

Review

Modification of the Water Quality Index (WQI) Process for Simple Calculation Using the Multi-Criteria Decision-Making (MCDM) Method: A Review

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Abstract: Human activities continue to affect our water quality; it remains a major problem worldwide (particularly concerning freshwater and human consumption). A critical water quality index (WQI) method has been used to determine the overall water quality status of surface water and groundwater systems globally since the 1960s. WQI follows four steps: parameter selection, sub-indices, establishing weights, and final index aggregation, which are addressed in this review. However, the WQI method is a prolonged process and applied to specific water quality parameters, i.e., water consumption (particular area and time) and other purposes. Therefore, this review discusses the WQI method in simple steps, for water quality assessment, based on two multi-criteria decision-making (MCDM) methods: (1) analytical hierarchical process (AHP); and (2) measuring attractiveness by a categorically based evaluation technique (MACBETH). MCDM methods can facilitate easy calculations, with less effort and great accuracy. Moreover, the uncertainty and eclipsing problems are also discussed—a challenge at every step of WQI development, particularly for parameter selection and establishing weights. This review will help provide water management authorities with useful knowledge pertaining to water usage or modification of existing indicators globally, and contribute to future WQI planning and studies for drinking, irrigation, domestic, and industrial purposes.

Keywords: water quality assessment; physicochemical and biological parameters; water quality index; multi-criteria decision-making; analytical hierarchical process; MACBETH

1. Introduction

Water quality is intrinsically connected to human health, food production, gender equality, reduction of poverty, ecosystem livelihoods, economic development, and social growth in our communities [1]. It is also one of the major problems in water resource planning and management. Furthermore, an increase in urbanization, construction, agricultural activities, industrial applications, and natural processes has adversely impacted the quality of surface water and groundwater, and its effects on human health throughout the world, as shown in Figure 1 [2]. Water quality is usually classified into biological, physical, and chemical parameters, and there are several parameters for each category [3]. The evaluation of these three categories, based on parameters through field monitoring

of water sampling, provides essential information for identifying trends, a wider range of knowledge to water resource authorities, and future planning recommendations [4]. Water quality analysis typically relates to the quality of natural water and its possible uses (drinking, domestic, irrigation, and industries). In reality, it is expensive and laborious to monitor the parameters of multiple contamination sources entering into surface water bodies and groundwater systems. Furthermore, numerous researchers and scientists have faced difficulties in describing and addressing water in a consolidated and simple way [5]. These difficulties happen because of the complexity of water quality parameters and the wide variability in parameters utilized for characterizing the status of water quality of water resources. This has contributed to several comprehensive efforts, without losing its scientific basis, to define the water quality status in simple ways [6].

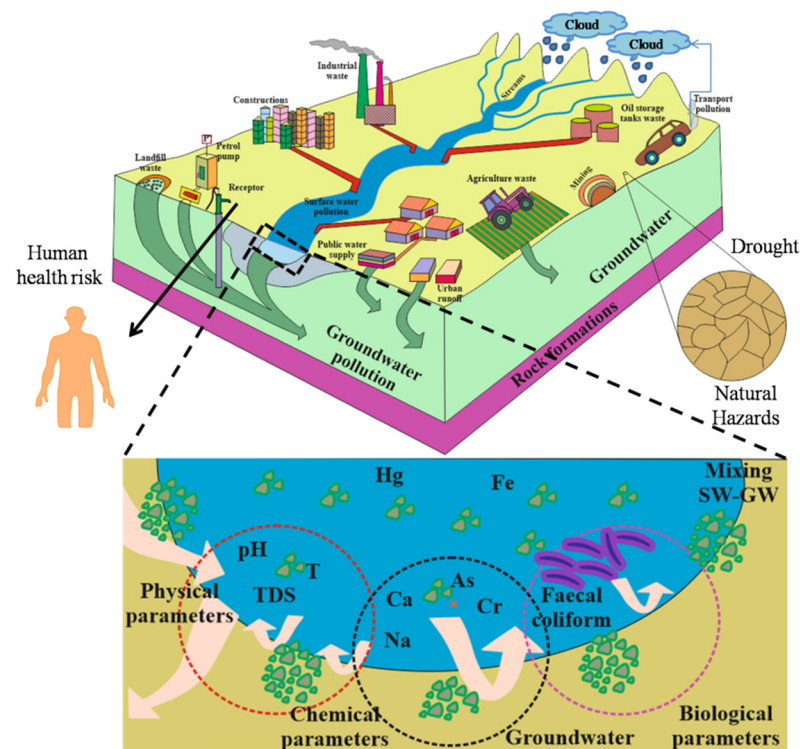


Figure 1. Shows the quality of surface water and groundwater resources degrading by anthropogenic and natural processes from various sources, as well as the effect on human health through these activities.

Regardless of this development, a simple evaluation of the water quality of groundwater and surface water is challenging to determine. The combined impact of many different factors that characterize the water quality and the challenges of classifying the significant parameters used to measure the status of water resources quantitatively are very complex to understand. Therefore, the water quality index (WQI) is considered a mathematical tool that significantly minimizes the complex water quality data sets and provides a single classifying value that describes the water quality status of water bodies or degree of pollution. Furthermore, WQI is a single dimensionless number that describes the overview of the overall water quality status in a simple way by aggregating the measurements of selected parameters such as pH, nitrate, dissolved oxygen (DO), heavy metal. [7]. As early as 1965, this method was introduced through mathematical equations to determine water quality status in the river by Horton [8]. The WQI is determined based on various biological, physical, and chemical parameters that define the various purposes of utilization of water bodies for human consumption, such as recreation, drinking, industries, irrigation, and domestic. After the proposed WQI method by Horton, the numbers of WQI methods have been developed for various purposes by numerous organizations across the globe, such as the National Sanitation Foundation Water Quality Index (NSFWQI) [9], Scottish

Research Development Department (SRDD) [10], River Status Index (RSI) [11], Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) [12], British Columbia Water Quality Index (BCWQI) [13], Overall Index of Pollution (OIP) [14], Oregon Water Quality Index (OWQI) [15], Bhargava Method Water Quality Index (BMWQI) [16], Malaysia Water Quality Index (MWQI) [17], Water Contamination Index (WCI) [18], Vaal Water Quality Index (Vaal WQI) [19], etc.

Moreover, four common steps have been used in the WQI method, including the parameters selection, sub-indices establishment, assigning of weights (equally or unequally), and aggregation of sub-indices to obtain the final index [4]. Previous studies have shown that most researchers have applied all steps (because they used unequal weights, such as NSFWQI, SRDD, MWQI, etc.). Some of them used three steps (equal weights, such as OIP, WCI, RSI, etc.), but few of them reported that they directly used the formula for water quality assessment (CCMEWQI) [20]. Furthermore, the WQI method has been applied for different purposes, but mainly for surface water quality (especially for river water) [21–29], groundwater quality [1,30–36], and wetland [37–42] across the world. Moreover, the Environmental Protection Agency (EPA) of the Republic of Serbia also utilizes WQI to inform about the overall status of the river water system [43]. In this technique, a large resource of water is easily accessed for water quality assessment because of the consistent scale using the WQI equation. Multiple parameters are used to calculate in a single number and the flexibility of selecting the characteristics of water quality. However, the calculation of WQI is a prolonged process in which numerous national and international standards are taken into consideration, in terms of criteria of water consumption. This makes the process more complicated, despite having simple calculations. Moreover, it is easy to bias the process of selecting parameters and calculating the individual weighting values. Therefore, the covered parameters cannot be definite in number that they would give a simple WQI; it may not be enough to understand, as a whole, the WQI of a large water body because certain parameters can influence the water quality in a wider manner, which can be neglected during the calculation.

The literature reviewed indicates that all of the indices have their limitations and strengths; therefore, many organizations and agencies do not consider this methodology for developing a WQI worldwide [7,44]. However, it is pertinent to mention that the strengths and weaknesses of the processes in establishing WQI for water quality assessment can be simplified by multi-criteria decision-making (MCDM) approaches to evaluate the parameter's weight separately. In previous years, analytical techniques have significantly increased to resolve the problems related to water resources, where MCDM procedures are generally regarded as very effective in addressing water management problems [45]. The effectiveness of such procedures depends on the conceptual framework of assessment processes and on the common language used to identify and address complex water challenges. Moreover, MCDM easily allows—in the process of decision-making—the impact of uncertainties that often define water management problems [46]. In previous decades, several authors have applied the MCDM method to various purposes in water resource management, assessment of water quality [46,47] as well as in other areas, to solve problems surrounding the environment, energy, and sustainability [48], safety and risk management [49], and technology and information management [50]. There are numerous MCDM approaches available for solving problems related to water resources, such as analytical network process (ANP), analytical hierarchical process (AHP), data envelopment analysis (DEA), fuzzy decision-making (FDM), measuring attractiveness by a categorically based evaluation technique (MACBETH), simple additive weighting (SAW), supply chain management (SCM), a technique for order preference by similarity to ideal solution (TOPSIS), compromise programming (CP), etc. [51–55].

The procedure for calculating the WQI, based on four fundamentals, was considered a prolonged process of steps to obtain the value of the final index; however we discuss these steps in this review article. Furthermore, two MCDM methods (AHP, MACBETH) are described to provide an easy calculation of WQI to evaluate the water quality. Therefore,

developing a simple WQI calculation process, with less effort and better accuracy, based on MCDM techniques for the determination of the quality of subsurface water and surface water, was the main purpose of this review.

