, it ignores all types of water consumption in the evaluation process (Bharti and Katyal 2011; Ewaid 2017).

The NSFWQI has been widely applied and accepted in Asian, African and European countries (Singh et al. 2013), and is based on the analysis of nine variables or parameters, such as, BOD, DO, Nitrate (NO<sub>3</sub>), Total Phosphate (PO<sub>4</sub>), Temperature, Turbidity, Total Solids(TS), pH, and Fecal Coliforms (FC).

Some of the index parameters have different importance, therefore, a weighted mean for each parameter is assigned, based on expert opinion which have grounded their opinions on the environmental significance, the recommended principles and uses of water body and the sum of these weights is equal to 1 (Table 1) (Ewaid 2017; Uddin et al. 2021).

Due to environmental issues, the NSFWQI has changed overtime. The TS parameter was substituted by the Total Dissolved Solids (TDS) or Total Suspended Solids (TSS), the Total Phosphate by orthophosphate, and the FC by *E. coli* (Oliveira et al. 2019).

The mathematical expression of the NSFWQI is given by the following Eq. (1) (Tyagi et al. 2013):

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

where,  $Q_i$  is the sub-index for  $i$ th water quality parameter.  $W_i$  is the weight associated with  $i$ th water quality parameter.  $n$  is the number of water quality parameters.

This method ranges from 0 to 100, where 100 represents perfect water quality conditions, while zero indicates water that is not suitable for the use and needs further treatment (Samadi et al. 2015).

The ratings are defined in the following Table 2.

In 1972, the Dinius index (DWQI) happened to be the second modified version of the NSF (USA). Expanded in 1987 using the Delphi method, the DWQI included twelve parameters (with their assigned weights): Temperature (0.077), color (0.063), pH (0.077), DO (0.109), BOD (0.097), EC (0.079), alkalinity (0.063), chloride (0.074), coliform count (0.090), *E. coli* (0.116), total hardness (0.065) and nitrate (0.090). Without any conversion process, the DWQI used the measured variable concentrations directly as the sub-index values (Kachroud et al. 2019b; Uddin et al. 2021).

Sukmawati and Rusni assessed in 2018 the water quality in Beratan lake (Bali), choosing five representative stations for water sampling representing each side of the lake, using the NSFWQI. NSFWQI's nine parameters mentioned above were measured in each station. The findings indicated that the NSFWQI for the Beratan lake was seventy-eight suggesting a good water quality. Despite this, both pH and FC were below the required score (Sukmawati and Rusni 2019).

The NSFWQI indicated a good water quality while having an inadequate value for fecal coliforms and pH. For that reason, WQIs must be adapted and developed so that any minor change in the value of

**Table 1** Weight scores of the nine NSF-WQI parameters

Parameters	Weighted mean
DO	0.17
FC	0.16
pH	0.11
BOD	0.11
Temperature	0.1
Nitrate	0.1
Total Phosphate	0.1
Turbidity	0.08
Total Solids	0.07

**Table 2** Colors and definition used in the classification of pollution using NSFWQI (Roozbahani and Boldaji 2013)

Color	The numerical value index	Definition
Red	0–25	Very bad
Orange	26–50	Bad
Yellow	51–70	Moderate
Green	71–90	Good
Blue	91–100	Excellent

any parameter affects the total value of the water quality index.

A study conducted by Zhan et al. (2021), concerning the monitoring of water quality and examining WQI trends of raw water in Macao (China) was established from 2002 to 2019 adopting the NSFQWI. NSFQWI's initial model included nine parameters (DO, FC, pH, BOD, temperature, total phosphates, and nitrates), each parameter was given a weight and the parameters used had a significant impact on the WQI calculation outcomes. Two sets of possible parameters were investigated in this study in order to determine the impact of various parameters. The first option was to keep the original 9-parameter model, however, in the second scenario, up to twenty-one parameters were chosen, selected by Principal Component Analysis (PCA).

The latter statistical method was used to learn more about the primary elements that contributed to water quality variations, and to calculate the impact of each attribute on the quality of raw water. Based on the PCA results, the 21-parameter model was chosen. The results showed that the quality of raw water in Macao has been relatively stable in the period of interest and appeared an upward trend overall. Furthermore, the outcome of environmental elements, such as natural events, the region's hydrology and meteorology, can have a significant impact on water quality. On the other hand, Macao's raw water quality met China's Class III water quality requirements and the raw water pollution was relatively low. Consequently, human activities didn't have a significant impact on water quality due to effective treatment and protection measures (Zhan et al. 2021).

Tampo et al. (2022) undertook a recent study in Adjougba (Togo), in the valley of Zio River. Water samples were collected from the surface water (SW), ground water (GW) and treated wastewater (TWW), intending to compare the water quality of these resources for irrigation and domestic use.

Hence, WQIs, water suitability indicators for irrigation purposes (WSI-IPs) and raw water quality parameters were compared using statistical analysis (factor analysis and Spearman's correlation).

Moreover, the results proposed that the water resources are suitable for irrigation and domestic use: TWW suitable for irrigation use, GW suitable for domestic use and SW suitable for irrigation use.

The NSFQWI and overall index of pollution (OPI) parameters were tested, and the results demonstrated that the sodium absorption ratio, EC, residual sodium carbonate, Chloride and FC are the most effective parameters for determining if water is suitable for irrigation.

On the other hand, EC, DO, pH, turbidity, COD, hardness, FC, nitrates, national sanitation foundation's water quality index (NSFWQI), and overall index of pollution (OPI) are the most reliable in the detection of water suitability for domestic use (Tampo et al. 2022).

Following these studies, it is worth examining the NSFQWI. This index can be used with other WQI models in studies on rivers, lakes etc., since one index can show different results than another index, in view of the fact that some indices might be affected by other variations such as seasonal variation.

Additionally, the NSFQWI should be developed and adapted to each river, so that any change in any value will affect the entire water quality. It is unhelpful to have a good water quality yet a low score of a parameter that can affect human health (case of FC).

#### 2.4.2 Canadian council of ministers of the environment water quality index (CCMEWQI)

The Canadian Water Quality Index adopted the conceptual model of the British Columbia Water Quality Index (BCWQI), based on relative sub-indices (Kizar 2018).

The CCMEWQI provides a water quality assessment for the suitability of water bodies, to support aquatic life in specific monitoring sites in Canada (Paun et al. 2016). In addition, this index gives information about the water quality for both management and the public. It can furthermore be applied in many water agencies in various countries with slight modification (Tyagi et al. 2013).

The CCMEWQI method simplifies the complex and technical data. It tests the multi-variable water quality data and compares the data to benchmarks determined by the user (Tirkey et al. 2015). The sampling protocol requires at least four parameters sampled at least four times but does not indicate which ones should be used; the user must decide (Uddin et al. 2021). Yet, the parameters may vary from one station to another (Tyagi et al. 2013).

After the water body, the objective and the period of time have been defined the three factors of the CWQI are calculated (Baghapour et al. 2013; Canadian Council of Ministers of the Environment 1999):

- (1) The scope (F1) represents the percentage of variables that failed to meet the objective (above or below the acceptable range of the selected parameter) at least once (failed variables), relative to the total number of variables.

$$F1 = \left( \frac{\text{Number of failed variables}}{\text{Total number of variables}} \right) \times 100 \quad (2)$$

- (2) The frequency (F2) represents the percentage of tests which do not meet the objectives (above or below the acceptable range of the selected parameter) (failed tests).

$$F2 = \left( \frac{\text{Number of failed tests}}{\text{Total number of tests}} \right) \times 100 \quad (3)$$

- (3) The amplitude represents the amount by which failed tests values did not meet their objectives (above or below the acceptable range of the selected parameter). It is calculated in three steps.

- a. The excursion is termed each time the number of an individual parameter is further than (when the objective is a minimum, less than) the objective and is calculated by two Eqs. (4,5) referring to two cases. In case the test value must not exceed the objective:

$$\text{excursion}_i = \left( \frac{\text{Failed test value}_i}{\text{Objective}_i} \right) - 1 \quad (4)$$

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

$$\text{excursion}_i = \left( \frac{\text{Objective}_i}{\text{Failed test value}_i} \right) - 1 \quad (5)$$

- b. The normalized sum of excursions, or *nse*, is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both meetings and not meeting their objectives):

$$nse = \frac{\sum_{i=1}^n \text{excursion}_i}{\text{number of tests}} \quad (6)$$

- c. *F3* is then calculated an asymptotic function that scales the normalized sum of the excursions from objectives (*nse*) to yield a range between 0 and 100:

$$F3 = \frac{nse}{0.01nse + 0.01} \quad (7)$$

Finally, the CMEWQI can be obtained from the following equation, where the index changes in direct proportion to changes in all three factors.

$$CCMEWQI = 100 - \left( \frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732} \right) \quad (8)$$

where 1.732 is a scaling factor and normalizes the resultant values to a range between 0 and 100, where 0 refers to the worst quality and one hundred represents the best water quality.

Once the CCME WQI value has been determined, water quality is ranked as shown in Table 3

Ramírez-Morales et al. (2021) investigated in their study the measuring of pesticides and water quality indices in three agriculturally impacted micro catchments in Costa Rica between 2012 and 2014. Surface

**Table 3** Water quality categorizations according to CCMEWQI (Kizar 2018; Canadian Council of Ministers of the Environment 1999)

Class	WQI Value	Water Quality	Description
I	95–100	Excellent	Water quality is protected with a virtual absence of threat. The conditions are very close to natural levels
II	80–94	Good	Water quality is protected with a minor degree of threat. The conditions rarely depart from natural levels
III	65–79	Fair	Water quality is usually protected but occasionally threatened. The conditions sometimes depart from natural levels
IV	45–64	Poor (Marginal)	Water quality is frequently threatened. The conditions often depart from natural levels
V	0–44	Very Poor (Poor)	Water quality is almost always threatened. The conditions usually depart from natural levels



water and sediment samples were obtained during the monitoring experiment.

The specifications of the water included: Pesticides, temperature, DO, oxygen saturation, BOD, TP, NO<sub>3</sub>, sulfate, ammonium, COD, conductivity, pH and TSS.

Sediment parameters included forty-two pesticides with different families including carbamate, triazine, organophosphate, phthalimide, pyrethroid, uracil, benzimidazole, substituted urea, organochlorine, imidazole, oxadiazole, diphenyl ether and bridged diphenyl.

WQIs are effective tools since they combine information from several variables into a broad picture of the water body's state. Two WQIs were calculated using the physicochemical parameters: The Canadian Council of Ministers of the Environment (CCME) WQI and the National Sanitation Foundation (NSF) WQI.

