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Assessment Water Quality Indices of Surface Water for Drinking and Irrigation Applications – A Comparison Review

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ABSTRACT

Water is one of the most important natural resources for all living organisms, including humans. Water consumption is increasing over the years as a result of the increase in the number of people, and at the same time, the causes of pollution of surface water sources increase. Water pollution is one of the most important causes of diseases and the transmission of infection to the organisms that use it. Also, the quality of agricultural crops is linked to the quality of the water used for irrigation. As a result, there was a need to monitor and evaluate the main water sources to maintain the quality of their water suitable for use by humans and other organisms. As is well known, it is difficult to evaluate the water quality of large samples with concentrations of many parameters using traditional methods, which depend on comparing experimentally determined parameter values with current standards. As a result, over the past century and the present, many methods of assessing water quality have emerged. This research aims to introduce the most important indices of water quality used at present to assess the quality of surface water for drinking and irrigation purposes, as well as the history of these methods and their development over time and their most important advantages, in addition to a group of the most important research that used these methods during the past few years.

Keywords: WQI, drinking uses, irrigation uses, index, WQR.

INTRODUCTION

Water is one of the many abundant natural resources used by all living things, including humans, animals, plants, and other organisms. The water demand is rising because of the growing population, expanding economic activity, and urban expansion. The decrease in water levels and the degradation of their quality, the overuse of surface water, which considers the most important of water resources, is threatening human life and its surrounding environment (Massoud, 2012). In many nations, the declining quality of surface water is becoming a severe problem (Witek, 2009) and one of the main goals of water resource conservation policy is monitoring water quality (Simeonov, 2002). As a result, developing countries have recently increased their efforts to focus evaluate the water quality of rivers (Kannel, 2007).

Surface water quality assessment is a comprehensive process that involves using several variables that can have significant impacts on the overall quality of the water. Evaluating water quality by testing many parameters, each separately and for several samples, is a complex process, and it is not possible to get a final decision on the water quality based on it (Almeida et al., 2007). Therefore, Various methods have been considered to analyze water quality such as statistical assessments of individual parameters and water quality indices (Venkatesharaju et al., 2010).

The water quality index (WQI) is a mathematical expression that converts the result values of several variables entered into a single value to indicate the water quality (Bordalo, et al., 2006). Several indicators of water quality have been developed around the world to enable researchers and those interested in the field of water sources to make an easy and clear judgment about the overall water quality in each study area quickly and effectively (Stambuk, 1999). Pure water is colorless, tasteless, and odorless. Water can dissolve most of the substances it meets, so there is no completely pure water in nature. Hence, water always contains various impurities and chemicals (Qasim et al., 2000). Increasing the concentration of these chemicals and biological impurities in the water of a particular water body above the acceptable limits leads to a deterioration of the water quality (WQ) in that water body, which leads to an increase in potential risks to humans, animals, plants, and the environment generally.

This research aims to introduce the most important indices of water quality used at the present time to assess the quality of surface water for drinking and irrigation purposes, as well as the history of these methods and their development over time and their most important advantages, in addition to a group of the most important research that used these methods during the past few years.

Water quality constituents

Inorganic and organic substances, as well as microbes, may be present in a dissolved and suspended form in natural water bodies. These substances could be derived from natural sources or through the leaching of waste deposits. A variety of organic and inorganic contaminants are also caused by municipal and industrial wastes. The weathering and leaching of rocks, soils, and sediments produce inorganic compounds. The main inorganic components are the bicarbonate, chloride, sulfate, nitrate, and phosphate salts of calcium, magnesium, sodium, and potassium.

The decomposing plant and animal debris, as well as agricultural runoffs, are where the organic compounds come from. The organic compounds range from natural humid materials to synthetic organics used as detergents, pesticides, herbicides, and solvents. These constituents and their concentrations influence the quality and use of natural water resources (Qasim et al., 2000).

WATER QUALITY INDICES

For agricultural and industrial activities, as well as human daily demands, WQ is just as crucial as water quantity. Both human activity and natural processes have an impact on water quality (WQ). Each year, between 300 and 400 million tons of toxic materials are dumped into the water bodies. in developing nations, 80% of sewage is discharged directly into water bodies without treating them (WHO-UN, 2010). Numerous local and international organizations had established guidelines and criteria for concentrations level of parameters in water bodies to ensure acceptable WQ. As a result, the World Health Organization (WHO) has established WQ guidelines for biological, chemical, and physical variables that are regularly modified to follow the changes in concentration of parameters due to many external and internal factors (WHO, 2017). Most countries have created local standard limits for parameters in water bodies to meet their needing (US EPA, 2017).

It is difficult to assess WQ for big samples with various concentrations for many parameters using traditional approaches. These approaches build on comparing experimentally established parameter values with current standards (Li, 2014). Considering this, the water quality index (WQI), which is used to simplify the complicated set of river WQ variables in one value, is regarded as a crucial component of sound water resource management (Sun et al., 2016).

WQI is often a dimensionless number that aggregates together various parameters for any water body to evaluate its water quality. The WQI methods significantly reduce the amount of data and streamline and describe the state of the quality of water in a single number (Kachroud et al., 2019).

The WQI methods' goal is to categories water bodies according to their chemical, physical and biological features, identify potential uses of them, and manage in a sound way (Boyacioglu, 2007). WQI methods can be considered as models to evaluate WQ, where reliable standards are adopted and given suitable weighing for each parameter and aggregate the factors are established (Figure 1). Four standard steps are employed in all WQI methods to implement their calculating process (Abbasi and Abbasi, 2012):

1. Choice of wanted variables.
2. Transformation of these variables, which initially have different dimensions, according to a common scale.
3. Creating subindices by giving each transformed variable a weighting factor.
4. The process of calculating a final index score by aggregating subindices. The following part includes the history of WQ indicators and an overview of the most important indicators used in evaluating WQ around the world.