2. Overview and Purposes of Developing Water Quality Index (WQI)

This review paper reviewed 46 water quality indices (WQIs) based on 167 publications in this study. Whereas 144 publications have been taken from the Web of Science (WOF) and Scopus, the remaining 23 publications were related to books and reports. Moreover, the comparison of different WQI method has been discussed in Table 1. Furthermore, WQI methods have been developed with four common steps (parameter selection, sub-indices, establishing weights, aggregation method), published from the 1960s to 2020, and are listed in Table 2, Section 3.2.3. Whereas, the WQI method is used for unequal weights to achieving the final index, as shown in Supplementary Materials Table S1, and for equal weights, as listed in Table S2. There are four common steps of WQI used throughout the indices, reviewed for each of the aforementioned steps required for the final index value of a WQI, as discussed in Section 3. Moreover, the method that can make an easy calculation for WQI with less effort, and provide accuracy, has been studied with the help of MCDM techniques (AHP, MACBETH) in Section 4.

2.1. Comparison of WQI

Studies by Landwehr and Deininger [56], supported by Ott [57], were among the first prevalent comparative studies on WQI used in the United States, providing detailed descriptions on theories and practices of the environmental index. Moreover, more than 20 WQIs were reviewed by Steinhart et al. [58] until the late 1970s. Cooper et al [59] and Richardson [60] proposed the production of indices for estuaries in Australia and South Africa, respectively. Moreover, around 30 WQIs were used throughout the globe; their contributions were used in Europe by Van Helmond and Breukel [61]. Pesce and Wunderlin [62] contrasted the quality of the Suquia River in Argentina with three WQI. Pesce and Wunderlin [62] contrasted the quality of the Suquia River in Argentina with three WQI. Then, the “subjective” and “objective” WQIs were calculated according to the normalized values, weight was allocated, and a constant representing the visual perception of the contamination level of the monitoring station was assigned in the case of a subjective index. A third “minimal” index has been estimated for only three parameters by the average normalized value. The study showed that the third minimum index was well-associated with the objective index, but that both WQIs were typically correlated with the calculated levels of various parameters.

The performance of many WQIs on Croatian waters have been compared by Stambuk-Giljanovic [63], in a similar study, and these indices were related to the objective index performed in Argentina. The results showed that the two updated arithmetic indices have been perfectly suited to distinguish areas according to the conditions of water quality. Liou et al. [11] established a WQI in Taiwan that specified nine parameters and provided them with standardized scores, in accordance with pre-developed rating curves. This index is based on the geometric means of the standardized values. Kim and Cardone [64] established the “Scatterscore” index to investigate water quality changes over space and time. This index does not depend on standards or guidelines for water quality and may comprise an unlimited set of parameters. Moreover, it was mainly utilized to predict—negatively or positively—water quality modifications around mining locations in the United States; however, it can also be applied to non-impacted locations. Tsegaye et al. [65] established an index based on the chemical data of 18 streams in one lake basin in northern Alabama, which contributes seven parameters to the maximum concentration of each parameter, after standardizing each parameter. Comparison of the WQI based on a national and global level is presented in Table 1.

Table 1. The development of WQI and its comparision based on national or regional scale.

Index (Author)	Method	Objectives
Water quality index for freshwater life [12]	Evaluate water quality for freshwater life against guidelines.	Inland water
The well-being of nations [66]	Evaluate inhabitants indices against ecosystem indices.	Human and ecosystem
Overall index of pollution [14]	Evaluating and categorising a range of water quality parameters in comparison with the Bureau of Indian Standards (BIS) and other recognized guidelines such as World health organization (WHO).	Stream/river health
Index of river water quality [11]	Using the multiplicative aggregate process for a variety of water quality parameters as standardized scores.	Stream/river health
The Scatterscore [64]	Evaluate decreases or increasess in parameters over space and time.	Water quality
Chemical water quality index [65]	Evaluate a range of parameters by standardizing the maximum concentration of each measurement to every parameter.	Lake basin
Environmental performance index [67]	Using a targeted proximity calculation for 16 indexes classified into six policy goals.	Environmental health and ecosystem vitality

2.2. Importance of WQI

In general, WQI is the comparison of the amount with an arbitrary or scientific standard or with a pre-specified base. Therefore, the WQI monitored and reported environmental status and trends on standards quantitatively. The WQI method provides effective information on the degree of purity and pollution of water, by avoiding an overwhelming quantity of data to demonstrate water quality [68]. The WQI tool also facilitates a perfect quality monitoring system accessible. The monitoring data should formulate easy to comprehend indices to executive management and the overall development of public policies to accomplish this. The National Academy of Sciences (NAS)'s Planning Committee on Environmental Indices [69], found that environmental indicators play an active role in assisting with program design, assigning policy details, and communicating facilitation with affected individuals.

Ott [57] identified the following six basic usages of WQI after examining relevant literature available on the subject: resource assignment, standard enforcement, trend analysis, location ranking, public information, and scientific research. This means that indices are descriptive and objective methods for evaluating water quality trends. Parameters are not concisely graphical against one another, or against time, and do not explicitly indicate the patterns due to overlap in data and volume.

- Scientific research: indices can be used to minimize a large number of data into a process that provide insight into research and perform an analysis of many of these environmental programs.
- Public information: indices can be applied to educate the public on environmental conditions.
- Trend analysis: indices can be utilized for environmental information, at various time periods, to evaluate changes in environmental quality that have taken place over the period.
- Standard enforcement: indices can be applied to particular areas to evaluate the extent to which legislature standards and existing criteria are fulfilled or exceeded.
- Resource assignment: the location ranking, by evaluating the environmental conditions at various places or geographical regions.

Almost every WQI relies on normalization, the data parameter-by-parameter, as per the predicted concentration levels, and the interpretation of “bad” versus “good” levels. After this, index is calculated as a weighted average for all observed values, with weighted parameters according to their perceived significance to overall water quality. The purposes

of the WQI method are, particularly, for the evaluation of the overall status of water quality (parameters of physical, biological, and chemical) and the use of water resources for multiple purposes. WQI methods were developed by individuals, organizations, and agencies, and classified into four groups (discussed below):

- Specific indices: the water classification in this category is based on the type of use and requirement (drinking, irrigation, industries, bathing, etc.), which is defined by OWQI, CCME, etc.
- Public indices: the type of water used in the assessment process, such as NSFWQI, (Horton 1965), are ignored in this category.
- Statistical indices: the statistical approaches are used in these indices and personal opinions are not included.
- Planning indices: this step includes an instrument tool that facilitates decision-making and makes a plan for managing water quality projects.

2.3. Background History and Concept of WQI

The first concept of WQI was developed in Germany (1848) for describing the water quality, according to the level of cleanliness or pollution of water bodies [5]. After this, Kolkwitz and Marsson [70] developed the “saprobic index (provides a saprobial index value based on the composition of organic pollution)” during the 19th century, as a biological principle to evaluate the water quality. Later on, the concept of water quality in the context of the saprobic index was established, and continued over a century to establish a simple mathematical technique to evaluate the water quality, based on ten parameters by Horton [8]. Horton defined a new approach in the context of a rating system for the Ohio River Valley Water Sanitation Commission and described the WQI method by choosing, rating, and integrating the important selected biological, chemical, and physical water quality characteristics. Each parameter has a rating scale ranging from 0 to 100. Each parameter is assigned a weighting value between one and four, according to its possible effect on the final index score [20]. A four-weight factor is allocated to high-quality parameters, while one-weight factor was assigned to those with low quality of water. Furthermore, numerous WQI models have been defined by multiple international and national organizations; the process depends on the area, place, purpose of water use, and water quality parameters for specific purposes (e.g., NSFWQI, CCMEWQI, OWQI, etc.) [71]. These organizations have demonstrated the significance of different WQI for water quality assessment, their current uses, and the steps used in their formulation. They also presented future recommendations and discussed the need to establish a globally accessible WQI method that is sufficiently flexible to split the existing information into various purposes for water quality analysis. WQI is also considered a significant aspect of the more comprehensive natural resources or environmental indices, such as the Stream Index [72] and the Environmental Performance Index [73].

The common framework of WQI is seen in Figure 2; it indicates a range of parameters of water quality, which are transformed into a specific scale. These transformations occur as the measured water quality data have distinct units or ranges. Such parameter values, which are transformed into a general scale, are considered sub-indices; after obtaining the sub-indices, the final index value is aggregated. The aggregation process can occur in the two consecutive phases, as shown in Figure 2, from the sub-indices to the aggregated sub-indices (whether there are existing aggregated sub-indices), then from the aggregated sub-index to the final index. After all of these stages are completed, the final index will be described to measure or determine the water quality status. The previous study indicates that the information obtained from the WQI can usually be utilized for the specified purposes, such as (1) to assist the community and the policymakers in avoiding subsequent biased views and subjective assessments [63], (2) to compare water quality from multiple sources and locations without a highly rigorous evaluation of water quality data [74], (3) to provide water authorities and the wider community with an overall water quality

status [75] and (4) to study the environmental quality impacts of administrative policies and environmental programs [76].

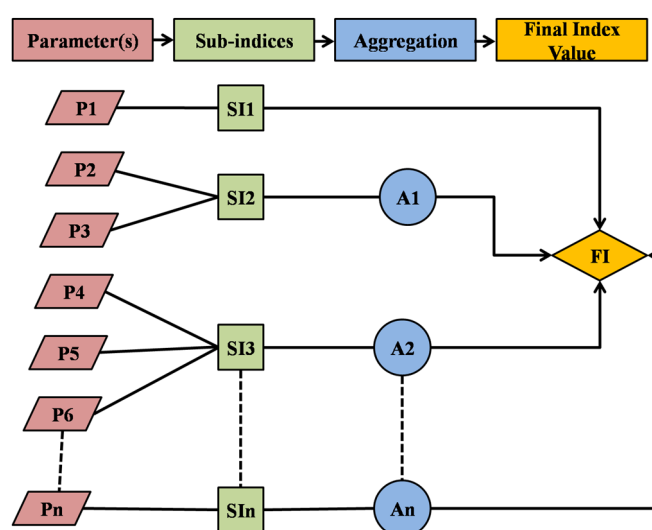


Figure 2. This figure is showing the common structure of the WQI.