These were chosen since they are both extensively used and use different criteria to determine water quality: The NSF WQI has fixed parameters, weights, and threshold values, whereas the CCME has parameters and threshold values that are customizable.

The assessment of water quality using physicochemical characteristics and the WQI revealed that the CCME WQI and the NSF WQI have distinct criteria. CCME WQI categorized sampling point as marginal/bad quality, while most sampling locations were categorized as good quality in the NSF WQI. Seemingly, the water quality classifications appeared to be affected by seasonal variations: during the wet season, the majority of the CCME WQI values deteriorated, implying that precipitation and runoff introduced debris into the riverbed. Thus, it's crucial to compare WQIs because they use various factors, criteria, and threshold values, which might lead to different outcomes (Ramírez-Morales et al. 2021).

Yotova et al. (2021) directed an analysis on the Mesta River located between Greece and Bulgaria. The Bulgarian section of the Mesta River basin, which is under the supervision of the West-Aegean Region Basin Directorate, was being researched. The goal was to evaluate the surface water quality of ten points of the river using a novel approach that combines composite WQI developed by the CCME and Self organizing map (SOM) on the required monitoring data that include: DO, pH, EC, ammonium, nitrite, nitrate, total phosphate, BOD and TSS.

The use of WQI factors in SOM calculations allows for the identification of specific WQI profiles for various object groups and identifying groupings of river basin which have similar sampling conditions. The use of both could reveal and estimate the origin and magnitude of anthropogenic pressure. In addition, it might be determined that untreated residential wastewaters are to blame for deviations from high quality requirements in the Mesta River catchment.

Interestingly, this study reveals that WQI appear more accurate and specific when combined with a statistical test such as the SOM (Yotova et al. 2021).

#### 2.4.3 Oregon water quality index (OWQI)

The Oregon Water Quality Index is a single number that creates a score to evaluate the water quality of Oregon's stream and apply this method in other geographical region (Hamlat et al. 2017; Singh et al. 2013). The OWQI was widely accepted and applied in Oregon (USA) and Idaho (USA) (Sutadian et al. 2016).

Additionally, the OWQI is a variant of the NSF WQI, and is used to assess water quality for swimming and fishing, it is also used to manage major streams (Lumb et al. 2011b). Since the introduction of the OWQI in 1970, the science of water quality has improved noticeably, and since 1978, index developers have benefited from increasing understanding of stream functionality (Bharti and Katyal 2011). The Oregon index belongs to the specific consumption indices group. It is a water classification based on the kind of consumption and application such as drinking, industrial, etc. (Shah and Joshi 2017).

The original OWQI dropped off in 1983, due to excessive resources required for calculating and reporting results. However, improvement in software and computer hardware availability, in addition to the desire for an accessible water quality information, renewed interest in the index (Cude 2001).

Simplicity, availability of required quality parameters, and the determination of sub-indexes by curve or analytical relations are some advantages of this approach (Darvishi et al. 2016a). The process combines eight variables including temperature, dissolved oxygen (percent saturation and concentration), biochemical oxygen demand (BOD), pH, total solids, ammonia and nitrate nitrogen, total phosphorous and bacteria (Brown 2019). Equal weight parameters were

used for this index and has the same effect on the final factor (Darvishi et al. 2016a; Sutadian et al. 2016).

The Oregon index is calculated by the following Eq. 9 (Darvishi et al. 2016a):

$$OWQI = \frac{n}{\sqrt{\sum_{i=1}^n \frac{1}{SI_i^2}}} \quad (9)$$

where,  $n$  is the number of parameters ( $n=8$ )  $SI_i$  is the value of parameter  $i$ .

Furthermore, the OWQI scores range from 10 for the worse case to 100 as the ideal water quality illustrated in the following Table 4 (Brown 2019).

Kareem et al. (2021) using three water quality indices, attempted to analyze the Euphrates River (Iraq) water quality for irrigation purposes in three different stations: WAWQI, CCMEWQI AND OWQI.

For fifteen parameters, the annual average value was calculated, which included: pH, BOD, Turbidity, orthophosphate, Total Hardness, Sulphate, Nitrate, Alkalinity, Potassium Sodium, Magnesium, Chloride, DO, Calcium and TDS.

The OWQI showed that the river is “very poor”, and since the sub-index of the OWQI does not rely on standard-parameter compliance, there are no differences between the two inclusion and exclusion scenarios, which is not the case in both WAWQI and CCMEWQI (Kareem et al. 2021).

Similarly, the OWQI showed a very bad quality category, and it is unfit for human consumption, compared to the NSFQI and Wilcox indices who both showed a better quality of water in Darvishi et al., study conducted on the Talar River (Iran) (Darvishi et al. 2016b).

**Table 4** Average values of river water index according to OWQI index (Darvishi et al. 2016a)

Numerical value	Condition	Color
90–100	Excellent	Blue
85–89	Good	Green
80–84	Medium	Yellow
60–79	Bad	Orange
10–59	Very Bad	Red

#### 2.4.4 Weighted arithmetic water quality index (WAWQI)

The weighted arithmetic index is used to calculate the treated water quality index, in other terms, this method classifies the water quality according to the degree of purity by using the most commonly measured water quality variables (Kizar 2018; Paun et al. 2016). This procedure has been widely used by scientists (Singh et al. 2013).

Three steps are essential in order to calculate the WAWQI:

- (1) Further quality rating or sub-index was calculated using the following equation (Jena et al. 2013):

$$Q_n = 100 \times \frac{[V_n - V_o]}{[S_n - V_o]} \quad (10)$$

where,

$Q_n$  is the quality rating for the  $n$ th water quality parameter.

$V_n$  is the observed value of the  $n$ th parameter at a given sampling station.

$V_o$  is the ideal value of the  $n$ th parameter in a pure water.

$S_n$  is the standard permissible value of the  $n$ th parameter.

The quality rating or sub index corresponding to  $n$ th parameter is a number reflecting the relative value of this parameter in polluted water with respect to its permissible standard value (Yogendra & Puttaiah 2008).

- (2) The unit weight was calculated by a value inversely proportional to the recommended standard values ( $S_n$ ) of the corresponding parameters (Jena et al. 2013):

$$W_n = \frac{K}{S_n} \quad (11)$$

where,

$W_n$  is the unit weight for the  $n$ th parameter.

$K$  is the constant of proportionality.

$S_n$  is the standard value of the  $n$ th parameter.

- (3) The overall WQI is the aggregation of the quality rating ( $Q_n$ ) and the unit weight ( $W_n$ ) linearly (Jena et al. 2013):

$$WQI = \frac{\sum Q_n W_n}{\sum W_n} \quad (12)$$

After calculating the WQI, the measurement scale classifies the water quality from “unsuitable water” to “excellent water quality” as given in the following Table 5.

Sarwar et al. (2020) carried out a study in Chau-gachcha and Manirampur Upazila of Jashore District (Bangladesh). The goal of this study was to determine the quality of groundwater and its appropriateness for drinking, using the WAWQI including nine parameters: turbidity, EC, pH, TDS, nitrate, ammonium, sodium, potassium and iron. Many samplings point was taken from Chaugachcha and Manirampur, and WQI differences were indicated (ranging from very poor to excellent). These variations in WQI were very certainly attributable to variances in geographical location. Another possibility could be variations in the parent materials from which the soil was created, which should be confirmed using experimental data. It is worth mentioning that every selected parameter was taken into consideration during calculation. Similarly, the water quality differed in Manirampur due to the elements contained in the water samples that had a big impact on the water quality (Sarwar et al. 2020).

In 2021, García-Ávila et al. undertook a comparative study between the CCMEWQI and WAWQI for the purpose of determining the water quality in the city of Azogues (Ecuador). Twelve parameters were analyzed: pH, turbidity, color, total dissolved solids, electrical conductivity, total hardness, alkalinity, nitrates, phosphates, sulfates, chlorides and residual chlorine over 6 months. The average WAWQI value was calculated suggesting that 16.67% of the distribution system was of ‘excellent’ quality and 83.33% was

of ‘good’ quality, while the CCMEWQI indicated that 100% of the system was of ‘excellent’ quality.

This difference designated that the parameters having a low maximum allowable concentration have an impact on WAWQI and that WAWQI is a valuable tool to determine the quality of drinking water and have a better understanding of it (García-Ávila et al. 2022a, b).

#### 2.4.5 Additional water quality indices

The earliest WQI was based on a mathematical function that sums up all sub-indices, as detailed in the 2.1. History of water quality concept section (Aljanabi et al. 2021). The Dinius index (1972), the OWQI (1980), and the West Java index (2017) were later modified from the Horton index, which served as a paradigm for later WQI development (Banda and Kumarasamy 2020).

Based on eleven physical, chemical, organic, and microbiological factors, the Scottish Research Development Department (SRDDWQI) created in 1976 was based on the NSFQI and Delphi methods used in Iran, Romania, and Portugal. Modified into the Bascaron index (1979) in Spain, which was based on 26 parameters that were unevenly weighted with a subjective representation that allowed an overestimation of the contamination level. The House index (1989) in the UK valued the parameters directly as sub-indices. The altered version was adopted as Croatia’s Dalmatian index in 1999.

The Ross WQI (1977) was created in the USA using only 4 parameters and did not develop into any further indices.

In 1982, the Dalmatian and House WQI were used to create the Environmental Quality Index, which is detailed in Sect. 2.1. This index continues to be difficult to understand and less powerful than other indices (Lumb et al. 2011a; Uddin et al. 2021).

The Smith index (1990), is based on 7 factors and the Delphi technique in New Zealand, attempts to eliminate eclipsing difficulties and does not apply any weighting, raising concerns about the index’s accuracy (Aljanabi et al. 2021; Banda and Kumarasamy 2020; Uddin et al. 2021).

The Dojildo index (1994) was based on 26 flexible, unweighted parameters and does not represent the water’s total quality.

**Table 5** WAWQI and status of water quality (Yogendra and Puttaiah 2008)

Water quality index level	Water quality status
0–25	Excellent water quality
26–50	Good water quality
51–75	Poor water quality
76–100	Very poor water quality
> 100	Unsuitable for drinking

With the absence of essential parameters, the eclipse problem is a type of fixed-parameter selection. The Liou index (2004) was established in Taiwan to evaluate the Keya River based on 6 water characteristics that were immediately used into sub-index values. Additionally, because of the aggregation function, uncertainty is unrelated to the lowest sub-index ranking (Banda and Kumarasamy 2020; Uddin et al. 2021).

Said index (2004) assessed water quality using only 4 parameters, which is thought to be a deficient number for accuracy and a comprehensive picture of the water quality. Furthermore, a fixed parameter system prevents the addition of any new parameters.

Later, the Hanh index (2010), which used hybrid aggregation methods and gave an ambiguous final result, was developed from the Said index.