A brief history of WQI methods

Water quality indicators have historically been used for WQ assessment by a variety of organizations and researchers from various nationalities. In the past ten years of the 20th century, this matter has become more obvious. The water quality index (WQI) was initially created by Horton (Horton, 1965) in the United States by choosing the ten parameters often used to assess WQ such as Cl, DO, conductivity, pH, coliforms, alkalinity, etc. Therefore, WQI has since gained widespread acceptance in European, Asian, and African nations. The allocated weight for a parameter had a significant impact on the index value and showed the importance of a parameter for specific usage.

Later, Brown et al. (1970) developed a new WQI, and selected nine parameters (DO, pH, BOD, FC, total nitrate and phosphate, temperature, turbidity, and TDS). They were based on the 142 water experts to assess the WQ. It was done by adopting five categories for water quality rating: blue for excellent, green for good, yellow for average, orange for poor, and red for very poor. They also calculated each variable's weighting. Brown et al.'s index had an arithmetic form, but they thought later that a geometric aggregation was preferable to an arithmetic aggregation since it was more sensitive to outliers in a single variable (Brown et al., 1973). Their index was given the moniker 'NSFWQI' because the National Sanitation Foundation financed these initiatives.

Then, during the last thirty years of the nineteenth century, many indicators of WQ appeared in various countries of the world. In Europe, another index based on standards for WQ was proposed by (Prati et al., 1971). Nemerow & Sumitomo (1971) presented three specific-use WQ indices that, when combined, produce a general WQI. Bhargava (1983) presented a new WQI in India where the combination of variables showed the pollution load was more specific. He described the WQI formula according to water use and afterward determined the variables that would be used. Another WQI was presented by (Tiwari & Mishra, 1985) based on the same concepts as those of (Horton, 1970 and Brown et al., 1970), but they changed the weighting approach by adding the normative values of the key water parameters. To maintain harmonicity in the magnitude of the sub-indices, logarithm, and antilogarithm have been applied in their aggregation.

New indices began to emerge in the twenty-first century, significantly streamlining the formulas already in use and defining the index's field of application. For instance, depending on the measurement and classification of each variable, the overall Index of pollution was evaluated by several WQ variables (Sargaonkar et al., 2003).

In recent years, many researchers have continued to find and develop new indices of water quality. The number of WQ criteria employed and the method by which they are implemented vary widely across the indexes.

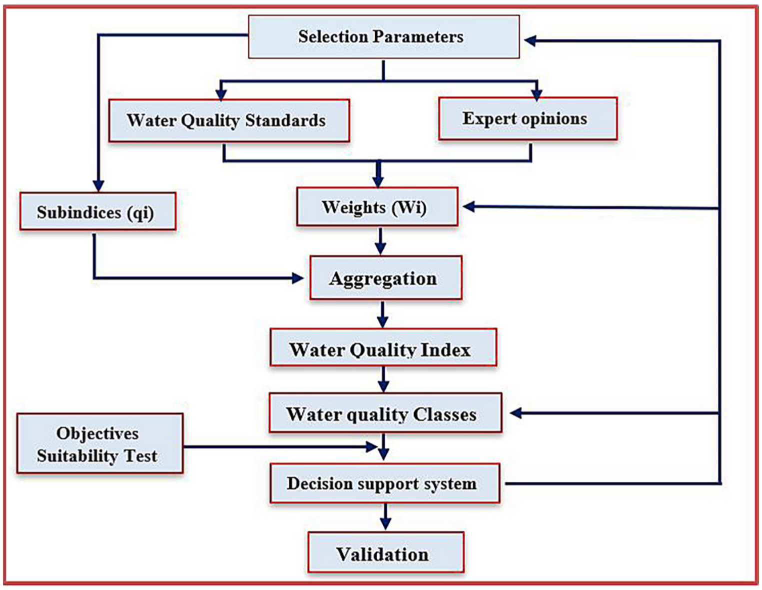

Figure 1. Basic steps that need to develop a WQI (Kachroud et al., 2019)

The significance of utilizing WQI methods

To interpret water results meaningfully, WQI methods are used to assess the WQ by monitoring data in the first place, especially when the pollutant concentrations are below the WQ standards. In general, WQI can completely ignore the importance of the sampling frequency used to assess WQ (Brown et al., 1973), but should be measuring the samples seasonally.

WQI methods give administrative decision-makers the ability to assess the effectiveness of regulatory programs and present WQ information to the audience in a straightforward and accessible way. Additionally, they help experts incorporate monitoring data into a wider framework (Sutadian et al., 2016). Practically all monitoring program goals, such as environmental planning, water quality monitoring, assessment, and treatment, are accomplished using indicators (Li, 2014).

Categories of WQI

In general, there are four basic categories for water quality indexes (Jena et al., 2013) are as follows:

First, public indices: these indices employ general WQ measurements rather than considering the type of water usage, such as the National Sanitation Foundation Water Quality Index (NSF-WQI) (Ott, 1978). Second, consumption indices: in this case, water is categorized according to the type of utilization and application (industrial, drinking, ecosystem preservation, etc.). The indices of British Columbia and Oregon are the most significant and applicable of these indicators (DEQ, 2003). The third category is indices of designing or planning: where these indices are an instrument that supports planning and decision-making in WQ management initiatives. Fourth, statistical indices: where statistical techniques are applied, rather than individual viewpoints. Here, the data are assessed using statistical methods. Another crucial component of the statistical method is the statistical validation of certain assumptions about observations data of WQ.