3. Common Steps for Developing Water Quality Index (WQI)

After Horton [8], many indices were established; however, there has been no world-wide acceptable way of creating water quality indices despite those efforts. The literature reviewed regarding to WQI are mentioned in this section, along with the specific region or country in which they were applied. The indices use the following four required common steps to develop a WQI method;

- Selection of parameters;
- Obtaining the sub-index value;
- Establishing of weights;
- Sub-index aggregation to get the value of the final index [7]

Most of the developed WQI methods followed the three steps (parameter selections, sub-index value, and final index value) for assessing the overall water quality status, while certain studies considered full steps for the development of WQI [20]. The third step in the WQI (establishing weights) has not been utilized in specific indices; however, equal weights were applied. This section describes the details of the four steps and the various methods used in each step. The three phases are shown in Figure 3.

3.1. Selections of Parameters

In developing an index, the selection of parameters is an essential step because the selected parameters (physical, chemical, and biological characteristics) are significant components of a WQI method. The indices have a range between four and twenty-six, which have various selected parameters [4]. Three system types can be utilized for parameter selection: open system, fixed system, and mixed system, as defined by Sutadian et al. [4].

3.1.1. Fixed System

In most cases related to WQI development, the majority have used a set of fixed parameters that are the most acceptable set of variables to measure the value of the final index, selected through the WQI user [9,10,15]. While the WQI user can evaluate and correctly compare the water quality status between different sites using a set of parameters, the system is rigid, a common issue with many water quality indices. Rigidity occurs when it becomes useful and essential to incorporate additional vital parameters in an index to define particular water quality problems; however, the WQI developer cannot include the new parameters required for the future index application [76].

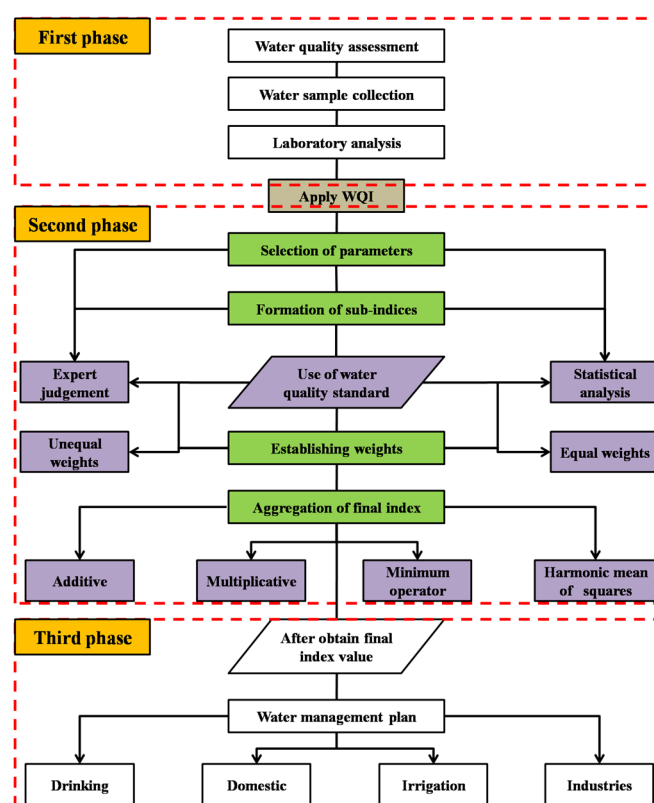


Figure 3. This show three phases for applying WQI method, in which the first phase demonstrates that the water quality assessment process. The second phase relates to the WQI process for four common steps (green color) wherein the method is applied to each step (purple color) and the third phase to the water management plan for different purposes.

3.1.2. Open System

A few WQIs permit a minimum number of parameters used in the open system by WQI users, based on their characteristics and their effects on water resources [12]. Although those WQIs are flexible and reduce rigidity, the comparison of results from various monitoring locations poses a critical issue. Therefore, the usage of these WQIs may vary from region-to-region, as the parameters are not defined. The maximum parameter selection number is not specified in the calculation of the final index. Therefore, users can add several characteristics from the list of possible parameters in applying such WQIs. This flexibility has the advantage of avoiding rigidity. Nevertheless, a fixed set of parameters poses crucial problems, including difficulties in contrasts between monitored locations and water resources.

3.1.3. Mixed System

The mixed system comprises of both open and fixed systems. Some parameters are applied if one of the various parameters has a sub-index value higher than the aggregation value, based on the final index calculation of the basic parameters. By considering or inserting additional parameters with higher sub-index values, the final aggregated index value in the mixed system should be recalculated. The selecting parameters have high effects on the quality of water bodies, particularly for mixed and fixed systems.

Abbasi and Abbasi [7] suggest that there is no index that can obtain 100% accurate results in the selecting parameters. The mixed system is the perfect match for the open and fixed systems; however, the open and mixed systems still struggle from the same issues, although with a decreased error margin. Because of the advantages and disadvantages of the open, fixed, and mixed systems, the mixed system can be utilized to compare and evaluate the water quality parameters, making it the simplest process for developing a single

WQI. The selection of parameters for a mixed system requires considerable proficiency, attention, care, and experience to ensure that the most critical parameters are compatible with the WQI. Sutadian et al. [4] describe the initial selection of water quality parameters for designing a WQI as follows: a review of the literature [77,78], availability of data [15], parameters should reflect the overall status of water quality [79,80], consistency of parameters (parameters with similar characteristics that need not be taken into account) [79] and the expected usage of the surface water and groundwater [25,81–83]. Two methods usually define the initial set (decided by the criteria mentioned above): expert judgment and statistical methods, to reduce subjectivity and uncertainty at this process, described in Section 3.2.

3.2. Formation of Sub-Indices

The formation of sub-indices was aimed to transform the water quality parameters into a common scale, as the actual parameter values have their distinct units [7]. For instance, the electrical conductivity (EC) is measured in $\mu\text{S}/\text{cm}$ (another turbidity measured in nephelometric turbidity units (NTU)), while all significant ions and most heavy metals are measured in mg/L or $\mu\text{g}/\text{L}$. Whereas every water quality parameter has different limits, units, and behavior concerning water resource parameter concentration. For examples, the range of mercury ($0.001 \text{ mg}/\text{L}$) is rarely found above the $1 \text{ mg}/\text{L}$ limit, while nitrate ($45 \text{ mg}/\text{L}$), hardness ($200 \text{ mg}/\text{L}$), chloride ($250 \text{ mg}/\text{L}$), and other parameters are often found above the $1 \text{ mg}/\text{L}$ limit, as prescribed by WHO [84]. In many conventional WQI methods, the parameters can only be aggregated if they have the same common scales, so the process of rescaling or the standardizing of parameter values is necessary to form sub-indices [85]. However, several WQIs do not take this step into consideration (e.g., CCME). Therefore, the actual parameter values are used instead of sub-indices in the final index aggregation.

For instance, CCME [12] has applied a multivariate analytical technique to aggregate actual parameter values without transforming them into a common scale. Similarly, a mathematical calculation was applied by Said et al. [77] for direct aggregation of the final index value, in which the parameters do not need to be standardized. In Some WQIs, specific parameter(s) are directly taken as individual sub-indices to be aggregated for the value of final index. Although the primary parameter sub-indices are grouped into a wider group of secondary sub-indices, in a few cases, they can be aggregated to the final index value (often called aggregated or composite sub-indices). For instance, Bhargava [16] analyzed four various composite sub-indices, such as organic, coliform, inorganic, toxic elements, and physical sub-indices. The index users have generally developed rating curves or sub-index functions for obtaining the values of sub-index, while the sub-index functions are mathematical relations between the sub-index values and actual values of the measured parameter. The values of an actual parameter can be converted into sub-index values utilizing sub-index functions, which can be used as rating curves, graphically (parameter values plotted to the corresponding sub-index values). Such rating curves or sub-index functions help index users describe all water quality parameters with dimensional values within the identical range, such as 0–100 or 0–1. The following three common methods of developing sub-index functions or rating curves were used:

- Expert opinion or judgment can be performed individually or as a group.
- Statistical methods.
- Use of water quality standards.

3.2.1. Expert Judgement

The selection of important parameters is one of the challenges in the final index aggregation in several WQIs. A large number of subjective assessments by the index users are part of the initial set of selected parameters. To deal with that, several experts in the parameter selection have been used to minimize subjectivity and uncertainty [85]. The parameter selection is generally integrated into the expert judgment process using three

methods: individual interviews, virtual groups, and the Delphi method [86]. Furthermore, the expert's opinion uses the parameter selection for the WQI to develop the rating curves or sub-index functions, for obtaining the values of sub-index formation. Generally, the WQI expert group is involved in collecting the relevant data by the Delphi method to develop sub-index functions through questionnaires.

The Delphi method (first reported on in 1970) has been commonly applied in selecting parameters among the above three methods. This approach is conducted to assess the experts' opinions and perspectives, without making the experts congregate at a time and place agreed upon. Linstone and Turoff [87] defined Delphi's method for structuring a group communication process, so that the process can efficiently solve a complicated challenge for a group of individuals as a whole. The index developers should distinguish water quality experts from each other, as they express their opinions and make their decisions anonymous. This attempts to eliminate some of the biasing impacts, in particular, because of expert interactions. These interactions may contribute to leading experts committing to a decision that they do not hold [86]. The implementation of this approach also requires two phases of questionnaire rounds before expert opinion is achieved. The developers are asked to indicate several parameters in the WQI for potential inclusion during the first phase of the questionnaire. In this step, the new water quality parameters that have not been included in the questionnaire can also be included. The first questionnaire finding will be discussed in the second phase, including the addition of new parameters. The objective was to create new criteria or parameters and implement a small discrepancy among water quality experts' opinions regarding various rating parameters. Such implementation will proceed until decisions are achieved on the number and types of parameters.