In addition to eliminating hazardous and biological indicators, the Malaysia River WQI (MRWQI developed in the 2.1 section) (2007) was an unfair and closed system that was relied on an expert's judgment, which is seen as being subjective and may produce ambiguous findings (Banda and Kumarasamy 2020; Uddin et al. 2021).

Table illustrated the main data of the studies published during 2020–2022 on water quality assessments and their major findings:

## 2.5 Advantages and disadvantages of the selected water quality indices

A comparison of the selected indices is done by listing the advantages and disadvantages of every index listed in the Table 7 below.

## 2.6 New attempts of WQI studies

Many studies were conducted to test the water quality of rivers, dams, groundwater, etc. using multiple water quality indices throughout the years. Various studies have been portrayed here in.

Massoud (2012) observed during a 5-year monitoring period, in order to classify the spatial and temporal variability and classify the water quality along a recreational section of the Damour river using a weighted WQI from nine physicochemical parameters measured during dry season. The WWQI scale ranged between “very bad” if the WQI falls in the range 0–25, to “excellent” if it falls in the range

91–100. The results revealed that the water quality of the Damour river is generally affected by the activities taking place along the watershed. The best quality was found in the upper sites and the worst at the estuary, due to recreational activities. If the Damour river is to be utilized it will require treatment prior any utilization (Massoud 2012).

Rubio-Arias et al. (2012) conducted a study in the Luis L. Leon dam located in Mexico. Monthly samples were collected at 10 random points of the dam at different depths, a total of 220 samples were collected and analyzed. Eleven parameters were considered for the WQI calculation, and WQI was calculated using the Weighted WQI equation and could be classified according to the following ranges: <2.3 poor; from 2.3 to 2.8 good; and >2.8 excellent. Rubio-Arias et al., remarked that the water could be categorized as good during the entire year. Nonetheless, some water points could be classified as poor due to some anthropogenic activities such as intensive farming, agricultural practices, dynamic urban growth, etc. This study confirms that water quality declined after the rainy season (Rubio-Arias et al. 2012).

In the same way, Haydar et al. (2014) evaluated the physical, chemical and microbiological characteristics of water in the upper and lower Litani basin, as well as in the lake of Qaraaoun. The samples were collected during the seasons of 2011–2012 from the determined sites and analyzed by PCA and the statistical computations of the physico-chemical parameters to extract correlation between variables. Thus, the statistical computations of the physico-chemical parameters showed a correlation between some parameters such as TDS, EC, Ammonium, Nitrate, Potassium and Phosphate. Different seasons revealed the presence of either mineral or anthropogenic or both sources of pollution caused by human interference from municipal wastewater and agricultural purposes discharged into the river. In addition, temporal effects were associated with seasonal variations of river flow, which caused the dilution of pollutants and, hence, variations in water quality (Haydar et al. 2014).

Another study conducted by Chaurasia et al., (2018), proposed a groundwater quality assessment in India using the WAWQI. Twenty-two parameters were taken into consideration for this assessment, however, only eight important parameters were chosen to calculate the WQI. The rating of water quality

shows that the ground water in 20% of the study area is not suitable for drinking purpose and pollution load is comparatively high during rainy and summer seasons. Additionally, the study suggests that priority should be given to water quality monitoring and its management to protect the groundwater resource from contamination as well as provide technology to make the groundwater fit for domestic and drinking (Chaurasia et al. 2018).

Daou et al. (2018) evaluated the water quality of four major Lebanese rivers located in the four corners of Lebanon: Damour, Ibrahim, Kadisha and Orontes during the four seasons of the year 2010–2011. The assessment was done through the monitoring of a wide range of physical, chemical and microbiological parameters, these parameters were screened using PCA. PCA was able to discriminate each of the four rivers according to a different trophic state. The Ibrahim River polluted by mineral discharge from marble industries in its surroundings, as well as anthropogenic pollutants, and the Kadisha river polluted by anthropogenic wastes seemed to have the worst water quality. This large-scale evaluation of these four Lebanese rivers can serve as a water mass reference model (Daou et al. 2018).

Moreover, some studies compared many WQI methods. Kizar (2018), carried out a study on Shatt Al-Kufa in Iraq, nine locations and twelve parameters were selected. The water quality was calculated using two methods, the WAWQI and CWQI. The results revealed the same ranking of the river for both methods, in both methods the index decreased in winter and improved in other seasons (Kizar 2018).

On the other hand, Zotou et al. (2018), undertook a research on the Polyphytos Reservoir in Greece, taking into consideration thirteen water parameters and applying 5 WQIs: Prati's Index of Pollution (developed in 1971, based on thirteen parameter and mathematical functions to convert the pollution concentration into new units. The results of PI classified water quality into medium classes (Gupta and Gupta 2021). Bhargava's WQI (established in 1983, the BWQI categorize the parameters according to their type: bacterial indicators, heavy metals and toxins, physical parameters and organic and inorganic substances. The BWQI tends to classify the water quality into higher quality classes, which is the case in the mentioned study (Gupta and Gupta 2021). Oregon WQI, Dinius second index, Weighted Arithmetic WQI, in addition to the NSF and

CCMEWQI. The results showed that Bhargava and NSF indices tend to classify the reservoir into superior quality classes, Prati's and Dinius indices fall mainly into the middle classes of the quality ranking, while CCME and Oregon could be considered as "stricter" since they give results which range steadily between the lower quality classes (Zotou et al. 2018).

In their study, Ugochukwu et al. (2019) investigated the effects of acid mine drainage, waste discharge into the Ekulu River in Nigeria and other anthropogenic activities on the water quality of the river. The study was performed between two seasons, the rainy and dry season. Samples were collected in both seasons, furthermore, the physico-chemistry parameters and the heavy metals were analyzed. WQI procedure was estimated by assigning weights and relative weights to the parameters, ranking from "excellent water" (< 50) to "unsuitable for drinking" (> 300). The results showed the presence of heavy metals such as lead and cadmium deriving from acid mine drainage. In addition, the water quality index for all the locations in both seasons showed that the water ranked from "very poor" to "unsuitable for drinking", therefore the water should be treated before any consumption, and that enough information to guide new implementations for river protection and public health was provided (Ugochukwu et al. 2019).

The latest study in Lebanon related to WQI was carried out by El Najjar et al. (2019), the purpose of the study was to evaluate the water quality of the Ibrahim River, one of the main Lebanese rivers. The samples were collected during fifteen months, and a total of twenty-eight physico-chemical and microbiological parameters were tested. The parameters were reduced to nine using the Principal Component Analysis (PCA) and Pearson Correlation. The Ibrahim WQI (IWQI) was finally calculated using these nine parameters and ranged between 0 and 25 referring to a "very bad" water quality, and between 91 and 100 referring to an "excellent" water quality. The IWQI showed a seasonal variation, with a medium quality during low -water periods and a good one during high-water periods (El Najjar et al. 2019).

### 3 Conclusion

WQI is a simple tool that gives a single value to water quality taking into consideration a specific number

**Table 6** Various research projects carried out on WQIs

Index	Date	Location	Parameters	Major Findings	Reference
WAWQI	January 2020	Glacial lakes from Rodnei mountains, Romania	pH, EC, turbidity, suspended materials, DO, oxygen saturation, $\text{NO}_2^-$ , $\text{NO}_3^-$ , $\text{SO}_4^{2-}$ , soluble orthophosphate, As, Cu, Fe, Pb, Se and 14 types of bacteria	The assessment of all the physico-chemical parameters indicated a good quality, with slight anthropic alteration and impact The water quality index (WQI) indicated excellent and good quality for the studied samples The heavy metal pollution index and heavy metal evaluation index indicated no metal pollution In some samples the fecal coliforms, fecal streptococci and aerobic heterotrophic bacteria were relatively high	Roşca (2020)
WAWQI	January 2020	Ithikkara and Kallada river basins, Kerala, In dia	pH, TDS, EC, turbidity, temperature, hardness, Ca, Mg, Na, K, carbonate, bicarbonate Cl, sulfate, nitrate fluoride, iron, silicate	The water quality, according to the WQI 90% of the monsoon and pre-monsoon was “excellent”, and the rest was “good” This study elucidates the relationship between the ions and the parameters	Nair et al. (2020)
WAWQI and IWQI (Irrigation WQI)	March 2020	Hilly terrain of Jammu Himalaya	pH, TDS, total hardness, $\text{HCO}_3^-$ , $\text{SO}_4^{2-}$ , $\text{Cl}^-$ , $\text{NO}_3^-$ , $\text{F}^-$ , $\text{Ca}^{2+}$ , $\text{Mg}^{2+}$ , $\text{Na}^+$ , $\text{K}^+$	The Wilcox diagram revealed that most of the spring samples are good (25%) to excellent (75) category for irrigation The US Salinity Laboratory diagram indicates that 83% of groundwater samples belong to medium salinity and low sodium hazards, whereas only 12% samples fall under the high salinity water which considered as unsuitable for soil with restricted drainage The water quality index of domestic uses was determined and found that 95% of the spring water samples are under excellent to good category (good source for drinking purposes)	Taloor et al. (2020)

**Table 6** (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WAWQI	March 2020	Monaragala, Sri Lanka	pH, alkalinity, hardness, chloride, sulphate, nitrate, phosphate, fluoride, calcium, sodium, potassium, magnesium, and TDS	This study demonstrated that groundwater quality is significantly influenced by the basement lithology thus indicating high contents of total hardness, EC, TDS, Cl, and fluoride WQI indicated a very poor GW quality due to high ionicity	Udeshani et al. (2020)
CCMEWQI	March 2020	Quebec, Canada	SS, pH, EC, N-NH <sub>3</sub> , Fe, Na, Ca, Cu, Fe, Mg, Mn, K, Na, Zn NO <sub>3</sub> <sup>-</sup> , NO <sub>2</sub> <sup>-</sup> and phosphorus	The CCMEWQI indicated that they are ammonia, conductivity, pH, and concentrations of suspended material. In two of the three regions under study, the results showed a substantial difference between the WQI values of water from harvested peatlands and those of streams Results also revealed that for harvested peatlands, the pH recommendation is frequently disregarded	Betis et al. (2020)
NSFWQI	March 2020	Saluran Tarum Barat, West Java	Temperature, turbidity, TS, pH, DO, BOD <sub>5</sub> , phosphate, nitrate and FC	The NSFWQI revealed a medium water quality due to agricultural, industrial and infrastructure activities	Cristable et al. (2020)
WWQI	March 2020	Boudaroua Lake, Morocco	pH, EC, turbidity, DO, total hardness, Ca <sup>2+</sup> , Mg <sup>2+</sup> , Na <sup>+</sup> , K <sup>+</sup> , NH <sub>4</sub> <sup>+</sup> , Cl <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> and NO <sub>3</sub> <sup>-</sup>	WQI reflects a good water quality however, contaminated by nitrogen organic compounds from agricultural practices with the first precipitation in autumn	En-nkhili et al. (2020)
Specified weighted WQI <sub>min</sub>	April 2020	The Middle-Route (MR) of the South-to-North Water Diversion Project of China (SNWDPC),	Total phosphorus, fecal coliforms, mercury, temperature and DO	The results demonstrated that the water quality status of the MR of the SNWDPC has been steadily maintained at an “excellent” level during the monitoring period the proposed WQI <sub>min</sub> model is a useful and efficient tool to evaluate and manage the water quality	Nong et al. (2020)