The first three indeces are subjected to the methodology of the experts' opinions (Harkins, 1974). The various ratings provided by the experts still have a chance of lowering objectivity and comparability. As a result, many alternative indices were created. However, applying statistical methods can help to reduce the subjectivity assumptions adopted when constructing the indices. The statistical methods can also be used to pinpoint crucial elements that determine a water body's quality and the degree to which they matter (Marta et al., 2010).

Selection of water quality systems

The most important part of every WQI method is its WQ parameters, where the index of WQI is created based on its parameters. As stated by (Sutadian et al., 2016), the parameter selection procedure can be applied to three different systems. therefore, the definition of these systems are as follows:

1. Fixed system: The selecting WQI parameters in this system are considered the most appropriate and essential set required for computing the final degree of the index. In this system, it is not allowed to add new parameters even if essential, but it is restricted to fixed parameters only. This restriction causes most employers a prevalent issue.
2. Open system: this system gives the free choice for users to select their parameters. An open system has great flexibility compared with a fixed system. When it comes to comparing the findings of WQI that resulted from various sites, there are limitations. It is unacceptable to apply the comparison in this system when a user uses different parameters.
3. Mixed system: this system integrates a fixed system and an open system. in the Mixed system, the final index value is computed based on fixed parameters desired, in addition to optional extra parameters that the user can input.

SOME OF THE MOST USED WQI METHODS FOR DRINKING USES

Over the years, several different organizations (local or international) sought to develop many indices of water quality, which have been used to evaluate the WQ in various circumstances. For any water body on a worldwide level, there isn't one index that can describe its total WQ. For any water body on a worldwide scale, there isn't one index that can describe its total WQ. Nevertheless, the development of WQI is necessary to measure variations in WQ over time and location as well as to assess the set goals of international agreements aimed to conserve water resources (Paun et al., 2016). Some common indices will be described among many WQI methods as follows:

National sanitation foundation water quality index (NSF-WQI)

Brown et al. (1970) set up the WQI that was supported by the National Sanitation Foundation to be defined as “NSF-WQI”. The NSF-WQI has the highest degree of acceptance for use in assessing water quality in the United States, despite the level of criticism of this method due to a lack sufficient of assessment of all regions in the U.S.A. This method was built based on the Dalkey technique by choosing parameters carefully. They created a standard scale after that, giving suitable weights for them. Nine parameters have been adopted for assessing the WQ, including temperature, pH, turbidity, fecal coliform, DO, BOD, PO4, NO3, and TDS (Tyagi et al., 2013).

To calculate a statistical score Qj from the received WQI, a graph of the weighting curve is employed. The weight of each parameter calculated by the NSF-WQI can be shown in Table 1.

The main formula of NSF-WQI is calculated as follows (Brown et al., 1970):

$$\mathrm{NSF-WQI} = \sum_{j}^{n} Q_j W_j \tag{1}$$

where: n – parameters number;
Q_j – category of quality for the jth parameter;
W_j – relative weight for the *jth* parameter ($\sum W_j = 1$). The rating of water quality according to NSF-WQI is given in Table 2.

Table 1. Parameters and their Weights for parameters entered in the NSFWQI method (Kachroud et al., 2019)

Parameter	Weight	Parameter	Weight
DO	0.17	PO_4	0.10
Fecal coliforms	0.16	Temperature	0.10
pH	0.11	Turbidity	0.08
BOD	0.11	TDS	0.07
NO_3	0.10	Total	1.00

Table 2. The rating of water quality according to NSF-WQI (Paun et al., 2016)

NSF-WQI	WQR
90–100	Excellent
70–90	Good
50–70	Medium
25–50	Bad
0–25	Very bad

The advantage of this method is that it summarizes the data in the value of one index in an objective, rapid and repeatable manner. Furthermore, easy to use by ordinary people and is not restricted to experts. For its disadvantages, it gives a general quality of water without giving importance to the potential water use. It is also considered a fixed system and other parameters cannot be added to it as needed (Paun, et al., 2016).

Canadian Council of Ministers of the environment water quality index (CCME-WQI)

The Canadian Council of Ministers introduced a comprehensive assessment of the appropriateness of river systems to maintain life in water bodies at specific control locations in Canadian. The CCME-WQI used relevant WQ standards as reference points to connect the water quality data with different beneficial uses of water. Each index is determined for each monitoring location during a selected predefined period.

Many water quality parameters are examined by water samples measured during a selected time. Each parameter measured values are compared to the relevant water quality standard. Three factors employed in the computation of the index include the proportion of parameters and tests that do not comply with the guidelines, as well as the deviation from the standards for tests that do not comply with the standards. These three factors are called scope (F1), frequency (F2), and amplitude (F3) (CCME, 2005).

$$\mathrm{F1} = \frac{\text{No. of failed parameters}}{\text{Total No. of parameters}} \times 100 \tag{2}$$

Scope (F1): the ratio of failed parameters to all parameters that do not compatible with the standards of water quality at any site during a selected time.

$$\mathrm{F2} = \frac{\text{No. of failed tests}}{\text{Total No. of tests}} \times 100 \tag{3}$$

where: frequency (F2) – the proportion of individual tests that don’t satisfy the standards of water quality.

The test is considered failed when any parameter value of the sample is higher than the standard limit. The total tests’ number that failed during the selected time includes all parameter values in each sample that failed. To get the total number of tests for a particular site is done by multiplying the total samples’ number measured during the selected time by the number of the mean parameters for each sample (Paun et al., 2016).