The Delphi method is also used to integrate the opinions of water experts on sub-index values. Further, Deininger [88] clarified that WQI developers were required to construct the rating curves on their opinion (often manually) to evaluate the range of differences in water quality through different measurements of each parameter. Several rating curves have been developed based on accepted essential points from the experts' opinions; these rating curves indicate the non-linear or linear sub-index functions. Moreover, the index developers obtain subindex values using subindex functions by direct calculation [4]. The Delphi methodology has been widely adopted throughout the development of different WQIs (NSFWQI, SRDD, CCMEWQI, BCWQI, OWQI, BMWQI and Vaal WQI, etc.).

The Delphi method has also been generally used to summarize specific expert opinions to develop parameter weights for different WQIs. For instance, Horton [8] assigned weights for parameters, such as one weight for four parameters (alkalinity, chlorides, carbon chloroform, and special conductivity), two for one parameter (coliform), and four for three parameters (pH, DO, and sewerage treatment). Furthermore, this method for parameter weighting has been used extensively in distinct water quality indices after Horton [8] to generate relative weights for the selected parameters, minimize subjectivity, and increase credibility. Index experts compare relative water quality parameters by applying a common scale of one (highest) to five (lowest) in this method. Moreover, for the ratings of all expert opinions, the mean arithmetic was calculated, which are transformed, consequently, into weight ratings of zero to one (lowest impact weight to the highest influential rating). Significantly, the total weight (all chosen water quality parameter weights should be one) for most water quality indices, as the combined impacts of parameters, should not exceed 100% [85].

3.2.2. Statistical Techniques

Statistical techniques are common tools for reducing subjectivity in selecting parameters, and have been widely used for many decades to the accuracy of the results. These techniques represent the most efficient tools for understanding variation between several variables and transforming them into smaller groups of independent variables through pattern recognition [89–94]. Furthermore, this methodology is related to statistical features, such as average values and different parameter concentrations calculated over a long time.

This technique was also applied effectively for the evaluation of water quality by several water quality index developers [16,79]. For instance, Dunnette [79] applied the mathematical average of the actual parameters of six observation locations between 1973 and 1975, and compared them to the values of the sub-index; such as 80 for biological oxygen demand (BOD), nitrogen, total solids, and oxygen, as well as 70 for fecal coliform (FC) in Willamette River in Oregon. Moreover, Hallock [95] established a ranking curve of turbidity, total suspended solids (TSS), total nutrients, and total phosphorus based on acceptable values of the sub-index, such as 100, 80, 40, and 20, to actual values of these characteristics at the 95th, 99th, 80th, and 10th percentages (%), respectively. The values of the sub-index should be integrated into the final index after determining the sub-index function, which can be obtained by multiplying the sub-index value by the allocated weight of parameter. Therefore, common methods are used in multivariate techniques, such as factor analysis and cluster analysis, to select and group the parameters, as briefly discussed below.

3.2.3. Factor Analysis (FA)

Factor analysis states that correlations reflect relationships with a low number of underlying factors across a set of variables. Furthermore, this method decreases the number of variables and identifies or classifies structure in the correlations between the parameters [96]. The fundamental objectives of FA are: to determine how many factors are needed to give a set of variables, analyze and evaluate the parameter weight, define correlation levels between variables and related statistical factors, and examine each of the factors identified through each score. A particular characteristic of this approach is the principal component analysis (PCA) or the extraction of factors that constitute linear combinations of all variables, which may describe the total variance of the dataset. The rest of the factors explain the maximum residual variability. Gulgundi and Shetty [97] applied the PCA application to evaluate the correlation of weighting parameters, as shown in Equation (1).

$$Z_{ij} = a_{i1}x_{j1} + a_{i2}x_{j2} + a_{i3}x_{j3} \dots + a_{im}m_{jm} \quad (1)$$

where Z indicates component score, x denotes the estimated variable value, i is the component number, j is the sample number, a is the loading component, and m is the total number of variables.

3.2.4. Cluster Analysis (CA)

Cluster analysis is used to identify the actual data groups in pursuance of their similarities. Total variables are also defined until subjected to cluster analysis standardized by z-score mode. The primary purpose of cluster analysis is to find the sub-groups in the large group and create content for more information about the data analysis of physicochemical characteristics [2]. This method's feature is the hierarchical cluster analysis (HCA) used to determine the number of clusters using the Ward's linkage and Euclidean distance procedures [98]. Log transformation implies that the outcomes are close to each element's normal distribution. The Z-scoring ensures the equal weighting of all HCA application parameters [99]. This method has been demonstrated with the formula by Daughney et al. [99], as follows in Equation (2).

$$Z_{ij} = \frac{x_{ij} - \bar{x}_j}{S_j} \quad (2)$$

where Z indicates the Z-score for the variable of j at sites i , S_j and $\bar{x}_j$ is the standard deviation and mean of the medians of the variable of j th for each site of monitoring, and x_{ij} denotes that the median of the variable j at site i in Equation (2). A limited Euclidean distance

indicates the strong resemblance between calculated variables, and it is used mostly as a similar way of measuring in HCA by Daughney et al. [99], as shown in Equation (3).

$$E_{ij}^2 = \sum_{j=1}^n (Z_{ij} - Z_{kj})^2 \quad (3)$$

where E is the Euclidean Distance square, Z_{ij} , and Z_{kj} indicate the Z-score at i and k for the variable j , and the description, including all n variables used within HCA, is carried out. The Ward's linkage method is subsequently used to identify clusters for non-residual sites, and is based on variance analysis, generating (different) smaller clusters based on the linkage principles, meaning that every site is more similar in the cluster to other places in the same cluster than any other site of the distinct cluster [100].

3.3. Use of Water Quality Standards

The legislative standard for water quality is used to develop rating curves or subindex functions. Each water quality parameter is allocated a rating value from 0 to 100 in sub-index development, which is based on national (India, Malaysia, etc.) and international (WHO, United States Environmental Protection Agency (USEPA), etc.) organizations, specifying acceptable and permissible limits [101]. The rating (100) of the sub-index indicates that the parameter values were below the acceptable value, whereas that sample exceeded the maximum permissible limit with a sub-index rating (50). Concerning the intended use of the water resources, the rating curves are essential to obtain the allowable values for every parameter, in contrast to the Delphi method. Moreover, House [102] also used standard limits for water quality, making sub-index values relatively easy to sub-division and provide more information for water consumers. Based on these values, the actual parameter values were measured for the sub-index by three methods: categorical scaling, linear interpolation rescaling, and a comparison with allowable limits.

The first linear interpolation rescaling process is utilized to obtain the identical range, generally between 0 to 100 or 0 to 1 for subset index values [81,103]. Similarly, the classification of water quality in a sequential order is established by the index developers, such as drinking usage (class 1), household consumption (class 2), agriculture (class 3), navigation (class 4), and wastewater system (class 5) [4]. Subsequently, every limit corresponding to the appropriate classification of water quality, and the associated sub-indices numbers, are assigned using permissible minimum to maximum limits. For instance, the acceptable limit of the selected parameter (e.g., BOD) is considered as 4, 6, 15, 20, and 50 mg/L for the sub-indices classes of 100, 75, 50, 25, and 1 respectively [103]. The pairing of data are considered as main points in rating curves, based on the relation between acceptable limits and subindex values, such as class 1 (4:100), class 2 (6:75), class 3 (15:50), class 4 (20:25) and class 5 (50:1), respectively [80]. Therefore, a simple linear interpolation process is applied to observe the sub-indices actual parameter values, which lies between two groups. The following basic formulas, Equations (4) and (5), are applied to sub-index functions by Prati [81], which measure the values of the sub-index in this process;

$$SI = \left[(S_1 - S_2) \times \left(\frac{x_i - x_1}{x_2 - x_1} \right) \right] - S_1 \quad (4)$$

$$SI = \left[(S_1 - S_2) \times \left(\frac{x_1 - x_i}{x_1 - x_2} \right) \right] - S_1 \quad (5)$$

where SI is the values of sub-index, S_1 and S_2 denotes the upper and lower classes of sub-indices values, x_1 and x_2 shows the upper and lower classes of permissible limit, and x_i is the i th parameters value (mg/L) respectively, and. When the value of a parameter decreases, regarding the water quality level, with an increase in the actual parameter values, then Equation (4) is utilized to obtain the sub-indices. Furthermore, a parameter increases the water quality level with an increase in the actual parameter values, then Equation (5)

is used for the sub-indices values. The second categorical scaling process is applied to transform the actual parameter values into sub-indices, where a constant value is assigned to the parameters between 0 and 1. Therefore, the formula is used to obtain the sub-indices values through this process. Sub-index SI = 0 indicates the parameter concentration is above the permissible limits, and SI = 1 denotes that the parameter concentration below the allowable limits. The latter method is based on comparing the actual value with the acceptable parameter limits to generate the values of the sub-indices, according to the level of water quality (worst to highest) and range (0–1). The sub-indices value is calculated by Liou et al. [11], as per Equation (6):

$$SI = \frac{x_i}{x_{\max}} \quad (6)$$

where x_i indicates the actual parameter value (mg/L) and $x_{\max}$ is the maximum permissible limit of parameters (mg/L). The use of national and international standard methods for water quality analysis, its allowable and unacceptable limits, and appropriate laboratory analysis methods and equipment techniques are presented in Table 2.

Table 2. The table listed suitable analytical methods and equipment using the physicochemical parameter's national and international standard evaluation methods.