Table 6 (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WAWQI UWQI (universal)	May 2020	South African River Catchments	Ammonia, Ca, Cl, chlorophyll, EC, fluoride, hardness, Mg, Mn, nitrate, pondus hydrogenium, sulphate turbidity, alkalinity,	All the tested parameters were within the permissible level except for nitrate turbidity, Mn and chlorophyll in different stations The UWQI is based on the weighted arithmetic sum method, with parameters, weight coefficients and sub-index rating curves established through expert opinion in the form of the participation-based Rand Corporation's Delphi Technique and extracts from the literature UWQI is considered technically stable and robust The study conducts research to unify WQIs based on multivariate statistical approaches	Banda and Kumarasamy (2020)
WWQI	May 2020	Limoeiro River watershed, São Paulo State, Brazil	DO, pH, BOD, temperature, total nitrogen, total phosphorus, turbidity, chlorophyll a, TS and E. coli	The water deficit season (autumn) had the worse WQI, however the water surplus season had the best WQI The trophic state index was improving during water surplus period, in dry periods the trophic state index wasn't influenced	Gomes (2020)
MWQI (Malaysia WQI)	June 2020	Klang River basin, Malaysia	DO, BOD, COD, SS, pH and ammoniacal nitrogen	The high value of correlation coefficient (r) indicated that the computed WQI values by utilizing the ANNs (artificial neural network) model were in quite good accord with the noted WQI The ANN model results indicate that DO affects the most the WQI and pH the less WQI accuracy decreases with the absence of DO, hence, it is still in the acceptable limits	Othman et al. (2020)



**Table 6** (continued)

Index	Date	Location	Parameters	Major Findings	Reference
NSFWQI BISWQI (bureau of Indian stand- ards) MWQI (Modified WQI)	July 2020	Twin Lakes of Tikkar Taal, Haryana state, India	Temperature, pH, EC, DO, turbidity, TDS, TSS, nitrate, total phos- phorous, BOD, COD, SO <sub>4</sub> , Ca, Mg, Cl, total alkalinity, bicarbonates, total hardness, fecal coliform, Zn, Fe, As, Cd, Hg, Pb, Ni and Cr	The water quality for both lakes is fit for irrigation, recreational activities, fisheries, and wildlife propagation The water may be used for drinking after treatment Using the NSFQI, the overall rating of water quality for both lakes for both sample periods was found to be in the good category Using the BISWQI, both lakes' overall water quality was rated in the good category for both sample periods Using this newly developed MWQI, the water quality was categorized to be excellent and good for samples collected in August and October respectively for both the lakes, providing means to reduce and eclipse the ambiguity and problems of WQI	Vasistha (2020)
NSFWQI CCMEWQI	July 2020	Greece	Ph, EC, DO, NH <sub>4</sub> <sup>+</sup> , Cd, Cr, Cl <sup>-</sup> , Cu, Pb, Mn, Ni, NO <sub>3</sub> <sup>-</sup> , NO <sub>2</sub> <sup>-</sup> , SO <sub>4</sub> <sup>-</sup> and Na <sup>+</sup>	The comparison of NSF and CCME WQIs shows that the latter is stricter since it estimates statistically significant lower values than the NSFQI Based on the performance of the examined indices, it is shown that, mostly, the CCME-WQI classification findings are close to those of the ground water directives	Alexakis (2020)

Table 6 (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WAWQI	July 2020	Arid Beichuan River Basin, China	pH, DO, TDS, K <sup>+</sup> , Na <sup>+</sup> , Ca <sup>2+</sup> , Mg <sup>2+</sup> , NO <sub>3</sub> <sup>-</sup> , NO <sub>2</sub> <sup>-</sup> , NH <sub>3</sub> <sup>+</sup> , Cl <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , total nitrogen, total phosphorus, COD, TOC, Al, Fe, Mn, Pb	The WQI results showed that the water quality deteriorated from upstream to downstream as a result of human activity Water quality was poorer during wet season, due to runoff of contaminants Spatial variations in river water quality showed that the concentrations of TDS, Cl, TN, Fe, and TOC increased from upstream to downstream The temporal variation in groundwater quality is affected by the rainfall runoff	Xiao et al. (2020)
CCMEWQI	July 2020	Agan River catchment, West Siberia	pH, NH <sub>4</sub> <sup>+</sup> , NO <sub>3</sub> <sup>-</sup> , PO <sub>4</sub> <sup>3-</sup> , BOD <sub>20</sub> , Cl <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , total petroleum hydrocarbons (TPH), Fe, Mn, Cu, Cr, Ni, Hg, Pb and Zn	CCMEWQI indicated a poor and marginal water quality High Mn, Fe, and Cu concentrations originated from natural leaching elements from acidic soils High amounts of TPH and chloride resulted from oil contaminated lands	Moskovchenko et al. (2020)
WAWQI	August 2020	Series of impounded lakes along the Eastern Route of China's South-to-North Water Diversion Project, China	Water temperature, EC, DO, pH, turbidity, nitrogen, ammonia, nitrate, nitrite, total phosphorus, orthophosphate, TSS, Cl, COD, and total hardness	The WQI indicated overall "Good" water quality with an improving trend from upstream to downstream lakes The upstream Gaoyou Lake had over 55% of the monitoring sites with "Moderate" water quality in all the seasons	Qu et al. (2020)
WAWQI IWQI	August 2020	Netravati River basin, India	pH, DO, EC, TDS, HCO <sub>3</sub> <sup>-</sup> , Na <sup>+</sup> , K <sup>+</sup> , Ca <sup>2+</sup> , Mg <sup>2+</sup> , Cl <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , PO <sub>4</sub> <sup>3-</sup> , NO <sub>3</sub> <sup>-</sup> , Fe <sup>2+</sup> , Pb <sup>2+</sup>	The overall WQI values were relatively high in the entire river, due to salt deposits, sewage, industrial and anthropogenic wastes etc The seasonal variation of WQI is distinct with the highest value in post-monsoon followed by pre-monsoon and monsoon Well waters showed an excellent water quality, and they were not influenced by seasonal variations IWQI indicated an excellent water quality for irrigation	Sudhakaran et al. (2020)

**Table 6** (continued)

Index	Date	Location	Parameters	Major Findings	Reference
IWQI	August 2020	Federal District, Brazil	Temperature, DO, pH, EC, TDS, turbidity, total hardness, total phosphorus, sodium adsorption ratio, TC, E. coli, Na <sup>+</sup> , K <sup>+</sup> , Ca <sup>2+</sup> , Mg <sup>2+</sup> , NH <sub>4</sub> <sup>+</sup> , Cl <sup>-</sup> , F <sup>-</sup> , NO <sub>3</sub> <sup>-</sup> , NO <sub>2</sub> <sup>-</sup> , PO <sub>4</sub> <sup>3-</sup> and SO <sub>4</sub> <sup>2-</sup>	PCA reduced the number of parameters to 6 for the IWQI The IWQI showed a difference between 2 different sampling points classified as “very good” in the dry period The other sample points were classified as “good” and “average” for irrigation in both dry and rainy periods	Muniz et al. (2020)
WAWQI	September 2020	Jamalpur Sadar area, Bangladesh	pH, TDS, Cl, SO <sub>4</sub> , PO <sub>4</sub> , Ca, Mg, Na, K, Cu, Fe, Mn, Zn, Pb, Cd and Cr	According to the WQI ratings, 95% of the groundwater samples were found in the ‘unsuitable’ category for drinking, while 18% of the surface and 25% of the groundwater samples identified as ‘suitable’ for irrigation usages The calculated results of the heavy metal pollution index (HMPI), heavy metal evaluation index (HMEI), and environmental water quality index (EWQI) also showed almost similar trends with the WQI The results revealed that surface water possessed more potential non-carcinogenic harmful health risks to the residents of the study area to compare to groundwater	Zakir et al. (2020)
ASEANWQI Malaysia WQI	September 2020	Selangor river basin, Malaysia	Ammoniacal nitrogen, BOD, COD, DO, pH, SS, TC, FC, PO <sub>4</sub> <sup>3-</sup> , NO <sub>3</sub> and turbidity	Due to the different aspects and standards of the parameters the grading of the river varied the indices that considered all types of parameters provided a consistent water quality (very poor), however the indices that considered either physicochemical or biological parameters gives a relatively less strict evaluation (fair to poor)	Wong et al. (2020)

Table 6 (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WAWQI	September 2020	Sacred Lake Hemkund, Garhwal Himalaya	pH, DO, BOD, TDS, free CO <sub>2</sub> , hardness, Ca, Mg, Cl, total alkalinity, nitrate, sulphate, phosphate, EC, FC and TC	The study reveals that WQI is an exceptional process to evaluate the health of an aquatic body and to manage and conserve an aquatic body WQI indicates an excellent water quality All parameters lay much less than the permissible value	Deep et al. (2020)
WAWQI	October 2020	Büyük Menderes River, Turkey	pH, EC, TDS, Cl, NO <sub>3</sub> -N, NH <sub>3</sub> -N, NO <sub>3</sub> -N, DO, COD, orthophosphates, sulphates, Na <sup>+</sup> , K <sup>+</sup> , Ca <sup>2+</sup> and Mg <sup>2+</sup>	WQI values varied over a wide range across the river between “good” and “very poor.” To prevent pollution and maintain the WQ wastewater originating from domestic and industrial sources must be treated prior discharge into the river Fertilizers and pesticides should also be regulated to reduce their exposure to the water	Yilmaz et al. (2020)
CCMEWQI WAWQI	November 2020	Lower Danube, Romania and Republic of Moldova	pH, DO, BOD <sub>5</sub> , COD, N-NH <sub>4</sub> <sup>+</sup> , N-NO <sub>3</sub> <sup>-</sup> , N-NO <sub>2</sub> <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , Cl <sup>-</sup> , total nitrogen, total phosphorus, total iron, Zn <sup>2+</sup> and total chromium	The spatial assessment demonstrates that the Danube is affected by the pollutants it transports The WQI tends to be lower near agricultural and industrial lands A lower quality is observed during summer and autumn Water pollution index and CCMEWQI classified the water as “good,” whereas WAWQI classified the water as 53% “fair” and 47% “good”	Calmac et al. (2020)
Serbian WQI (SWQI)	December 2020	Morača river basin, Montenegro	Oxygen saturation, BOD <sub>5</sub> , ammonium, pH, total nitrogen, orthophosphates, SS, temperature, EC and coliforms	The SWQI indicated an improvement of the water quality during the years, hence, in the lower part of the Morača River the water quality was assigned as “poor” due to wastewater in the city, garbage disposal and agricultural practices It is mandatory to control and reduce the pollution especially during low flow	Doderovic et al. (2020)