Amplitude (F3) – the average deviation of failed test values from their standards is represented by the amplitude factor.

$$\mathrm{F3} = \frac{\mathrm{nse}}{0.01\ \mathrm{nse} + 0.01} \quad (4)$$

An excursion is the relative value of deviation for a failed test from the standard value, and it is computed as follows:

- When the test value should be within the allowable limit of standards:

$$\mathrm{excursion_i} = \left(\frac{\text{failed test value}_\mathrm{i}}{\text{standard value}_\mathrm{i}}\right) - 1 \quad (5)$$

- When the test value should not be lower than the standards:

$$\mathrm{excursion_i} = \left(\frac{\text{standard value}_\mathrm{i}}{\text{failed test value}_\mathrm{i}}\right) - 1 \quad (6)$$

- The following formula is used to compute the overall value for specific tests that are out of conformance:

$$\mathrm{nse} = \frac{\sum \mathrm{excursion_i}}{\text{total number of tests}} \quad (7)$$

where: nse represents the entire sum of all normalized excursions from the standards. Equation 8 is used to determine the CCME-WQI as follows:

$$\mathrm{CCME - WQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right) \quad (8)$$

where: 1.732 – represented as the factor that uses to convert the resulting values of the CCMEWQI method into a scale of 0–100.

The preceding formula generates a CCME-WQI value between and gives the water quality a digital value. A value near 100 indicates excellent water quality, whereas zero indicates water quality is very poor. It requires professional judgment and expectations of public water quality. Table 3 shows the water quality rating (WQR) according to CCME-WQI.

Table 3. WQR according to CCME-WQI (Paun et al., 2016)

CCME	WQI
95–100	Excellent
80–94	Good
60–74	Fair
45–59	Marginal
0–44	Poor

Oregon water quality index (O-WQI)

Another WQI widely used in the public field is the Q-WQI. This method was established by the Oregon Department of Environmental Quality in the last years of the 1970s, and it has since undergone numerous updates (Cude, 2001). Nevertheless, due to the significant resources needed to calculate and publish the results. Due to improvements in computer systems, new techniques for collecting data and analysis, as well as a better knowledge of the QW, the O-WQI method was modified in 1995. The original subindices were modified, temperature and total phosphorus subindices were added, and the aggregation calculation was improved.

The O-WQI evaluates and expresses 8 different WQ elements. The parameters covered in this method are temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), pH, ammonia and nitrate nitrogen, total phosphorus, total solids, and fecal coliform (Dinius, 1987).

It offered Oregon's streams' ambient water quality for broad recreational use. Thus, it should be used with caution when applying to other geographic areas or water body kinds. Since the O-WQI was introduced in the 1970s, the science of water quality has significantly advanced (Dunn, 1995). The original O-WQI was modeled after the NSF-WQI, which chose variables using the Delphi approach (Dalkey, 1968). The recreational water quality index was developed using the Delphi technique. This approach can be characterized as a means of assembling information from a variety of experts so that consensus can be achieved regarding the most up-to-date information on how to manage a challenging circumstance (Rowe & Wright, 1999). The findings of the water quality variables were transformed into subindex values using logarithmic operations by both indices. The advantage of logarithmic transforms is that a change in magnitude at lower levels of impairment has a larger effect than a change in magnitude at higher levels of impairment. The following formula is provided by (Poonam et al., 2013):

Table 4. WQR according to O-WQI (Paun et al., 2016)

O-WQI Value	WQR
90–100	Excellent
85–89	Good
80–84	Fair
60–79	Poor
0–59	Very poor

$$\mathrm{O-WQI} = \sqrt{\frac{\mathrm{m}}{\sum_{\mathrm{j=1}}^{\mathrm{m}} \frac{1}{\mathrm{STI}_{\mathrm{j}}^2}}} \tag{9}$$

where: m – the subindices number;
STI – the subindex of each parameter.
Table 4 presents the WQR using the O-WQI values.

One advantage of this method is that the aggregation method used to integrate the sub-indices gives the most affected parameters the highest impact on the final WQI. The equation is also sensitive to changing conditions and significant effects on water quality.

The disadvantage of this method is that it does not consider changes in the concentrations of toxins or habitats. Without considering all pertinent physical, chemical, and biological data, it is impossible to establish the quality of water for a particular purpose or to employ it to deliver conclusive data about the WQ (Paun et al., 2016).

The weighted arithmetic water quality index (WA-WQI)

The WA-WQI method is superior to other methods to compute the WQI since it involves a single fundamental mathematical equation for many quality parameters and can assess the quality of both surface water and groundwater (Călmuc et al., 2018). Numerous Physicochemical variables are employed for both the analysis of information for each station and their potential value to human use.

In this method, different water quality parameters are multiplied by a weighting factor. Then, they are aggregated using the simple arithmetic mean. The weight (Wi) for various parameters is inversely proportional to the recommended standard (Si) for the corresponding parameter. Wi values are calculated from the following formula (Tyagi et al., 2013):

$$W_i = \frac{1}{S_i} \tag{10}$$

where: S_i – the allowable standard value of the ith parameters. Then, Equation (11) is used to calculate the relative value of quality ranging (q_i) for each parameter in water bodies and compare it with upper standard limits as follows:

$$q_i = \frac{X_i - X_o}{S_i - X_o} \times 100 \tag{11}$$

where: q_i – the relative value of quality ranging for each parameter in water bodies;
X_i – the measured value for each parameter;
X_o – the measured value for each parameter in pure water;
S_i – the allowable standard value for each parameter.

For all parameters, the ideal value (X_o) = 0, while for pH and DO parameters the (X_o) is equal to 7 and 14.6 respectively. The main formula to calculate WA-WQI is as follows (Tyagi et al., 2013):

$$\mathrm{WA-WQI} = \frac{\sum_{i=1}^{i=n} Wi \times qi}{\sum_{i=1}^{i=n} Wi} \tag{12}$$

Table 5 shows the WQR according to WA-WQI. The advantages of this method are that it allows the use of a smaller number of water quality parameters based on the user's desire, allowing the possibility of obtaining accurate results. Give different weights to each variable depending on its importance. It describes the suitability of surface and groundwater for human use and is useful for giving comprehensive information on WQ to the worried public.