Water Quality Parameters	Parameters (Units)	Usage of Parameters	WHO [84]	BIS [104]	USEPA [105]	INWQS [106]	Method	Equipment and Analytical Techniques
Physical Parameters	Color (TCU)	D	15	5–15	-	15	Solution by (Pt-Co)	Spectrophotometer
	Taste and Odor (TON)	D	-	-	-	-	ASTM D-1292 triangle	Attitude taste Scale (ATS)
	Temperature (°C)	D	-	-	-	-	KM 3002	Digital Thermometer
	EC (µS/cm)	D, I, H, A	250	250	-	1000	Electrometric	Conductivity meter—Hach
	TDS (mg/L)	D, I, H, A	-	500–2000	-	500–1000	Gravimetric Method	Hach potable meters
	Turbidity (NTU)	D, A	-	1–5	-	5	Turbidimeter	Hach Turbidimeter
	Salinity (ppt)	D, I	-	-	-	0.5	Filtration	SHKY Conductivity meter
Chemical Parameters	pH	D, I, H, A	-	6.5–8.5	6.5–8.5	6.5–8.5	Electrometric	pH meter—Hach
	Hardness (mg/L)	D, I, H, A	200	200–600	-	250	Titration	Digital Burette
	DO (mg/L)	D	-	6	-	>7	Colorimetric	Portable meter
	BOD (mg/L)	D, A	-	2	-	1	Titration	UV Visible Spectrophotometer
	COD (mg/L)	D	-	-	-	10	Titration	
	TOC (mg/L)	D	-	-	-	-	Titration	
	DOC (mg/L)	D	-	-	-	-	Titration by H ₂ SO ₄	pH meter
	Alkalinity (mg/L)	D, I, H, A	-	200–600	-	-	Titration by H ₂ SO ₄	
	Acidity (mg/L)	D, I, H, A	-	-	-	-	Titration by H ₂ SO ₄	
Biological parameters	Total coliform (100 ml)	D	-	-	-	-	Maximum probable number (MPN)	Bacteriological Incubator
	Fecal coliform (10 ml)	D	-	-	-	-		

Table 2. Cont.

Water Quality Parameters	Parameters (Units)	Usage of Parameters	WHO [84]	BIS [104]	USEPA [105]	INWQS [106]	Method	Equipment and Analytical Techniques
Anions	Carbonate (mg/L)	D, I, H, A	-	-	-	-	Titration by H ₂ SO ₄	Digital Burette
	Bicarbonate (mg/L)	D, I, H, A	-	600	-	-	Titration by H ₂ SO ₄	
	Chloride (mg/L)	D, I, H, A	250	250–1000	250	200	Argentometric Method	Ion Chromatograph, Dionex (ICS 5000), ICP-MS, flame photometer, UV-Vis Spectrophotometer
	Fluoride (mg/L)	D, I, H, A	1.5	1–1.5	4	1.5	SPADNS colorimetric	
	Nitrate (mg/L)	D, I, H, A	45	45–NR	10	7	Phenol disulphonic acid	
	Sulfate (mg/L)	D, I, H, A	500	200–400	-	250	Gravimetric	
Cations	Calcium (mg/L)	D, I, H, A	-	75–200	-	-	Conductivity	Ion Chromatograph, Dionex (ICS 5000), ICP-MS, flame photometer, Atomic fluorescence spectrometry (AFS)
	Magnesium (mg/L)	D, I, H, A	-	0.1–0.3	-	-	Conductivity	
	Sodium (mg/L)	D, I, H, A	20	-	-	-	Conductivity	
	Potassium (mg/L)	D, I, H, A	-	-	-	-	Conductivity	
Heavy Metals	Arsenic (mg/L)	D	0.01	0.01–0.05	0.01	0.05	American Public Health Association [107]	Atomic fluorescence spectrometry (AFS), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), Atomic absorption spectrometer (AAS), Inductively Coupled Plasma Optical emission spectroscopy (ICP-OES), X-ray fluorescence (XRF)
	Aluminium (mg/L)	D	0.1	0.03–0.2	-	-		
	Chromium (mg/L)	D	0.05	0.05–NR	0.1	0.05		
	Copper (mg/L)	D	2	0.5–1.5	1.3	0.02		
	Iron (mg/L)	D	0.5	0.30–NR	-	1		
	Lead (mg/L)	D	0.01	0.01–NR	-	0.05		
	Manganese (mg/L)	D	0.10	0.1–0.3	-	0.1		
	Cobalt (mg/L)	D	-	-	-	-		
	Cadmium (mg/L)	D	0.003	0.003–NR	0.005	0.01		
	Nickel (mg/L)	D	0.07	0.02–NR	-	0.05		
	Zinc (mg/L)	D	3	5–15	-	5		
	Mercury (mg/L)	D	0.006	0.001–NR	0.002	0.001		

TCU is the true colour unit, $\mu\text{S}/\text{cm}$ is the micro-Siemens per centimeter, TON is the threshold odour number, $^{\circ}\text{C}$ is the degree Celcius, TDS is the total dissolved solids, COD is the chemical oxygen demand, TOC is the total organic carbon, DOC is the dissolved organic carbon, D is the drinking water, H is the household water, NTU is the nephelometric turbidity unit, A is the agriculture usage, and I is the industrial purposes of parameters.

3.4. Establishing Weights

Index developers have used the step of assigning weights to calculate final index values. Weights are used—either equal or unequal—for all of the water quality parameters, which are related to their significance, to specific end-use (drinking suitability and ecological health), and their effects on the value of the final index [30]. The value of the final index is strongly influenced by changes in the expert's opinion and water quality parameter guidelines. Furthermore, equal weights are allocated when an index parameter is equally significant, while unequal weights are assigned when specific index parameters are lesser or more important than others. In developing WQI, some index developers

used equal weights, such as Hallock's index, Diljido's index, Hanh's index, Liou's index, etc. [1,80,95,108], while others used unequal weights, including MWQI, Smith's index, Almeida's index, etc. [17,82,108], respectively.

These studies favored equal weights rather than unequal weights because there were concerns regarding subjectivity over experts' opinions in achieving convergence (as a community of experts sometimes gives distinct weights to the same parameters) [4]. A small number of index developers used equal weight due to the possibilities of unfairness in allocating the weighting variables. In other cases, unequal weights may encourage index model sensitivity, preferring highly weighted variables of water quality if due diligence is not exercised [85]. The final index's sensitivity to the heaviest weighted parameter could also lead to different weights. However, necessary steps should be taken to choose the most effective method for designing unequal weights in WQI that will eliminate biases and ratify the index model's credibility. The different weights in WQI for parameters could produce various classes of water quality and other values of WQI. Therefore, two methods for establishing water quality parameters are widely applied. The first method—of choosing variables and established weights—is based on an expert's opinion. The second approach is based on guidelines for water quality standards, as discussed in Section 3.2.2.

3.5. Aggregation of Sub-Indices

In this step, mathematical calculations are used to aggregate the sub-indices. These calculations provide a sub-index value for the allocated weights in the selected parameters and achieve a total water quality status, usually presented as a single number. The required level of accuracy regulates their implementation and whether the parameters of weights are described unequally or equally. The aggregation process can occur in sequential steps, depending on whether the index has aggregated sub-indices. There are four common aggregation methods; the additive (arithmetic), multiplicative (geometric), minimum operator, and harmonic mean of squares methods for the sub-indices.

3.5.1. Additive Method

Horton applied the additive method for the aggregation of sub-indices. A simple formula introduced by Horton [8], since the 1960s, is shown in Equation (7).

$$WQI = \frac{[W_1S_1 + W_2S_2 \dots W_nS_n]}{W_1 + W_2 \dots W_n} M_1 M_2 \quad (7)$$

where S is the rating number of i th parameter concentration (sub-indices) from 0–100, W is the weighting of the i th parameter from 1–4, n is the parameter number, M_1 and M_2 are the additional parameters. Bhargava [16] demonstrated a lack of sensitivity to decrease the values for specific parameters of water quality in the weighted mean used by Horton [8], which is traditionally regarded as “eclipsing”. Moreover, the arbitrariness in the parameters selection that form the water quality index, according to Lumb [5], was a significant problem in Horton's index. Deininger and Maciunas [109] and Brown et al. [9] improved the version of the additive method in the 1970s, with the support of NSFQI, which is based on the Delphi method. It is mathematically represented by Deininger and Maciunas [109] and Brown et al. [9], as follows in Equations (8) and (9), respectively.

$$WQI = \sum_{i=1}^n S_i \quad (8)$$

$$WQI = \sum_{i=1}^n W_i \times S_i \quad (9)$$

where WQI is the aggregated index value, S_i is the sub-indices value, W_i is the weight values, and n is the number of sub-indices. In addition, the Equation (8) indicate unequally weighted sub-indices, Equation (9) denote equally weighted sub-indices. This approach

also produces some issues known as “eclipsing,” in which the final index’s value does not represent the current status of overall water quality as higher ranges of other sub-indices or vice versa exceed the lower ones in one or more sub-indices [11]. Smith [82] also pointed out that this technique will never generate a zero index value, while 0 is one of the sub-indices. Bascarón [103] introduced another corrected version of the index aggregation additive method (known as Bascarón index). In this edition, the overall aggregation values should be subdivided by the selected parameters’ overall weights by Bascarón [103], as expressed by an Equation (10)

$$WQI = \frac{\sum_{i=1}^n P_i \times C_i}{\sum_{i=1}^n P_i} \quad (10)$$

where WQI is the aggregated index value, C_i is the sub-indices value, P_i is the weight values of the parameter, and n is the number of sub-indices. In the 1980s, the NSFQWI index was further improved by Tyson and House [110]. The use of a weighted additive model in England, divided by 100 by Tyson and House [110], as shown in Equations (11) and (12).

$$WQI = \frac{1}{100} \sum_{i=1}^n (S_i)^2 \quad (11)$$

$$WQI = \frac{1}{100} \sum_{i=1}^n (W_i \times S_i)^2 \quad (12)$$

where WQI is the aggregated index value, S_i is the sub-indices value, W_i is the weight values, and n is the number of sub-indices. Equation (11) also indicates unequally weighted sub-indices; Equation (12) denotes equally weighted sub-indices. It was noticed that the additive formulation lacked sensitivity, in terms of the impact a single low parameter value would have on the WQI, even though it was simple to understand and calculate [5].