**Table 6** (continued)

Index	Date	Location	Parameters	Major Findings	Reference
NSFWQI adapted by CETESB,	January 2021	Mirim Lagoon, Brazil	DO, thermotolerant coliforms, pH, BOD, temperature, N, P, turbidity, and TS	The results demonstrated that the new WQI did not differ significantly from the original one The new WQI was only based on 3 parameters (thermotolerant coliforms, phosphorus and DO) to reduce the cost and eclipse effect, however the original WQI used all 9 parameters	Valentini et al. (2021)
WWQI	January 2021	upper Napo basin, Ecuador, Amazon	DO, pH, temperature, TDS, turbidity, COD, FC, color, $PO_4^{3-}$ , $NO_3^-$ , $NO_2^-$ , $Ca^{2+}$ , $Mg^{2+}$ , $Cl^-$ , $SO_4^{2-}$ , $NH_3$ and $NH_4^{++}$	The urban areas and the landfills areas had the worse WQI and phytotoxicity Intermediate values were demonstrated at the gold mining and fish farming areas In gold mining areas, macroinvertebrate was absent which elucidates a warning signal concerning long term impacts on the area The combination of WQI and benthic macroinvertebrates with phytotoxicity allowed a clear conclusion about the environmental impacts	Galarza et al. (2021)
WAWQI	January 2021	Karaoun Reservoir, Lebanon	Temperature, salinity, $NH_3$ ,m EC, DO, $NO_3^-$ , $NO_2^-$ , pH, $PO_4$ , $SO_4$ , TDS, water depth data, flow data of Litani River, daily precipitation data	The PCA showed that the deterioration of water quality is due to erosion, municipal sewage, and pollution by fertilizers Precipitation higher than 250 mm was associated with higher WQI therefore better quality	Fadel et al. (2021)

Table 6 (continued)

Index	Date	Location	Parameters	Major Findings	Reference
NSFWQI	January 2021	Doce River basin, Brazil	DO, thermotolerant coliforms, pH, BOD, nitrate, total phosphorus, temperature, turbidity, and total solids	<p>According to the findings of the temporal trend analysis, most of the stations did not exhibit a statistically significant trend for the WQI</p> <p>Analyzing the parameters, the nitrate deteriorated the WQ harmed by the pervasive pollution coming from agricultural areas</p> <p>The <i>Escherichia coli</i> results confirmed the effects of the release of residential effluents and revealed the lack of a significant trend is nevertheless concerning because it could mean that the state of the water bodies' degradation is being maintained</p>	Fraga et al. (2021)
Serbian WQI	January 2021	Nišava River, Serbia	Oxygen saturation, BOD <sub>5</sub> , ammonium, pH, total oxidized nitrogen, orthophosphates, suspended solids, temperature, conductivity and coliform bacteria	<p>The SWQI classified one of the tributaries (Jerma River) as "bad" quality, while other controls' water quality points were "good" in nature</p> <p>Since 2013 there has been a decrease especially at the most downstream station (went from good to bad)</p> <p>BOD, total oxidized nitrogen and phosphates concentrations were high due to loaded organic compounds originating from the wastewater from the settlements which are discharged into water courses without any treatment</p>	Stričević et al. (2021)
Malaysian WQI	February 2021	Malaysia	DO, pH, COD, SS, NH <sub>3</sub> -N and BOD	<p>Aspects of water quality were significantly influenced by weather, pollutants, industrial, commercial, and residential wastewater</p> <p>The machine learning algorithms predicted sudden change and high accuracy</p> <p>The Putrajaya Lake, showed a significant increase in water quality (class D),</p>	Najah et al. (2021)

Table 6 (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WAWQI	February 2021	Gomti lake, India	DO, BOD <sub>5</sub> and total coliform	<p>The COVID-19 lockdown deteriorated 69% of the water quality's sites</p> <p>The upstream site suggested a slight decrease due to anthropogenic activities</p> <p>The 2 downstream stations witnessed an improvement in water quality due to self-healing from ground water</p> <p>Within Lucknow city all the water quality was deteriorating</p>	Khan et al. (2021)
WWQI	February 2021	Upper Krishna River basin, Telangana, India	pH, temperature, EC, TDS, hardness, alkalinity, F <sup>-</sup> , Cl <sup>-</sup> , NO <sub>3</sub> <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , HCO <sub>3</sub> <sup>-</sup> , Na <sup>+</sup> , Ca <sup>2+</sup> , and Mg <sup>2+</sup>	<p>Seasonal fluctuations showed that runoff water during the monsoon is what causes the amount of the spread of dissolved ions in groundwater quality</p> <p>Because farming predominates in the area, leaching agricultural fertilizer wastes is one of the major sources of nitrate contamination in groundwater</p> <p>At the location, close to the stream origin or joining of higher-order streams, most of the groundwater samples were found to be higher/above permitted limits of various ions</p> <p>Most crucially, WQI indicates that the number of people in the "poor to unfit for drinking" category has increased by almost twice as much, indicating a rapid decline in water quality caused by leaching during the monsoon season</p> <p>According to hazard quotient values, there is a significant risk of non-carcinogenic disease for children and new/borns in the research area</p>	Vaiphei and Kurakalva (2021)

Table 6 (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WWQI	February 2021	Lower Danube and Tributaries, Romania	pH, DO, BOD <sub>5</sub> , COD, NH <sub>4</sub> <sup>+</sup> -N, NO <sub>3</sub> <sup>-</sup> -N, total phosphorus, TS, Cl <sup>-</sup> and SO <sub>4</sub> <sup>2-</sup>	WQIs typically drop with time, showing that water quality has increased in most places The used methodology was helpful for combining several characteristics into a single number to evaluate the quality of the water, for spotting long-term trends at various places, and for contrasting locations in terms of pollution	Frñcu (2021)
NSFWQI	February 2021	Macao, China	Color, temperature, odor, pH, turbidity, conductivity, total hardness, chloride, DO, COD and TSD, FC, BOD <sub>5</sub> , total phosphorus, nitrate and TS	The NSFQI classified the river as “good to excellent” with a study upward trend and a high impact of the natural factors compared to the anthropogenic The impact of human activities on the river is minim due to positive protective measures	Zhan et al. (2021)
WWQI	March 2021	Turawa reservoir, Mała Panew river, Poland	Temperature, pH, DO, BOD <sub>5</sub> , COD, NH <sub>4</sub> <sup>-</sup> -N, dissolved substances, TSS, NO <sub>3</sub> <sup>-</sup> -N, NO <sub>2</sub> <sup>-</sup> -N, organic nitrogen, total nitrogen, total phosphorus, phosphates, Zn, Cu, and Cr	The analysis revealed that high temperatures and an alkaline reaction may promote the release of nitrogen and phosphorus compounds from sediment during the dry months of the summer, which suggests an elevated concentration of phosphorus, organic N, phosphate, and NH <sub>4</sub> <sup>-</sup> -N in waters The WQI indicated that the water improved after passing by the reservoir Both nitrite and nitrate nitrogen are responsible for the eutrophication process Additionally in comparison to the concentration of these compounds flowing into the reservoir, the Turawa reservoir lowers the concentration of nitrate and nitrite nitrogen	Gruss et al. (2021)



**Table 6** (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WWQI	March 2021	Salda Lake Basin, Turkey	Temperature, EC, oxidation–reduction potential, pH, TDS, Ca, Mg, Na, K, CO <sub>3</sub> , HCO <sub>3</sub> , Cl, SO <sub>4</sub> , NO <sub>2</sub> , NO <sub>3</sub> , NH <sub>4</sub> , F, Al, As, Fe, Mn and Pb	<p>The physical properties and ions in GW are due to rock–water interaction</p> <p>The primary processes that affect water chemistry are the chemical decomposition and evaporation of rock-forming minerals</p> <p>According to the WQI the GW was rated from excellent to good during wet season and poor during dry season</p> <p>GW is unsuitable for irrigation (following the fertilizer and trace elements and magnesium hazard analysis), in addition GW is unsuitable for industrial areas (crusting metal),</p>	Varol et al. (2021)
WWQI	April 2021	Suzhou, China	Temperature, DO, COD, total nitrogen, nitrate nitrogen, total phosphorus, turbidity, TSS, pH, chlorophyll-a and TOC	<p>The advantages of convenient data collection, extensive region coverage, low cost, and spatial variation demonstration are shared by remote sensing photos and open social data</p> <p>It was possible to assess geographical changes in ecological conditions and offer strong policy-making support for the management and protection of wetlands</p>	Yang et al. (2021)
CCMEWQI	April 2021	Anyang-Cheon Stream, Korea	Depth, velocity, substrate, DO, BOD and COD	<p>The results showed that flow depth, velocity enhanced, in addition to COD, DO and BOD improved therefore aquatic life improved</p> <p>CCMEWQI indicated an overall improvement of the water quality from marginal to good quality due to the ecological river restoration project</p>	Choi and Choi (2021)