One of the disadvantages of this method is the excessive or eclipse in emphasizing the value of one parameter that is not valid. An index can't accommodate all applications for data of WQ (Paun et al., 2016).

Table 5. WQR according to WA-WQI (Brown et al., 1970)

WA-WQI Value	WQR
0–25	Excellent
26–50	Good
51–75	Poor
76–100	Very poor
more than 100	Unsuitable for human uses

Table 6. Limiting values of computing water quality (Wqi) for each parameter (Meireles et al., 2010)

HCO_3 (meq/L)	Cl (meq/L)	Na (meq/L)	SAR $(mmol/L^{-1})^{1/2}$	EC(μscm^{-1})	Wqi
(1.0–1.5)	(1.0–4.0)	(2.0–3.0)	(2.0–3.0)	(200–750)	85–100
(1.5–4.5)	(4.0–7.0)	(3.0–6.0)	(3.0–6.0)	(750–1500)	60–85
(4.5–8.5)	(7.0–10.0)	(6.0–9.0)	(6.0–12.0)	(1500–3000)	35–60
1 > HCO_3 = 8.5	1 > Cl = 10	2 > Na = 9	2 > SAR = 12	200 > EC = 3000	0-35

IRRIGATION WATER QUALITY INDEX (WQIFIR)

Meireles et al. (2010), introduced the mathematical method to calculate the water quality index for irrigation uses (WQIFIR). This method can be estimated by using equation (13) as follows:

$$\text{WQIFIR} = \sum_{i}^{m} Wq_i \times W_i \tag{13}$$

where: WQIFIR – proportion values for the selected parameters with a range of (0 -100); Wq_i – stands for each parameter's quality, which ranges from 0 to 100; W_i – stands for each parameter's normalized weight.

EC, Na^{+1}, Cl^{-1}, HCO_3^{-1}, and SAR are the most important variables that influence the water quality for agricultural use. The values of Wqi are determined for each parameter by the following equation (Meireles et al., 2010):

$$Wq_i = q_{imax} - \left(\frac{(X_{ij} - X_{inf}) \times q_{iamp}}{X_{amp}}\right) \tag{14}$$

where: q_{imax} – the maximum class value of q_i; X_{ij} – the parameter's observed value; X_{inf} – the value that corresponds to the class's lower limit to which the parameter belongs, qiamp is the class's amplitude; X_{amp} – the class's amplitude to which the parameter belongs.

Table 6 shows the limiting values for each parameter. The relative weights for each parameter were assigned and their importance for irrigation water quality by the determinants of the Committee of Consultants at the University of California (Table 7) (Abdullah et al., 2016).

The advantages of this method are a confident way that contributes to decreasing the time and effort. Less number of parameters is required in comparison to all water quality parameters for a particular use. The index value relates to irrigation water use only, which makes it more accurate for this purpose.

Table 7. Weights of parameters used in the irrigation using (the WQIFIR) method (Meireles et al., 2010)

Parameters	Wi
EC (electrical conductivity)	0.211
Na (sodium)	0.204
HCO_3 (bicarbonate)	0.202
Cl (chloride)	0.194
SAR (sodium adsorption ratio)	0.189

The lack of integrating this approach with more indicators or information of biological is one of its drawbacks. It is not allowed to add other parameters to the indicator even if they are important (Paun et al., 2016).

Table 8 illustrates water use restrictions and recommendations for utilizing water for soil and plants depending on the resulting readings of the WQIFIR.

Other irrigation water quality indices

In addition to the previous WQI methods, some other indices classify the acceptable water for use in irrigation depending on some main components (such as Na, Ca, Mg, etc.) in the water. The popular indices for water use in irrigation will be mentioned as follows:

Sodium adsorption ratio (SAR)

The SAR refers to sodium content (alkali risk), which has a significant indication to figure out whether irrigation water is suitable for usage (Srinivasamoorthy et al., 2014). The qualities of the soil are negatively impacted by too much sodium in the water, which also reduces soil permeability (Sundaray et al., 2009). Higher salinity prevents water from reaching plant leaves because it interferes with osmotic processes, which reduces water and nutrient absorption from the soil (Arumugam and Elangovan 2009). SAR measures sodium hazard and it can estimate using Equation 15 (Wilcox, 1955; Shil et al., 2019):

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\frac{\mathrm{Mg}^{2+} + \mathrm{Ca}^{2+}}{2}}} \tag{15}$$

Ionic concentrations are measured in meq/L. Table 9 shows the categories of using water in irrigation according to the SAR readings.

Kelly's index (KI)

Kelly's index is also used to verify the WQ is appropriate for use in irrigation. Index of Kelly is referred to the water that contains too much sodium. Equation 15 is used to determine the KI value (Kelly 1940; Shil et al., 2019):

$$\mathrm{KI} = \frac{\mathrm{Na}^{+}}{\mathrm{Mg}^{2+} + \mathrm{Ca}^{2+}} \tag{16}$$

where: Na, Mg, and Ca are computed in meq/L. Table 10 shows the categories of using water in irrigation according to the KI values.