3.5.2. Multiplicative Method

Brown et al. [56] proposed a multiplicative function as a revision for the NSFQWI, to properly address the eclipsing problem, as shown in Equations (13) and (14).

$$WQI = \prod_{i=1}^n S_i^{\left(\frac{1}{n}\right)} \quad (13)$$

$$WQI = \prod_{i=1}^n S_i^{W_i} \quad (14)$$

where WQI is the aggregated index value, S_i is the sub-indices value, W_i is the weight values, and n is the number of sub-indices. Equation (13) also indicates unequally weighted sub-indices; Equation (14) denotes equally weighted sub-indices. The subsequent evaluation appeared to indicate that the multiplicative formulation agreed perfectly with the expert’s opinion than the additive method, but both remained in use. A WQI value of zero is obtained for all multiple aggregation functions if one of the sub-indices is zero. In such situations, the eclipsing issue did not happen. However, if one sub-index shows low water quality, the overall water quality index will react adequately and indicate low water quality. In the 1980s, Bhargava [16] introduced another simple multiplication method and rationale for calculating the final index values expressed by Equation (15):

$$WQI = \left[\prod_{i=1}^n f_i \times (P_i) \right]^{1/n} \quad (15)$$

where $f_i(P_i)$ is the sensitivity function of the i th parameter and n is the number of variables. Bhargava [16] stated that Brown et al. [56] were not substantially sensitive to alters in water quality parameter values and proposed a multiplied model [6]. The multiplicative models have been designed to remove the eclipse problem. They react effectively when sub-indices

near approach or equivalent to zero; the index will respond accordingly and reach a smaller index value.

3.5.3. Minimum Operator

Ott [57] proposed a minimum operator method, significantly used by Smith [82] to calculate the final index value. Smith's index was established for four specific water usages: such as bathing, water supply, general use and fish spawning (salmonids). The minimum operator to combine sub-indices is described by Ott [57], as the Equation (16) to address these limitations.

$$I_{\min} = \sum \min(I_{\text{sub}1}, I_{\text{sub}2}, \dots, I_{\text{sub}n}) \quad (16)$$

where $I_{\min}$ is the lowest value of sub-indices, $I_{\text{sub}1}$ is the sub-index value of the first parameter and $I_{\text{sub}n}$ is the sub-index value of the last parameter. It is simple to enforce the minimum operator index's simplicity and flexibility without ambiguities or eclipsing issues. Conversely, the Smith index accuracy is questionable, as the method can only maintain the minimum subindex value without considering the impact of other sub-indices. It cannot be used to monitor a source or compare two sources. Therefore, the minimum operator method's implementation has been limited to several indices of water quality.

3.5.4. Harmonic Mean of Squares Method

As per Dojlido et al. [111] the harmonic mean of squares process was used for the aggregation of sub-indices to resolve the problem of eclipses in the WQI. Equation (17), for the harmonic mean of squares method by Dojlido et al. [111] is as follows:

$$WQI = \sqrt{\frac{n}{\sum_{i=1}^n \frac{1}{SI^2}}} \quad (17)$$

where SI is the i th sub-indices value and n is the number of sub-indices.

According to Cude [15], this approach allows low-quality parameters to affect the WQI significantly and recognizes that the various parameters have different consequences for overall water quality in specific times and locations. Furthermore, Swamee and Tyagi [98] emphasized that such a method of aggregation sub-indices struggles from the problem known as "ambiguity". There is ambiguity when all sub-indices are acceptable, yet the overall index is not acceptable. Liou et al. [11] suggested other aggregation methods to solve eclipsing and ambiguity issues, using a combined aggregation process (additive and multiplicative methods). Moreover, the parameters have a strong relationship that is first divided into three classes: organics, particulate matter, and fecal coliform. Therefore, to develop the values of aggregated sub-indices for each group, the similar groups of parameters are aggregated through the equal additive process, aggregated by the geometric mean to get the final index value. The aggregate index is multiplied by three scaling coefficients through Liou et al. [11], as define in Equation (18);

$$WQI = C_T C_{pH} C_{tox} \left[\left(\sum_{i=1}^3 I_i W_i \right) \times \left(\sum_{j=1}^2 I_j W_j \right) \times \left(\sum_{k=1}^1 I_k \right) \right]^{1/3} \quad (18)$$

where I_i , I_j , and I_k are the sub-index values (for organics, particulates, and fecal coliform) and C_{temp} , C_{pH} , C_{Tox} are the scaling coefficients that define the sub-indices of temperature, pH, and toxic substances, respectively. Furthermore, Said et al. [77] used another simple method for calculating final aggregation. This method can calculate the final aggregated index through direct formalised criteria with the parameters selection and without producing the sub-indices. However, this calculation has been established for a particular area,

and it cannot be suitable for other sites, which are defined by Said et al. [77], as shown in Equation (19);

$$WQI = \log \left[\frac{(DO)^{1.5}}{(3.8)^{TP} (15)^{FC/10000} (Turb)^{0.15} + 0.14(SC)^{0.5}} \right] \quad (19)$$

where DO is the dissolved oxygen (percentage oxygen saturation), TP is the total phosphorus (mg/L), turb is the turbidity (NTU), FC is the fecal coliform, and SC is the specific conductivity (MS/cm). Moreover, some aggregation methods, such as MWQI, (CAWQI), Catalan Index, WWQI, and the fuzzy logic, are presented in Table 3. Furthermore, another essential method of WQI, such as the CCME method, based on the scope, frequency, and amplitude, directly employed as a formula, is also discussed in Table S1 in Supplementary Material. The abovementioned literature studies show that no unique technique is available to select various parameters and assess the WQI of groundwater and surface water resources. Whereas 46 WQI methods have been briefly discussed in the Supplementary Material (Tables S1 and S2), based on four steps in this study. In addition, several relevant indices, their applications, advantages, and disadvantages are addressed in Table 4.

Table 3. This table addressed 46 WQI methods, from the 1960s to 2020. Several WQI developers used four steps, and several users applied a few steps.

Serial No.	Index (References)	No of Selection Parameters	Formation of Sub-Indices	Establish Weights	Aggregation Method
1	Horton Index [8]	8	✓	✓	✓
2	Fuzzy Index [112]	No guidelines	Fuzzy logic	✓	Fuzzy logic
3	National Sanitation Foundation (NSFWQI) [9]	11	✓	✓	✓
4	Prati Index [81]	13	✓	✓	✓
5	Water Contamination Index [18]	6	✓	*	✓
6	Weighted Arithmetic Index (AW-WQI) [113]	2	✓	✓	✓
7	Walski and Parker Index [114]	10	✓	✓	✓
8	Harkins Index [115]	No guidelines	✓	✓	✓
9	SRDD Index [10]	10	✓	✓	✓
10	Ross Index [116]	4	✓	✓	✓
11	Storet Index [117]	No guidelines	✓	✓	✓
12	Stoner Index [83]	13	✓	✓	✓
13	Bascarón Index [103]	23	✓	✓	✓
14	Deininger Index [88]	11	✓	✓	✓
15	Tiwari and Mishra Index [118]	14	✓	✓	✓
16	Bhargava Index [16]	4	✓	✓	✓
17	Dinius Index [119]	12	✓	✓	✓
18	House Index [102]	9	✓	✓	✓
19	Smith Index [82]	7	✓	✓	✓
20	Anzali Index [120]	9	✓	✓	✓
21	Dojlido Index [111]	7	✓	*	✓
22	British Columbia Index [13,121]	4	*	*	*
23	Aquatic toxicity Index [122]	12	✓	✓	✓
24	Oregon Index [15]	8	✓	✓	✓
25	Canadian Index (CCMEWQI) [12]	4	*	*	*

Table 3. Cont.

Serial No.	Index (References)	No of Selection Parameters	Formation of Sub-Indices	Establish Weights	Aggregation Method
26	Contact Recreation Index [123]	8	✓	*	✓
27	Hallock Index [95]	8	✓	*	✓
28	Dalmatian Index [63]	9	✓	✓	✓
29	Overall Index of Pollution [14]	8	✓	✓	✓
30	River Status Index [11]	13	✓	*	✓
31	Kaurish Index [124]	9	✓	*	✓
32	Schiff Index [125]	9	✓	*	✓
33	Universal Index [126]	12	✓	✓	✓
34	Malaysia Index [17]	6	✓	✓	✓
35	Catalan Index [127]	5	✓	✓	✓
36	Hanh Index [80]	11	✓	*	✓
37	Almeida Index [108]	9	✓	✓	✓
38	Ved Prakash Index [7]	4	✓	✓	✓
39	Modified Canadian Index (MCWQI) [128]	4	*	*	*
40	Vaal Index [19]	15	✓	✓	✓
41	Wanda Index [129]	7	✓	✓	✓
42	Medeiros Index [130]	11	✓	✓	✓
43	Garcia-Ávila Index [131]	13	✓	✓	✓
44	West Java Index [132]	17	✓	✓	✓
45	Drinking Water Quality Index [101]	17	✓	✓	✓
46	Wastewater Water Quality Index [71]	23	✓	✓	✓

Star (*) indicates that the full four common step(s) in WQI have not been used in the given index methods.

Table 4. Numerous important WQI methods, their application, advantages and disadvantages.