Table 6 (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WWQI	May 2021	Mirim Lagoon and the São Gonçalo Channel, Brazil	Turbidity, DO, BOD, total nitrogen, total phosphorus, thermotolerant coliforms, TS, temperature, pH and chlorophyll-a	The water quality index (WQI), the trophic state index (TSI) and statistical methods observed how agricultural operations and the discharge of untreated effluents into their beds have a strong impact, degrading these water resources. Despite this, the collecting points, for the most part, had good WQI and TSI ranging from quality ranges 1 to 3 (great to acceptable)	da Silveira et al. (2021)
Vietnamese WQI	May 2021	Dong Thap province, Vietnam	Temperature, pH, turbidity, DO, BOD, COD, TSS, ammonia, nitrite, total nitrogen, orthophosphate, chloride, sulfate, coliforms, and E. coli	The findings demonstrated that TSS, BOD, COD, ammonia, nitrite, and orthophosphate were the main constraint on the water quality. The deteriorated water quality was in order of microbiological > nutrients > organic matters. WQI evaluated the water's quality as poor and the set pair analysis as medium	Giao et al. (2021)
NSFWQI	May 2021	Tegal City, central Java	temperature, TDS, TSS, pH, BOD <sub>5</sub> , DO, PO <sub>4</sub> and NO <sub>3</sub>	The increasing trend of NSFWQI during rainy season in Sibelis estuary, classified as poor quality due to industrial activities, as for the Kemiri estuary indicated a decreasing trend falling into the medium category due to pond fisheries, agricultural activities, and domestic pollutions	Ristanto et al. (2021)
CCMEWQI	May 2021	Mariisa River, Southern Bulgaria	N-NH <sub>4</sub> , N-NO <sub>3</sub> , N-NO <sub>2</sub> , N-tot, P-tot, P-PO <sub>4</sub> , Al, As, Fe, Cu, Mn, Ni, Pb, and Zn	Most of the parameters are not within the requirements of water quality. CCMEWQI and heavy metal pollution index classified the water as poor due to unregulated discharge raw effluents of mining, anthropogenic activities, and industrial sources	Radeva and Seymenov (2021)

**Table 6** (continued)

Index	Date	Location	Parameters	Major Findings	Reference
CCMEWQI	June 2021	Chapala lake, Mexico	pH, DO, S, NO <sub>2</sub> <sup>-</sup> , N, NO <sub>3</sub> <sup>-</sup> , PO <sub>4</sub> <sup>3-</sup> , Alkalinity, TS, COD, SO <sub>4</sub> <sup>2-</sup> , Cl <sup>-</sup> , F <sup>-</sup> and SiO <sub>2</sub>	The WQI calculations indicated a poor water quality Metals, especially zinc were able to interact with gills of fish The correlation, cluster and factor analysis demonstrated that pollutants related with both agricultural and tourist activities produce an increase of agrochemicals, organic matter, and poorly treated waters	Murillo-Delgado et al. (2021)
CCMEWQI	June 2021	Troizina basin, Greece	pH, EC, Cl <sup>-</sup> , NH <sub>4</sub> <sup>+</sup> , NO <sub>2</sub> <sup>-</sup> , NO <sub>3</sub> <sup>-</sup> and SO <sub>4</sub> <sup>2-</sup>	The CCMEWQI and the GW directives a polluted GW due the diffusion of contaminants from agricultural practices, over exploitation of GW and livestock excrement	Alexakis (2020)
WWQI to obtain the Santiago River WQI	June 2021	Santiago River, western Mexico	temperature, pH, DO, BOD <sub>5</sub> , FC, NO <sub>3</sub> <sup>-</sup> , TDS, TSS, NH <sub>3</sub> -N, fats, oils, and grease, Pb, Zn, Cr, Cd, F, sulfides, and Hg	The study proposed a high sensitivity WQI to parameter values outside of permitted ranges along with an outstanding ability to discriminate across sampling locations and seasons, amply demonstrating temporal and geographical variability	Kothari et al. (2021)
CCMEWQI	June 2021	Honghu Lake, China	pH, DO, COD, BOD <sub>5</sub> , NH <sub>3</sub> -N, total phosphorus, total nitrogen, F, FC and eigenvalue	The CCME-WQI also discovered that from 2004 to 2011, the water quality of Honghu Lake exhibited an overall improving trend, while from 2012 to 2017, the data revealed an overall falling trend According to source appointment results, it was predicted that Honghu Lake's concentration of most water quality indicators would meet requirements after 2017 However, rainfall non-point source pollution must be controlled in the future to ensure that TN concentration reaches the desired level	Chen et al. (2020)

Table 6 (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WWQI	July 2021	Lijiang River, China	pH, temperature, DO, EC, Cr, Mn, Co, Cu, Zn, As, Cd, Sb and Pb	It was noticed that the parameters were varying between normal season and the rainstorm season due to natural and anthropogenic sources WQI was categorized as good, and can be used for drinking but treated prior drinking during rainstorm seasons	Deng et al. (2021)
WAWQI	July 2021	Juan diaz river, Panama	pH, temperature, conductivity, turbidity, DO, BOD <sub>5</sub> , TS, SS, dissolved solids, NO <sub>3</sub> , PO <sub>4</sub> , fecal coliforms and total coliforms	The WQI values classified the Villalobos Bathing Site as acceptable, little polluted and polluted waters, while the Los Pueblos Mall corresponded to the categories highly polluted, polluted and little polluted waters, as for South Bridge Corridor presents the lowest values with the category of highly polluted, polluted and little polluted waters due to anthropogenic environmental impacts: domestic and industrial wastewater discharges and hydro morphological pressures in the river	Ortega-Samaniego et al. (2021)
Comprehensive WQI based on single factor pollution index and Comprehensive pollution index	August 2021	Fenghe River Basin, China	Temperature, pH, DO, redox potential, EC, Cu, Pb, Ni, Cd, Cr, Zn, Ti and Mn	The WQI results showed that the most serious pollution came from one sampling site due to sewage outlets Other sites indicated an elevation of heavy metals in the water and sediments due to pollution from factories, businesses, residents, town building and agricultural activity	Luo et al. (2021)

**Table 6** (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WAWQI CCMEWQI	August 2021	Lake Hawassa Ethiopia	pH, EC, TDS, temperature, turbidity, DO, BOD <sub>5</sub> , COD, total phosphorus, soluble reactive phosphorus, Secchi depth, NO <sub>3</sub> <sup>-</sup> , NO <sub>2</sub> <sup>-</sup> , NH <sub>4</sub> + -N + NH <sub>3</sub> -N, total nitrogen, Mg <sup>2+</sup> , Na <sup>+</sup> , K <sup>+</sup> and Ca <sup>2+</sup>	The watershed's water quality was depending on the intended use and sampling, roughly categorized as inappropriate to excellent locations The results of the river and lake water quality index revealed that they were unfit for drinking, marine life, and recreational uses Both indicators indicate that the water in lakes and rivers is unfit for drinking, marine life, recreational uses, and irrigation The lake is phosphorus-deficient and is classified as eutrophic These worrisome analyses highlight the immediate necessity for pollution mitigation and control measures	Lencha et al. (2021)
NSFWQI	August 2021	Mirim Lagoon, Brazil	DO, thermotolerant coliforms, pH, BOD, temperature, total nitrogen, total phosphorus, turbidity, TS	The results showed that the factors may have a larger or smaller impact on the outcome of the WQI The value of monitoring water quality using statistical techniques like correlation because they allow for well-supported assumptions about the monitoring data used	Kunst Valentini et al. (2021)
CCMEWQI	August 2021	Paraná river lower basin, Buenos Aires, Argentina	Alkalinity, EC, BOD <sub>5</sub> , COD, hardness, organic matter, DO, pH, depth, TSS, temperature, turbidity, ammonium, chlorophyll-a, Cl <sup>-</sup> , DOC, phosphate, nitrate, nitrite and sulfate	The study revealed a degraded water quality in the lower basin, mainly at the mouth of the river Negative impacts on developing amphibians were caused by altered physico-chemical properties, the presence of pesticides and elevated metal concentrations in water samples from various sites	Peluso (2021)
CCMEWQI	October 2021	Danube River Chilia Branch	ammonium nitrogen, nitrite nitrogen, nitrate nitrogen, orthophosphate, nitrogen and phosphorus	CCMEWQI integrated parameters stand into the marginal quality range All sampling points ranged between excellent, good and fair	Teodorof et al. (2021)

Table 6 (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WAWQI	December 2021	Warta river, Poland	TDS, phosphate, Cl, Ca, Mg, total hardness, pH, nitrate, fluoride, sulphate and manganese	Using the artificial neural network along with the WQI, the maximum error percentage did not exceed 4%. ANN allows water quality to be tested with lesser parameters	Kulisz and Kujawska (2021)
DOEWQI	December 2021	Dungun River Basin, Terengganu, Malaysia	DO, BOD, COD, Ammonia, TSS and pH	The Dungun River basin in Malaysia has been classified as clean with minimum pollution. The mean values of water quality parameters were classified as Class I (DO and ammonia), Class II (BOD and TSS) and Class III (COD and pH). This indicates that the phytoplankton growth in this river was controlled by P-based nutrients	Uning et al. (2021)
WAWQI	January 2022	Tolo Harbour and Channel, Hong Kong	BPD <sub>5</sub> , COD, total Kjeldahl nitrogen, total phosphorus, TSS, NH <sub>3</sub> -N, NO <sub>2</sub> -N, NO <sub>3</sub> -N, PO <sub>4</sub> <sup>3-</sup> , chlorophyll-a, oil and grease, DO, pH, turbidity, temperature, F <sup>-</sup> , Cu, Zn, and As	The study area's water quality was typically outstanding or good, according to the overall WQI values, which ranged from 68.571 to 95.952. The majority of the overall WQI values were between 91 and 100 and 90 to 71. Additionally, there were notable regional changes in the water quality state but no evident seasonal variations	Wang et al. (2022)
WAWQI CCMEWQI	January 2022	Shatt-Al-Hilla river in Babel city, Iraq	Temperature, total hardness, EC, pH, TDS, SO <sub>4</sub> <sup>2-</sup> , Ca <sup>2+</sup> , Mg <sup>2+</sup> , Na <sup>+</sup> , K <sup>+</sup> , BOD and turbidity	Based on correlation and PCA parameters were downsized to 6 parameters, which improved the evaluation efficiency, as well as reduced the time and cost of measurement and analysis of a large dataset The WQI showed that the three stations ranged from good to unfit to unsuitable. According to the CCMEWQI the water was good to fair. Additionally, it should be highlighted that these stations' low water efficiency and poor raw water quality contribute to the low water quality	Al-Kareem and ALKizwini (2022)