Sodium percentage (Na%) or (SSP)

Because irrigation water with a higher sodium level has less permeability, the soluble sodium content is another index used to classify irrigation water (Todd, 1980). Na percentage (Na%) is frequently used to assess a water's appropriateness

Table 8. Restrictions and recommendations of WQIFIR for plants and soil (Meireles et al., 2010)

IWQFIR	Restrictions	SOIL	PLANT
(85–100)	No restriction (NR)	It is indicated to be leached during irrigation processes and can be used on most soils with a low risk of causing salinity and sodicity issues unless the soil exhibits exceptionally poor permeability.	For the majority of plants, there is no toxicity concern.
(70–85)	Low restriction (LR)	Salt leaching is advised for usage in irrigated soils with a light texture or moderate permeability. It is advised to avoid using heavy texture soils in soils with a high clay content due to the possibility of soil sodicity.	Avoid plants that are susceptible to salt
(55–70)	Moderate restriction (MR)	Suitable for usage in soils with values ranging from moderate to high permeability, with a suggested moderate salt leaching.	Plants that can tolerate salts just somewhat can be grown.
(40–55)	High restriction (HR)	It is applied to soils that have high penetration and loose underlying layers. A high-frequency irrigation program needs to be put in place for water with EC > 2000 dS m^{-1} and SAR > 7.0.	With the exception of waters that have low levels of Sodium, Chloride, and Bicarbonates, which shouldn't be used to water plants with specific salinity management strategies and moderate to high salt tolerance.
(0–40)	Severe restriction (SR)	Should refrain from using it for irrigation when things are normal. occasionally used in exceptional circumstances. For water with a high SAR and little salt content, gypsum application is required. In water that has a high content of salt, soils must be very permeable, and additional water needs should be met to prevent salt buildup.	Except for waters with exceptionally low Na, Cl, and HCO_3 levels, just plants that have high salt tolerance.

Table 9. Irrigation water classes according to the SAR (Richards, 1954; Shil et al., 2019)

SAR value	Water suitability for irrigation	Sodium hazard class
SAR less than 10	Excellent	I
10 < SAR < 18	Good	II
18 < SAR < 26	Fair poor	III
SAR more than 26	Unsuitable	IV

Table 10. Irrigation water classes according to the KI values (Kelly 1940; Shil et al., 2019)

KI value	Water suitability for Irrigation	KI value refers to
KI < 1	Good	Acceptable for irrigation
KI > 1	Not good	Excess sodium in water

Table 11. Irrigation water classes according to the SSP values (Belkhiri et al., 2010)

SSP value	Suitability of water for irrigation
SSP < 20	Excellent
20 < SSP < 40	Good
40 < SSP < 60	Permissible
60 < SSP < 80	Doubtful
SSP > 80	Unsuitable

for agricultural usage. This expression is also known as the soluble sodium percentage (SSP). It is calculated by the following equation (Wilcox 1955; Ewaid et al., 2019):

$$\text{Na\% or SSP} = \frac{(Na^{+} + K^{+}) * 100}{Mg^{2+} + Ca^{2+} + Na^{+} + K^{+}} \quad (17)$$

Each parameter is converted to uint of (meq/L). Table 11 shows the categories of using water in irrigation according to the SSP values.

Permeability index (PI)

The PI is another approach for determining whether irrigation water is suitable. Exposed irrigation water with significant ion concentrations affects the topsoil permeability (Ca, Mn, & CO3) (Ravikumar et al. 2011). Equation (17) shows the formula for calculating PI according to Doneen (1964) and Ewaid et al. (2019):

$$PI = \frac{\left(Na^{+} + \sqrt{HCO_3^{-}} \right) * 100}{Mg^{2+} + Ca^{2+} + Na^{+}} \quad (18)$$

Each parameter is converted to uint of (meq/L). Table 12 shows the categories of using water in irrigation according to the PI values.

PREVIOUS RELATED STUDIES

Since appeared the first water quality index in 1965 by Horton et al. and the subsequent development of the WQI, many researchers have studied surface WQ for drinking and irrigation purposes by applying the WQI methods in addition to ArcGIS software. Several main recent previous studies have considered the issue of this study earlier in the world and Iraq over the last years.

Meireles, et al. (2010) conducted a study on the quality of the surface water used for irrigation in the Ceará state in Brazil's Acara Basin. The area's irrigation project's water supply from the Acara River was assessed for its qualitative dynamics. To create a water quality index (WQI) that accounts for soil salinity and sodicity threats, as well as water toxicity for plants, the WQI was utilized for evaluating the WQ. Ten sampling sites around the basin were used to collect water samples between April 2003 and September 2005, and the physical and chemical factors that affect the WQI were assessed at these sites. The findings demonstrated that, if the soil-water-plant is not adequately monitored, the use of water for irrigation in the Acara basin is possibly prone to create toxicity (crop cycle) problems in the long term.

Ji et al. (2016) evaluated water quality deterioration in 2010 based on seven hadrochemical variables measured every two weeks at seventeen sites on the River of Wen-Rui Tang, China. The WQ of the river had evaluated using seven different techniques. These techniques consisted of Principal Component Analysis (PCA), Fuzzy Comprehensive Evaluation (FCE), Comprehensive Water Quality Identification Index (CWQII), Comprehensive Pollution Index (CPI), Water Quality Grading (WQG), Single-Factor Assessment, and Nemerow Pollution Index (NPI). The CWQII technique was determined accurately in highly polluted waters with numerous impairments, therefore it was applied to evaluate the WQ in the Wen-Rui Tang River. Based on its approaches, qualities, and effectiveness, it was recommended to adopt it. The findings showed that total nitrogen, primarily composed of ammonium, was the predominant pollutant affecting the quality of the water. Because of dilution, temporal change in WQ was closely tied to precipitation. Water flow direction and anthropogenic effects (urban, industrial, and agricultural activities) were linked to the regional variance of water quality.

Haritash et al. (2016) investigated the Ganges River in India. In December 2008, water samples were taken from River Ganga to evaluate

Table 12. Classification of irrigation water according to the PI values (Sundaray et al. 2009; Shil et al., 2019)

PI value	Suitability of water for irrigation	Class
PI > 75%	Suitable for irrigation	I
25% < PI < 75%	Moderately suitable for irrigation	II
PI < 25%	Unsuitable for irrigation	III

its suitability for drinking and irrigation. In Rishikesh, water in the upper part can be used for drinking but after being disinfected (Class A); in the middle part, it can be used for outdoor bathing (Class B); then, in the lower part, it can be utilized as a drinking water source (Class C). Except for *Escherichia coli* (E. coli) bacteria, all the criteria for drinking water quality were within the limits ranges. The appropriateness indices for irrigation application were also assessed. Except for sodium concentration, the water quality for irrigation practically everywhere was acceptable.