Index (References)	WQI Applications Reviewed by Government Agencies Allowed	WQI Applications Reported and Applied in Country	Advantages	Disadvantages
National Sanitation Foundation (NSFWQI) [9]	Maharashtra Pollution Control Board (15 May 2014). Compilation of Water Quality Data Recorded by MPCB 2011-12. http://mpcb.gov.in/ereports/pdf/Water_Quality_Report_2011-12_TERI.pdf 12 March 2020 Central Pollution Control Board, Government of India (2003). http://mpcb.gov.in/images/pdf/WaterQuality0709/Chapter3_WQ.pdf 5 April 2020. USEPA (1974). Water Quality Index Application in Kansas River Basin. http://nepis.epa.gov/Exe/ZyPDF.cgi/20008TH7.PDF?Dockey=20008TH7.PDF 19 June 2020.	USA, India [9,133]	The data can be obtained in a single index value with a goal, quick and compete more effectively. Assessment of changes in water quality in multiple regions. Index values refer to the possible utilisation of water.	It is not a particular use of water since it describes a general quality of water. Some data are lost during manipulation.
Weighted Arithmetic Index (AW-WQI) [113]	Not Applicable	India [134]	It comprises the values of different physical-chemical water quality parameters in a mathematical calculation demonstrating the environmental status of the water. It represents the importance of each parameter in water quality assessment and management. It can be applied to characterise the suitability of water for human usage.	This index may not give adequate details on the real water quality situation. This index does not contain all variables that can characterise water quality. This index measures only the direct impact of pollution on the water body.
Oregon Index [15]	Oregon Department of Water Quality. (2014). http://www.deq.state.or.us/lab/wqm/docs/wqiAnnualRep2014.pdf 16 January 2021. Oregon Department of Environmental Quality. (1993). http://www.oregondeq.com/lab/wqm/wqindex/malowy3.htm 2 June 2020. Idaho Department of Environmental Quality (2002). https://www.deq.idaho.gov/media/457032-assessment_river_entire.pdf 6 January 2020.	Oregon, USA Idahu, USA [15,74,79]	Through use of weighted harmonics to aggregate sub-indexes allows the OWQI to control the most affected parameters. The formulation is sensitive to environmental conditions and has major effects on the quality of water.	It does not give conclusive information on changes in habitat, toxicity, or biology concentrations. It is unable to assess all health toxicity (bacteria, elements, toxics).

Table 4. Cont.

Index (References)	WQI Applications Reviewed by Government Agencies Allowed	WQI Applications Reported and Applied in Country	Advantages	Disadvantages
Canadian Index (CCMEWQI) [12]	Water Quality results for New Brunswick watersheds. http://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/water/content/watersheds.html 15 September 2020. CCME Water Quality Index 1.0 User's Manual. http://www.ccme.ca/files/Resources/calculators/WQI%20User%20Manual%20(en).pdf 24 December 2020. The British Columbia Water Quality Index. http://www.env.gov.bc.ca/wat/wq/BCguidelines/indexreport.html 9 October 2020.	Spain, Canada [135–137]	Simple to measure. It has low sensitivity for missing data. High adaptability to various water consumption. The analysis of data from automatic sampling is sufficient.	In determining the index, all parameters are of equal significance. The quality of the water is only partially defined. It cannot be combined with other biological data or indicators. F1 doesn't operate effectively if there are too few parameters taking into account.
Malaysian Index [17]	DoE Malaysia (2002). Malaysia environmental quality report 2001. Putrajaya, Malaysia: Department of Environment, Ministry of Science, Technology, and Environment	Malaysia [17]	Some basic water quality parameters are comprised. The width of each parameter is specified to estimate the effect of the database.	The use of water is not taken into account. There are no biological parameters.
Fuzzy Index [112]	Not Applicable	Spain [75]	Natural language simple to interpret May deal with a vague and complicated situation Can explain several nonlinear connections by simple rules Will provide a mathematically transparent model Can address missing information without affecting the WQI value Free of uncertainty and with careful selection of parameters can reflect different water quality purposes Can account for interconnection between parameters (interdependencies)	Simple to manage or can be biased because of people subjectivity To some degree rigidity (alert parameter selection can decrease it) Not free of eclipsing, but trial and error mechanism can be done Cannot include water quality parameters recommendations

4. Multi-Criteria Decision-Making (MCDM)

According to Gade and Osuri [138], decision-making is a process of defining and selecting alternatives, based on the decision-makers values and preferences, with multiple criteria or single criterion. The decision-making process encompasses the subjective input from decision-makers and provides an appropriate output alternative. The decision-making process also develops a single alternative or a set of alternatives. There are three essential processes involved in decision-making: define the decision problem based on goal, identify criteria, and identify alternatives (as discussed in Figure 4). When the alternatives are chosen in the process, the overall objective depends on two or more criteria based on the goal(s). For instance, the purpose defines the decision problem related to research objectives (water quality, water resources management, and planning), which depends on two or more criteria (drinking, irrigation, industrial, domestic, etc.) for the selection alternatives (physical, chemical, and biological parameters). The MCDM method has been a useful research area since the 1960s, generating numerous conceptual and applied books and articles [43]. It is also a helpful tool for resolving problems related to conflicting criteria, to help people and aid in water resource management issues. A review of the MCDM method used for water management and planning was conducted by Hajkowicz and Collins [139]. Therefore, MCDM methodologies have been proposed to define a better alternative, identify alternatives into several small classes, and rank alternatives into a subjective order of importance [140].

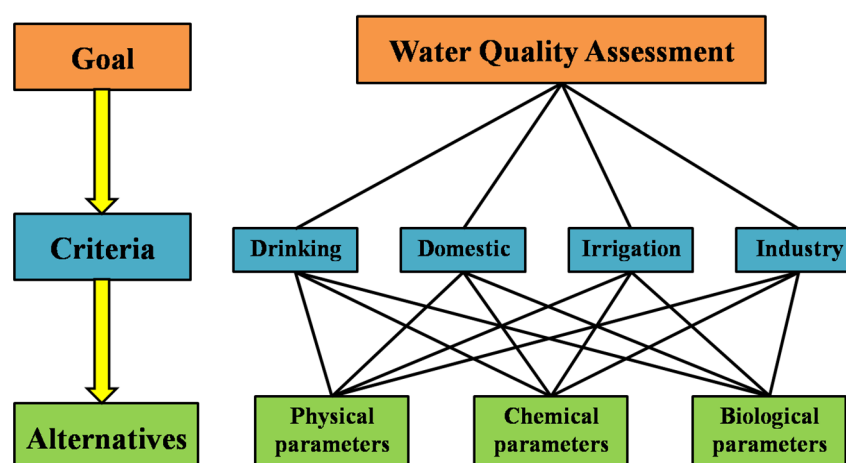


Figure 4. A common structure of the multi-criteria decision making (MCDM) method. When alternatives are selected, the total goal depends on the multiple criteria, where a goal is shown (water quality assessment) and criteria (drinking, irrigation, commercial, domestic) are indicated, as well as alternatives (physical, chemical and biological parameters).

The two MCDM methods are discussed in this study—AHP and MACBETH, for weighting of parameters and rating of variables, with the help of MCDM methods, which allow assessing weight values of select parameters, regardless of their national and international standards (WHO, BIS, etc.). This makes the formulation simple and minimizes errors since both processes are used for various water usages (drinking, domestic, irrigation, and industrial) and multiple variations [44]. Therefore, this study aims to establish a relationship between formal WQI and MCDM methods to create a simple calculation, with less time, and to provide more accuracy. These two approaches are based mainly on four steps in this study, including the criteria selection based on user demand and the alternative selections that are taken, ranking the criteria and alternatives based on user importance, and the comparison between the alternatives and the criteria (Figure 4). The MACBETH method was utilized to rank analytical alternatives in this study as the selected decision-making procedure. Finally, the weightage value assessment was used to evaluate the most critical parameters, with the help of the AHP method. The processes of MCDM

(MACBETH and AHP), uncertainty and sensitivity analyses, as well as comparison of WQI calculated by NSFWQI, were discussed in this section, and are defined in Figure 5.

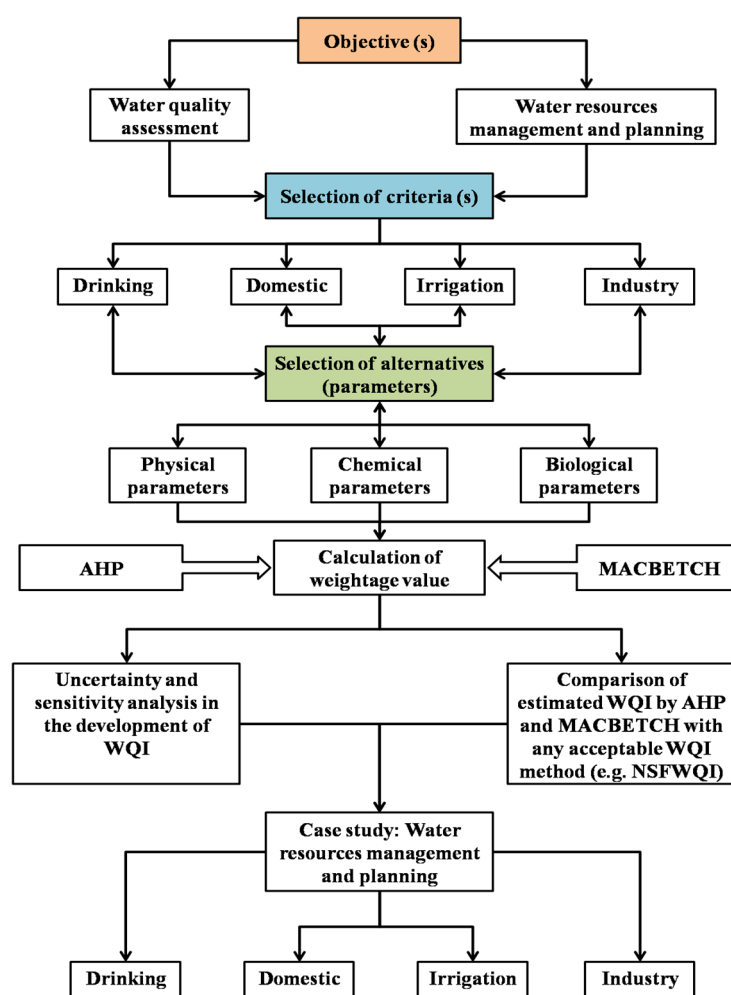


Figure 5. Diagram indicated that the calculation process of WQI with MCDM methods have been discussed step by step.