**Table 6** (continued)

Index	Date	Location	Parameters	Major Findings	Reference
Malaysian WQI	January 2022	Kuching, Sarawak, Malaysia	DO, BOD, pH, COD, ammoniacal nitrogen, TSS, FC and TC	Most water parameters at all the station had similar values WQI indicated a clean water category, however high FC and TC classified the water as class III Of the five antibiotics tested, erythromycin showed the highest rate of resistance 60, followed by chloramphenicol 40	Mohammad Hamdi et al. (2022)
CCMEWQI WAWQI	February 2022	Azogues, Ecuador	pH, turbidity, color, total dissolved solids, electrical conductivity, total hardness, alkalinity, nitrates, phosphates, sulfates, chlorides, residual chlorine	the CCME WQI methodology classifies drinking water quality as 'excellent' and the WAWQI as 'good' to 'excellent' The investigation revealed that the WAWQI's sensitivity to the standard value utilized in its calculation is exceptionally high. The benefit of utilizing these two indices to assess water quality is that there is no restriction on the number of characteristics employed	García-Ávila et al. (2022a, b)
WWQI	February 2022	India	pH, EC, TDS, total hardness, Na <sup>+</sup> , Ca <sup>2+</sup> , Mg <sup>2+</sup> , K <sup>+</sup> , CO <sub>3</sub> <sup>2-</sup> , HCO <sub>3</sub> <sup>-</sup> , Cl <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , NO <sub>3</sub> <sup>-</sup> and F <sup>-</sup>	The water quality deterioration was mainly due to natural weathering, oxidation etc. of the parent rock The water quality at 26.67% of the samples was moderate, doubtful at 13.33% of the samples and unsuitable at 6.67% The water is unsuitable for using due to high hazard quotient and high ion concentrations	Panneerselvam et al. (2022)
WWQI	February 2022	karst areas, southwest China	Total hardness, TDS, Na, Fe, As, Zn, Pb, Cu, Ni, Cd, Cr, B, Ba, Al, Cl <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , NO <sub>3</sub> <sup>-</sup> , Mn, F <sup>-</sup> , Se and Sb,	Higher TDS, HCO <sub>3</sub> <sup>-</sup> and Ca, higher dissolution of carbonate rocks and high ion ratios were indicated in the exposed karst region (EKR) EKR is more polluted and more fragile WQI of groundwater suggested a better quality in the buried karst region (BKR) than EKR, although 95.7% of the water samples in the study area were classified as excellent based on their WQI values	Peng (2022)

Table 6 (continued)

Index	Date	Location	Parameters	Major Findings	Reference
High Andean WWQI	February 2022	Chumbao River, Andahuaylas, Peru	Temperature, turbidity, TDS, pH, EC, hardness, color, nitrates, nitrites, ammonium, phosphates, Pb, Cr, Zn, Fe, COD, DO BOD, thermotolerant coliforms and TC	The sections around the head of the basin exhibit good quality, are not in danger, and display levels that are nearly natural. However, because of anthropogenic actions, urbanized regions are frequently threatened and deteriorated, and this degradation has been escalating over time	Choque-Quispe et al. (2022)
WAWQI	February 2022	Jishan River, China	pH, ORP, TDS, TN, NH <sub>4</sub> <sup>+</sup> -N, TP, chromaticity, COD, NO <sub>2</sub> <sup>-</sup> -N, NO <sub>3</sub> <sup>-</sup> -N, SO <sub>4</sub> <sup>2-</sup> , DO	Multiple contaminants have entered the river as a result of disturbances from various anthropogenic activities, leading to significant geographical variation in water quality indicators and bacterial communities WQI indicated a “low” or “moderate” water quality	Zhu et al. (2022)
WAWQI	February 2022	Gomti River, India	pH, turbidity, EC, TS, TDS, TSS, DO, BOD, COD, nitrate, phosphate, sulfate, total alkalinity, total hardness, chloride, and fluoride	The pre monsoon water quality was significantly better than the post monsoon The WQI values showed the degree of degradation and impairment to the water quality from upstream to downstream sampling sites Additionally, the assessment of bed sediment and water quality for seasonal effects and regional comparisons has been confirmed by multivariate statistical analysis The findings suggest reducing the sources of toxins that pour into the Gomti and creating remediation plans to lessen river contamination	Kumar et al. (2022)



**Table 6** (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WAWQI	March 2022	Nanxi River, China	Temperature, pH, EC, DO, NH <sub>3</sub> -N, BOD, petrol, VP, COD, total phosphorus, total nitrogen, F, S, FC SO <sub>4</sub> , Cl, NO <sub>3</sub> -N, total hardness, NO <sub>2</sub> -N, and NH <sub>3</sub>	According to the WQI findings, the majority of monitoring stations' water quality was rated as "medium–low," with a steady improvement trend The 14 monitoring stations were sorted by cluster analysis into three groups: low contamination, medium contamination, and high contamination The investigation revealed that nutrients, salt ions, and hazardous organic pollution were the main causes of water contamination. Fluoride, pH, temperature, and petroleum are in cluster C, while fecal coliform, organic pollution, temperature, and nutrients are in cluster A	Zhang et al. (2022)
CCMEWQI	March 2022	Damodar River, India	Ammonia, BOD, Ca, Cl, COD, EC, DO, FC, F, Mg, NO <sub>3</sub> , pH, phosphate, K, Na, temperature, alkalinity, TC, TDS, total fixed solids, hardness, TSS and turbidity	Study showed that there is a spatial pollution Seasonal variations in pollution are primarily caused by point and non-point sources. Ionic concentration fluctuates regionally but does not show much seasonal change This river has been severely overtaken by pollution with a pathology. This diseased population nearly doubles during the monsoon season	Maity et al. (2022)

Table 6 (continued)

Index	Date	Location	Parameters	Major Findings	Reference
CCMEWQI	March 2022	Cuba	salinity, temperature, pH, oxygen saturation, $\text{N-NH}_4^+$ , $\text{N-NO}_2^-$ , $\text{N-NO}_3^-$ , $\text{P-PO}_4^{3-}$ , COD, $\text{BOD}_5$ , fats and oils, chlorophyll-a, thermotolerant and total coliforms, and phytoplankton	The non-eutrophic average assessments obtained using various classification schemes corresponded to average judgments of water quality between fair and good The PCA identified the summertime increase in $\text{BOD}_5$ levels and the relationship between COD and biological response, which leads to a lower water quality Overall, the assessed bathing sites had modest levels of phytoplankton variety and abundance All of the beaches that were evaluated had few if any harmful algal species, supporting the high standard of the coastline. Additionally, despite their modest concentrations, some toxic microalgae pose a concern to swimmers in the examined beaches	Losa et al. (2022)
Integrated WQI WAWQI	April 2022	Tuo River, China	Permanganate index, $\text{F}^-$ , total nitrogen, $\text{BOD}_5$ , COD, $\text{NH}_3\text{-N}$ , DO, total phosphate, EC, $\text{NO}_3^-$ , $\text{SO}_4^{2-}$ and Cl	The principle of the IWQI is that if the concentration of any water quality parameter will increase the total index value if it is both below or over the lower or upper threshold limits According to IWQI, 67.8% of the samples were rated as "medium," 29% as "poor," and 3.2% as "bad."	Fu et al. (2022)
WAWQI	April 2022	Kelani River Basin, Sri Lanka	pH, total phosphate, EC, $\text{BOD}_5$ , temperature, nitrates, DO, COD and chlorine	The levels of DO, phosphate, COD, $\text{BOD}_5$ , and nitrate were frequently over the recommended levels in 2 ferries The same ferries reported the lowest water quality as well	Makubura et al. (2022)

**Table 6** (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WAWQI	May 2022	Hetao Irrigation District, China	pH, total nitrogen, total phosphorus, EC, TDS, Cl <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , HCO <sub>3</sub> <sup>-</sup> , Ca <sup>2+</sup> , Mg <sup>2+</sup> , Na <sup>+</sup>	The groundwater of the study area is weakly alkaline The continuing effects of rock weathering, ions exchange, and evaporate crystallization are all felt by the groundwater. Ca <sup>2+</sup> comes through the breakdown of gypsum and carbonate, while Na <sup>+</sup> mostly comes from the dissolution of evaporate salt rock and silicate rock	Yuan et al. (2022)
WWQI deriving from Scottish Research Development NSF, CCME, Hanh and West Java indices	May 2022	Cork Harbour, southwest coast of Ireland	Transparency, dissolved inorganic nitrogen, ammoniacal nitrogen, BOD <sub>5</sub> , chlorophyll, Temperature, orthophosphate, total organic nitrogen, dissolved inorganic nitrogen, pH, transparency and DO	A machine-learning model has been developed to identify and rank water quality indicators based on their relative importance to overall water quality status A weighted quadratic mean aggregation function and an unweighted arithmetic mean function were found to have the lowest instances of eclipsing and ambiguity and are recommended for WQI approaches. Use of objective, mathematical approaches like these can reduce model uncertainty that might be introduced using expert rankings/weightings	Uddin et al. (2022)
WWQI	June 2022	Ganges River Basin, India	pH, EC, total hardness, TDS, Ca <sup>2+</sup> , Mg <sup>2+</sup> , Na <sup>+</sup> , K <sup>+</sup> , HCO <sub>3</sub> <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , NP <sub>3</sub> <sup>-</sup> , F <sup>-</sup> and Cl <sup>-</sup>	Most of the surface and groundwater studied has an alkaline pH The WQI indicated that 57% of groundwater samples from the study area are characterized as poor water due to geogenic and anthropogenic sources Water could be used for agricultural practices except irrigation due to high nitrate and fluoride	Khan (2022)

Table 6 (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WWQI	June 2022	Yangtze River, China	Temperature, EC, DO, turbidity, TSS, total hardness, pH, Cl <sup>-</sup> , COD, total nitrogen, total phosphorus, NH <sub>4</sub> <sup>+</sup> , NO <sub>3</sub> <sup>-</sup> , NO <sub>2</sub> <sup>-</sup> and PO <sub>4</sub> <sup>3-</sup>	In the rainy and dry seasons, the WQI rated the water quality as "Moderate" and "Good," respectively. Monitoring sites immediately downstream of the Three Gorges Dam had lower TP, TN, TSS and turbidity, and higher WQI in both seasons compared to other monitoring sites. These sites also had lower and higher water temperatures in the wet and dry seasons, respectively.	Xiong et al. (2022)
CCMEWQI NSFWQI	June 2022	Lake Union, Washington State-USA	Chlorophyll-a, temperature, FC, DO, EC, nitrate-nitrogen, pH, total phosphorus and turbidity	The values reported by NSF-WQI were always lower than the CCMEWQI. Findings suggest that temperature is an important factor in the assessment of NSF-WQI and may be related to changes in temperature. The NSF-WQI is more stringent and reliable than the CCME-WQI since it exhibits continuous lower values and less seasonal volatility.	Gamvroula and Alexakis (2022)
CCMEWQI	June 2022	Weishui Reservoir, China	DO, pH, COD, BOD <sub>5</sub> , total phosphorus, total nitrogen, NH <sub>4</sub> -N and F <sup>-</sup>	Water was very polluted in 2013 and recovered gradually in 2018. The main factors influencing the reservoir's water quality were total nitrogen and total phosphorus, which were nearly two times greater than the grade II standard. These demonstrated the reservoir's susceptibility to non-point source pollution. The ARIMA model's prediction that the CCMEWQI would remain at 80.46 indicates that water quality will be steady going forward.	Hu et al. (2022)