Yldz and Karakus (2020) conducted a study on the quality of surface water used for irrigation in the Sivas district, Turkey. To calculate the SAR, KI, PI, as well as IWQI for the assessment of surface water quality, they used the data from 32 irrigation stations. The obtained Na%, KI, SAR, and values ranged from 3.3 to 57.9%, 0.05 to 1.4 meq/l, and, 0.1 to 9.4 respectively. According to the computed PI values, 93.8 percent fall into the (suitable) class, while 6.2 percent fall into the class of (non-suitable). The computed values of the IWQI were classified as very poor (68.9%), bad (15.5%), excellent (12.5%), and unsuitable (3.1%).

Marselina et al. (2022) tested the quality of water in the Citarum River, West Java Province, Indonesia. They selected four sites along the river for nine years. Marselina et al. (2022) adopted three methods to calculate the WQI. These methods are NSF-WQ), CCME-WQI, and OWQI. The results for the nine years were evaluated by using the relationship between wet and dry years as well as between wet and dry months. The NSF-WQI method rated the water quality of Citarum River as fair and bad based on the WQI readings with a range of (42.9–65.6) during dry years, (39–58.8) during wet years, (49–62.3) during wet months, and (38.2–60.9) during dry months. According to the CCME-WQI method, the water quality of the river was classified into three categories (Fair, Marginal, and Bad). This classification was built based on the WQI results that ranged between (12.6–31.5) during dry years, (12.1–28.7) during wet years, (12.6–31.5) during dry months, and (21.2–33.1) during wet months. The Citarum River was rated as a very bad water quality when applying the method of O-WQI. the calculated values of the WQI ranged between (11.5–18.8) and (13.8–24.5) during dry and wet months, respectively. In addition, between (11.5–25.7) and (11.5–15.9) during dry and wet years, respectively. These findings found that the assessment of the NSF-WQI method was the most effective in determining the water quality in the Citarum River.

Godwin and Oborakpororo (2019) used the WA-WQI to study the quality of the surface water of the river around the Nigerian city of Warri. Numerous physicochemical elements were used to calculate the WQI. These elements are pH, temperature, dissolved oxygen, electrical conductivity, total dissolved solids, total suspended particles, sulphates, nitrates, phosphates, chlorides, turbidity, and biochemical oxygen demand. The obtained values for the water quality index ranged widely from 110.12 to 821.5. The high value of WQI is related to the high levels of total suspended solids (124 mg/l) and turbidity (119 mg/l).

Abbas & Hassan (2018) used the water quality index (WQI) to examine the Diwanyiah River's water quality from September 2015 to June 2016. Along the river, four locations were chosen. The WQ of Diwanyiah River was subjected to applying the method of the Canadian Water Quality Guideline-Water Quality Index (CCME-WQI). To evaluate the WQ in the river, nine elements were chosen (water temperature, hydrogen ion, dissolved oxygen, total dissolved solids, turbidity, total alkalinity, nitrite, nitrate, and phosphate). The WQI readings indicated that the river's water quality are ranging from poor to marginal.

Al-Musawi (2018) examined the WQI of the Diyala River, where three stations were picked along the river. These stations are D12 in Jalawla City, upstream of the Diyala River, station (D15) in Baaquba City, in the middle section of the river, and the final station (D17) near Baghdad City, which is located before the confluence point of the Rivers of Diyala and Tigris. The WQI was assessed using the Bhargava method for both irrigation and drinking purposes. The findings of the WQI values classified the Diyala River as excellent for irrigation and good for drinking in the first section of it but poor for irrigation and unsafe for drinking in the middle section of the river. In the third section of the Diyala River, the WQ was suitable for irrigation but dangerous for drinking.

Ewaid et al. (2019) created an irrigation water quality guide and Visual Basic software based on United Nations Food and Agricultural Organization criteria and the irrigation water quality index. This guide was evaluated using a three-year (2013–2015) monthly dataset for Al-Gharraf Canal in southern Iraq that included 612 tests for 17 different variables. Assuming good management of permeability and salinity, the guide classified the canal water as (Moderate Restriction) with a degree score of (65.6), indicating its suitability for use in the irrigation of the majority of local crops. The outcomes also demonstrated the software's strong performance as a tool for evaluation, interpretation, guidance, and problem-solving related to irrigation water quality.

To compare the findings with the CCME-WQI and NSF-WQI, Ahmed et al. (2020) studied the 16 physical and chemical in addition to biological variables in the Lower Zab River in Kirkuk City at two sites for the years from 2013 to 2019. The results showed, except for turbidity, DO, nitrate, and calcium, which were readings greater than the standard limits, the analysis of all parameter levels were within the ranges recommended for drinking water (World Health Organization standards, and Iraqi standards). The high pollution in the Lower Zab River caused the water quality at the second site to be lower than it was at the first site, according to the calculated values of the WQI. Generally, drinking directly from the Lower Zab River is not permitted and required pretreatment before the usage of drinking.

Al-Ridah et al. (2020) used the WA-WQI and the CCME-WQI for studying WQ for drinking in the Shatt Al-Hillah River. Moreover, there are four water treatment plants (WTP) that take water from the river, which are Al-Tayarah, New Al-Hillah, Al-Hesain, and Al-Hashimyah. Water samples were taken monthly from January to December 2018 from the river and WTP. Nine variables measured are turbidity, pH, TH, Alk., EC, Mg, Ca, Cl, and TDS. The WA-WQI method for all stations showed that the treated water quality ranged from good to severely contaminated and the raw water quality ranged from severely polluted to unfit for human consumption. The river water was rated as Fair, and the treated water was rated as Good for drinking by the CCME-WQI method. The results of comparing the two models revealed that the CCME-WQI provided a better value for WQ than the value from the other method. In other words, the CCME-WQI is more flexible in application compared with WA-WQI.