**Table 6** (continued)

Index	Date	Location	Parameters	Major Findings	Reference
CCMEWQI	June 2022	Lepenci River, Kosovo Republic	Temperature, turbidity, EC, TDS, pH, DO, oxygen saturation, TSS, BOD <sub>5</sub> , COD, TOC, detergents, phosphates, total phosphorus, nitrates and sulfates	Station 1 had a high WQI (excellent), lower quality was shown at S3 (marginal) and S2 was the most polluted station of the river The expansion of ecotourism and hospitality in high areas close to the source areas, as well as an increase in population, urbanization, industrialization, and agricultural output, are all factors that contribute to water quality damage	Rizani et al. (2022)
WAWQI	June 2022	Sevilla de Oro sector, Azuay province, Ecuador	DO, BOD, TC, FC, real color, turbidity, alkalinity, total hardness, Cl <sup>-</sup> , EC, pH, fats and oils, TSS, TDS, NO <sub>3</sub> -N, NH <sub>3</sub> -N, PO <sub>4</sub> <sup>3-</sup> and detergents	The environmental impact on streams 1, 3, and 4 has been examined in an “irrelevant” manner, the impact of activities carried out in a camp on stream 2 turned out to be “moderate”, tending to “severe” PCA indicated an evident relationship between the parameters It is obvious that anthropogenic activities have an impact on the streams that pass through this camp, particularly stream 2. As a result, anthropogenic activity control	García-Ávila, Jiménez-Ordóñez et al. (2022a; b)
WAWQI	June 2022	Oued Tighza, Morocco	pH, T°, Electrical Conductivity, DO, NH <sub>4</sub> <sup>+</sup> , NO <sub>3</sub> <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , PO <sub>4</sub> <sup>3-</sup> , BOD <sub>5</sub>	The values of WQI and organic pollution index indicated that the site is very degraded due to discharge of water from the wastewater treatment plant	Hachi et al. (2022)

Table 6 (continued)

Index	Date	Location	Parameters	Major Findings	Reference
WWQI	July 2022	Sindh, Province, Pakistan	TDS, pH, turbidity, $\text{Ca}^{2+}$ , $\text{Mg}^{2+}$ , $\text{Na}^+$ , $\text{K}^+$ , $\text{Cl}^-$ , $\text{SO}_4^{2-}$ , $\text{HCO}_3^-$ , $\text{NO}_3^-$ , $\text{F}^-$ , As and Fe	GW samples were contaminated due to high As levels which might cause high risk to children WQI revealed an excellent water quality Gibbs plots revealed that rock dominance has a major impact on groundwater chemistry with little contribution to evaporation in both districts, signifying the evaporation importance in the shallow groundwater depth zone. Carbonate dissolution implies a substantial influence on the hydrochemistry evolution of groundwater in the study area	Ghani et al. (2022)
WAWQI	July 2022	Ruzizi River, east central Africa	pH, $\text{HCO}_3^-$ , $\text{Cl}^-$ , COD, BOD, organic matter, $\text{NH}_4^+$ , $\text{NO}_2^-$ , $\text{PO}_4^{3-}$ , $\text{SiO}_2$ , turbidity, and total alkalinity	The WHO Water Quality Index (WQI) standards were used to evaluate the purity of the drinking water The Ruzizi River is now unfit for drinking water purposes, according to WQI values that are higher than WHO drinking water requirements Strong correlations between turbidity and land usage were found upstream and downstream of dams	Muvundja et al. (2022)
NSFWQI	August 2022	Siliguri city, West Bengal, India	pH, Temperature, Conductivity, TDS, Turbidity, Total Hardness, DO, BOD, COD, $\text{NO}_3^-$ , $\text{PO}_4^{3-}$ , $\text{Cl}^-$ , FC and E. coli	While the upstream sampling site has acceptable water quality status, the NSF-WQI results indicated low WQI scores at similar sampling points, indicating intermediate water quality	Parween et al. (2022)
WWQI	August 2022	Sindh River in the Northwestern Himalayas	Temperature, pH, EC, TDS, DO, free carbon dioxide, total alkalinity, total hardness, Ca, Mg, $\text{Cl}^-$ , $\text{SO}_4^{2-}$ , $\text{NO}_3^-$ , $\text{NO}_2^-$ , $\text{NH}_3\text{-N}$ , total phosphorus, $\text{PO}_4\text{-P}$ and Fe	The criteria chosen for calculating WQI changed, but not significantly enough to modify the water's acceptability for drinking. In the current study, the inability to examine the effects of the power plants before they were built was a drawback. To properly comprehend the ecological effects of RoR hydro-power facilities, long-term data sets on water quality and biological reactions are also required	Sofi et al. (2022)

**Table 6** (continued)

Index	Date	Location	Parameters	Major Findings	Reference
VWQI	August 2022	Hau Giang Province, Vietnam	Temperature, pH, DO, color, BOD, COD, TSS, $N-NH_4^+$ , $N-NO_3^-$ , $N-NO_2^-$ , $P-PO_4^{3-}$ , $Cl^-$ , $Fe$ , $CN^-$ , and coliforms	<p>The surface water quality was contaminated with organic and micro-organisms</p> <p>The WQI indicated that the water quality ranged from poor to excellent</p> <p>The spatial distribution revealed that the majority of the pollution components were concentrated in urban, rural, and suburban areas, landfills, harbor areas, and at the confluence of rivers or neighboring provinces</p> <p>The water quality is influenced the most by industrial, domestic, transportation and agricultural activities, salinity, hydrological conditions and stormwater runoff</p>	Cong Thuan (2022)

of physical, chemical, and biological parameters also called variables in order to represent water quality in an easy and understandable way. Water quality indices are used to assess water quality of different water bodies, and different sources. Each index is used according to the purpose of the assessment. The study reviewed the most important indices used in water quality, their mathematical forms and composition along with their advantages and disadvantages. These indices utilize parameters and are carried out by experts and government agencies globally. Nevertheless, there is no index so far that can be universally applied by water agencies, users and administrators from different countries, despite the efforts of researchers around the world (Paun et al. 2016). The study also reviewed some attempts on different water bodies utilizing different water quality indices, and the main studies performed in Lebanon on Lebanese rivers in order to determine the quality of the rivers (Table 6).

As mentioned in the article (Table 7); WQIs may undergo some limitations. Some indices could be biased, others are not specific, and they may not get affected by the value of an important parameter. Therefore, there is no interaction between the parameters.

Moreover, many studies exhibited a combination between WQIs and statistical techniques and analysis (such as the PCA, Pearson’s correlation etc.). with a view to obtain the relation between the parameters and which parameter might affect the water quality.

In other research, authors compared many WQIs to check the difference of water quality according to each index. Each index can provide different values depending on the sensitivity of the parameter. For that reason, WQIs should be connected to scientific advancements to develop and elaborate the index in many ways (example: ecologically). Therefore, an advanced WQI should be developed including first statistical techniques, such as Pearson correlation and multivariate statistical approach mainly Principal Component Analysis (PCA) and Cluster Analysis (CA), in order to determine secondly the interactions and correlations between the parameters such as TDS and EC, TDS and total alkalinity, total alkalinity and chloride, temperature and bacteriological parameters, consequently, a single parameter could be selected as representative of others. Finally, scientific and technological advancement for future studies such

**Table 7** Advantages and disadvantages of the selected water quality indices

Advantages	Disadvantages	References
<i>National Sanitation Foundation (NSF) WQI</i>		
Summarized in a single index value in an objective, rapid and reproducible manner	Eclipsing which occurs when at least one sub-index reflects poor water quality	Bharti and Katyal (2011), Phadatare et al. (2016), Tyagi et al. (2013)
Index values are related to a potential water use	Represents a general water quality, therefore does not represent specific use of water	
Evaluation between areas and identifying changes in water quality	Loss of data during handling	
	Lack of dealing with uncertainty and subjectivity present in complex environmental issues	
<i>Canadian Council of Ministers of Environment (CCME) WQI</i>		
The ability to represent measurements of many variables in a single number	Loss of information	Sutadian et al. (2016), Tirkey et al. (2015), Tyagi et al. (2013)
The ability to combine various measurements with a variety of measurements units in a single metric	Loss of interactions among variables	
The ability to determine the final aggregated index through direct calculations using the selected parameters and without generating the sub-indices	Lack of portability of the index to different ecosystem types	
Easy to understand	Loss of information about the objectives specific to each location and particular water use	
Easy to calculate	Sensitivity of the results to the formulation of the index	
No restriction on the number of parameters	Easy to manipulate (biased)	
Tolerance to missing data	The same importance given to all parameters	
Adaptability to different legal requirements and different water uses	No combination with other indicators or biological data	
Statistical simplification of complex multivariate data	Only partial diagnostic of the water quality	
Suitable for analysis of data coming from automated sampling	F1 not working appropriately when too few variables are considered or when too much covariance exists among them	
<i>Oregon WQI</i>		
Simple method	Cannot determine the quality of water for specific uses	Brown (2019), Cude (2001), Darvishi et al. (2016a), Lumb et al. (2011b), Tyagi et al. (2013)
Availability of required quality parameters	Does not include many possible stressors to river	
Determination of sub-indices by curve or analytical relations	The data is representative of just the sampling site and does not represent the water quality conditions of other locations in the same basin or of the whole river	
Uses unweighted parameters	Cannot determine the quality of water for specific uses, nor can it be used to provide definitive information about water quality without considering all appropriate chemical, biological, and physical data	
Employs the concept of harmonic averaging		
Method acknowledges that different water quality parameters will pose differing significance to overall water quality at different times and locations		
Formula is sensitive to changing conditions and to significant impacts on water quality		
<i>Weighted Arithmetic WQI</i>		



**Table 7** (continued)

Advantages	Disadvantages	References
<p>Use of water simplifies with less comparison as a smaller number of parameters required</p> <p>It uses number of quality parameters into mathematical equation that give rating and grading to the water bodies</p> <p>For the policy makers and citizens this number is very useful for communication of overall water quality information</p> <p>Assurance about suitability of water for human consumption in case of freshwater bodies</p> <p>Different parameters that can be used with their composition that is important for assessment and management of water quality</p>	<p>The number given by water quality index may not give real situation of quality of water</p> <p>A single bad parameter value changes the whole story of Water Quality Index</p> <p>There are many other water quality parameters that are not considered in index</p> <p>The eclipsing or over-emphasizing of a single bad parameter value</p> <p>WQI based on some very important parameters can provide a simple indicator of water quality</p>	<p>Phadatare et al. (2016), Tyagi et al. (2013)</p>

as GIS techniques, fuzzy logic technology to assess and enhance the water quality indices and cellphone-based sensors for water quality monitoring should be used.

**Declarations**

**Conflict of interest** All authors declare that they have no conflict of interest.

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