Using the CCME-WQI, Hommadi et al. (2020) examined the water quality in the Euphrates River upstream of the Alhindya Barrage. Using the available data, a comparison of the water quality between the years 2008 and 2009 was made. Measured flow rates underwent statistical analysis, and the results showed that there is a statistically significant difference between the measured flow rates for that years. Compared to the CCME-WQI of 79 for 2009, the data showed that the CCME-WQI for 2008 was 94. This resulted from the mean water quantity falling from 370 m^3/s in 2008 to 213 m^3/s in 2009. The main cause of dry seasons, low rainfall intensity, and poor water quality is the phenomena of global warming.

El Behairy et al. (2018) studied the Shatt Al-Arab River, in southern Iraq. They generated a WQI map using GIS and the Water Quality Index to characterize the river's level of pollution. Numerous water quality parameters, including pH, temperature, DO, BOD_5, COD, nitrate, phosphate, TDS, TSS, turbidity, and EC, which were sampled at 37 sites along the river, were used to create the WQI. At the river branches, close to the governorate's administrative headquarters in Basra, poor water quality was seen. Additionally, it was found that unlawful discharges of industrial effluent and sewage, as well as high levels of sewage water discharged into river branches, were the main causes of river contamination.

Chabuk et al. (2020) used the WA-WQI and GIS software for assessing the WQ along the Tigris River. Twelve variables have gathered at 14 sites along the river (11 for calculating the WQI, and 3 for checking), including Ca, Mg, Na, K, Cl, SO_4, HCO_3, TH, TDS, BOD_5, NO_3, and EC. The water quality index was calculated using the weighted arithmetic method (WQI). The findings found the readings of all measured variables in wet and dry seasons raised from site 1 to site 11, while HCO_3 concentration was decreased for the selected sites (11). Along the river, the readings of BOD5, Na, Cl, Mg, SO_4, Ca, TH, and NO_3 were higher in the dry season than they were in the wet season, while other readings levels of HCO_3, EC, TDS, and K were higher in the wet season than they were in the dry season. The results found that the readings of WQI for sites (1-7) classified the WQ for drinking uses as poor, and classified the WQ at sites (8-11) as good. During the wet and dry seasons in 2016, the Inverse Distance Weighted (IDW) technique, as a tool in the GIS, has used to create the distributing maps of WQI for the total length of the river.

El Azhari et al. (2022) studied WQ in Northern Morocco's Oued Laou watershed. 26 physicochemical and biological variables were assessed in 13 surface water samples. The sources of surface water pollution were determined using cutting-edge methods such as multivariate statistical methods, irrigation water quality, and GIS. Except for HCO_3 and BOD_5, the results showed that practically other variables had concentrations that were below WHO standards. The Oued Laou river was exposed to two types of contamination, the first of which can be linked to anthropogenic activities like agriculture and the second of which is a result of the interaction between water and sediment, according to the Principal Component Analysis (PCA). According to the WQI's Inverse Distance Weighting (IDW), 7.7% and 38.5% of surface water are of excellent and good quality for drinking, respectively. The IWQI also showed that 92.2% of the water surface is suitable for irrigation.

Elsayed et al. (2020) estimated the WQ for irrigation in Egypt (Northern Nile Delta) by applying six methods of the WQI for irrigation. In this study, 110 surface water samples were collected in the summer season from a network of water channels in 2018 and 2019. Twenty-one physical and chemical variables were measured. 82% of the WQI values for irrigation were within the high class, while the remaining values (18%) were within the medium class. The Na (%) values were calculated. 96 percent of the Na (%) values were within the healthful category, and others were within the category of irrigation permissible. The whole samples of the Northern Nile Delta have been rated as suitable for irrigation. According to the results, the other methods for evaluating the surface water for irrigation uses showed that valid for irrigation. These methods are SAR, KI, PI, and RSC.

Krishan et al. (2022) conducted a study on one of India's most polluted rivers, the Gomti River. They employed the synthetic pollution index (SPI) and the water quality index (WQI). Additionally, the data integration with the geographic information system (GIS) has been carried out for the seven sampling stations (L1 to L7) throughout 2013–2017 along with 12 water quality parameters. In five years, the study area's WQI varied from 78.98 to 249.4, and its SPI was from 0.9 to 2.1. The WQI is classified as badly contaminated and unfit for human consumption, according to the map interpolated using GIS, while SPI is classified as moderately polluted and severally polluted. It was discovered that the WQI and SPI scores were considerably influenced by the BOD and COD.

CONCLUSIONS

From reviewing all the previous research, the following can be concluded. There are many indices of water quality around the world, and they are diverse, as there are special indices for specific purposes, or indices that assess water quality in general without worrying about the purpose of using water. Water quality indices also vary in terms of the number of parameters used for each of them, as well as methods of weighing and aggregation. The most common methods used to evaluate the water quality index are WA-WQI, and CCME-WQI. Other methods of the WQI are based on a limited number of parameters and on charts to calculate the WQI values, where these charts do not fit with the standard limits. Most of the research focused on evaluating river WQ for drinking purposes only or utilizing general indices to assess WQ for both drinking and irrigation uses. Very few researchers in Iraq used the irrigation water quality index (WQIFIR). Hence, many researchers use different water quality indices in different countries due to the importance of continuous monitoring of water quality, especially as a result of the increasing demand for fresh water due to the increase in population numbers and the expansion of cities, in addition to the deterioration of water quality for various reasons.

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