4.1. Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) Method

In the early 1990s, Costa et al. [141] proposed the MACBETH method. It is an MCDM technique anchored on the theory of multiple attributes and depends on decision-makers pair wise comparisons between alternatives and criteria. MACBETH analyzes attractiveness by purposes of a classification formulation process through different scales. It improves accuracy to assess how similarly important decisions get the same rank; the options that are more attractive than others are highly valued. After this, it helps rank the alternatives according to decision criteria based on the aggregate value of the relative weighted attraction of alternatives. The most crucial step for decision-makers in MACBETH is to make a clear and reasonable appraisal of the effectiveness of the criteria, otherwise the findings that can lead to irrelevant directions. Considering the significance of access to safe drinking water, multi-objective assessment is essential to improve the authority's decision to analyze the suitability of water for different purposes.

Furthermore, this method has been used for various purposes; Joerin et al. [142] used the MACBETH method to evaluate microbiological contamination in a safe potable water system. MACBETH has been applied by Lavoie et al. [143] to identify groundwater pollution in a multi-criteria decision analysis, taking into account that land use and hydrological data as groundwater is clean for use by people, and may be influenced by land-use activi-

ties. MACBETH has also been used by Lavoie et al. [144] to assess the ecological benefits of wetlands. Furthermore, Carvalho et al. [145] proposed a Regulative Impact Assessment (RIA) to determine the possible effect of water management acts on water resources in environmental and socio-economic areas using MACBETH. Moreover, MACBETH has been successfully applied to various fields in the literature, such as performance measurement systems (PMSs), human resources management, research and development, career choice problems, natural phenomena, medical science, potable water, drinking water utilities, projects development, politics, etc. [146].

4.2. Analytical Hierarchical Process (AHP) Method

Saaty and Vargas [147] proposed an AHP method that depends on the MCDM method, which splits the issue based on decision criteria, sub-criteria, and alternatives to achieve a specific purpose. AHP is discussed as an appropriate alternative to the non-physical measurable requirements, which integrates the difficulty in decision-making with the use of the ratio scale, and can be used in group and individual decision-making [148]. This approach is used to examine the relative weights of available alternatives, and also applies to different fields of study, including energy, banking, defense, education, fishery, medicine, food, supply chain, etc. [34]. Moreover, this process has been accepted throughout the world due to its multifunctional characteristics described by Forman and Gass [149] who stated the distribution of resources, quality measurement, and forecasting. AHP consists of three main segments: (1) the decomposition criterion; (2) the alternative by comparative decisions, (3) the priority planning of the criteria. It uses the eigenvalue method to formulate decision hierarchy by connecting criterion with each alternative. Furthermore, Ishizaka and Labib [150] commenting on the AHP weight allocation, have allowed for the hierarchical path of deciding criterion that allows decision-makers to concentrate on main and sub-criteria. Moreover, comparison matrices can be developed to make the decision-making method more precise. The criteria rating are relevant since the numerous structures can provide negligible results.

There is an issue of the rank reversal for inversion scaling in the eigenvalue process for priority derivation. It is complicated and most critical to use AHP to make a dynamic model more straightforward and make decisions on hierarchy and scaling accurately. Previous studies indicated that a lot of research had been performed to investigate surface and groundwater characteristics for various purposes with the AHP method's help. This method has been used by Carbajal-Hernández et al. [151] for an assessment of the WQI for aquaculture, by choosing parameters concerning ecosystem priorities, feeding rate for environmental conditions, and the outcomes compared with CCME. The AHP method has been used by Delgado-Galvan [152] for the assessing and evaluation of externalities in leakage management. Moreover, Dar et al. [153] used the AHP method for investigation of potential groundwater systems in Kashmir Valley, northwestern-Himalayas. Furthermore, Kazakis et al. [154] used the AHP method for research of potential groundwater systems in Kashmir Valley, northwestern-Himalayas. Also, Kazakis et al. [155] used a distributed hierarchical analysis to evaluate the water cycle status in Beijing, China; therefore, the states of the water cycle are essential for modeling the potential water for sustainable progress.

MACBETH is based on comparisons, such as AHP on pair-wise comparisons. There are some differences between MACBETH and the AHP method. In AHP, the decision hierarchy is developed, while MACBETH's decision problem is defined as a decision tree. Moreover, AHP uses the eigenvalue for assessing the weights, but MACBETH uses the linear approach of programming. Another difference is that AHP permits a 10% inconsistency, but MACBETH makes no inconsistency. The significant advantage of MACBETH is that decisions are tested for theoretical and semantic consistency. In MCDM problems, both can be used to calculate requirement weights and the ranking of alternatives, despite their variations.

4.2.1. Selection of Criteria

The identification and selection of criteria that differentiate between alternatives must be based on objectives. A decision-making problem involving several criteria is especially useful in providing better alternatives. Being optional, significant, and non-repetitive should be an ideal set of criteria. Therefore, the purpose of choosing criteria depends on the consumption of water. It is essential to calculate WQI because of the water resources' potable water quality conditions. In selecting criteria, a helpful analysis has been carried out to determine the quantities of water consumption in various sectors. From the guidance of experts, scientific reviews, and literature surveys, the use of water for agriculture, domestic, and industrial purposes, as well as potable and non-potable uses, are more significant.

4.2.2. Selection of Alternatives

Analysis of a finite set of alternatives is an essential part of decision-making. All available alternatives are compared to the aspects selected, and any alternatives that fail to fulfil the aspects are discarded until only one alternative remains; thus, achieving the desired objective. Therefore, the selection of parameters as physicochemical and biological for water quality analysis is challenging; there is no particular technique. The selection of physicochemical parameters for water quality can be used from the previous citation frequency studies. For instance, the determination of water quality status was estimated through the WQI method for Dokan Lake, Kurdistan region, Iraq, where 10 parameters (pH, turbidity, DO, EC, TH, alkalinity, Na^+ , BOD, NO_3^- , and TDS) have been applied by Alobaidy et al. [156]. Furthermore, as with Zotou et al. [157] 13 water quality parameters were taken into consideration, in applying the specific WQI and in determining their quality status: pH, NO_3^- , DO, EC, TSS, turbidity, T, NH_4^+ , BOD, COD, NO_2^- , TKN (total Kjeldahl nitrogen), and TP (total phosphorus).

Moreover, Nong et al. [23] and other researchers [1,34,68,158,159], considered the above-described parameters of water quality in critical aspects, such as drinking, domestic, agriculture, and industrial purposes. For example, using the NSFQI, selecting parameters in this method can help determine WQI between the areas and gives overall water quality status. This is one of the techniques used by the NSF to assess WQI to provide the comparative status of different water bodies' water quality. This indexing approach is not unbiased since a panel of experts found those, as mentioned, above 11 physicochemical parameters. Some other expert panels may measure the quality parameters differently, as well as resulting in different findings to comparability and uniqueness [5].

4.2.3. Aggregation of AHP and MACBETH Methods for Parameters Weights

Both MACBETH and AHP are the MCDM methods that help decision-makers construct a complicated problem. These two approaches generally follow four stages: selecting criteria, selecting alternatives, rating the criteria and alternative as per user requirement, and contrasting every alternative with criteria. AHP appears to act on a ratio scale, while MACBETH operates on various scales. This study considers the alternatives based on citation frequency of the physicochemical and biological parameters (pH, TDS, EC, turbidity, TH, DO, BOD, COD, TOC, alkalinity, salinity, temperature, fecal coliform, heavy metals, and major ions), which are essential for water quality status. Moreover, there are four main criteria for water usage, such as drinking water, agriculture, domestic, and industrial. When assessing the WQI, each parameter weighing is multiplied by the quantification field or laboratory, experimentally obtained by the overall parameter's total value leading from the WQI. This process does not require a standard or permissible calculation value of the selected parameters. Therefore, WQI determination can be directly written, mathematically, as seen in Equation (20), and defined by Horton [8].

$$\text{WQI} = \sum_{i=1}^n W_i \times Q_i \quad (20)$$

where WQI is the water quality index, (n) denotes number of selected parameters, W_i denotes individual parameter weightage, and Q_i indicates laboratory experimental value or field value of parameters.

4.2.4. Comparison with WQI Estimated by AHP/MACBETH and Developed Index (NSFWQI, OWQI, BMWQI and WAWQI)

WQI computation with certain authorized indices (for example, NSFWQI is already discussed in Supplementary Materials. NSFWQI has been established by the National Sanitation Foundation, which is one effective method to assess WQI to give relative water quality status of different water bodies. This indexing approach is not objective since the select eleven parameters have been taken into account by experts. It can occur that other experts will provide the quality parameters of different ratings, resulting in less reliability and uniqueness. The obtained value of the sub-index for each parameter and the standard values should be considered, which is distinct for each factor, including industrial, domestic, and irrigation purposes of water usage. The sub-index process makes the calculation more complicated and unnecessary, as discussed in Section 3.2. For each water use criterion, different weights of parameters should also be calculated. Therefore, the procedure is simple using AHP since the method provides an overall weighting of the parameters, combining all four criteria. WQI calculations have also been carried out using MACBETH to use the same approach for selecting criteria and alternatives for AHP (Figure 4).

4.2.5. Uncertainty and Sensitivity Analysis in the Development of WQI

The parameters selection, sub-index values formation, establishing weights, and selecting the index aggregation method are not accepted 100% objectively or accurately when developing WQI throughout the world. Several index developers use all four steps to establish a WQI while certain WQI users apply a few steps to consider the final index value. Therefore, problems such as eclipsing, uncertainty, and rigidity are always a challenge for developing WQI. Parameters selection, parameter establishing weights, and aggregation methods can be sources of uncertainty. The previous study indicated that the sensitivity and uncertainty analysis had been rarely performed to reduce the uncertainty to the established WQI [34]. Therefore, the purpose of the uncertainty technique is to evaluate the sources and the uncertainty in developing a WQI and their impact on the aggregation of final index values. Moreover, the aim of the sensitivity analysis helps to explain how the input variable uncertainties influence the uncertainties of an output variable of a model [44]. Therefore, sensitivity analysis is a method that calculates the effect on a dependent variable of several independent variables. There are certain essential approaches associated with sensitivity analyses for selecting parameters, including the one-at-a-time method, local strategies, statistical analysis; variance-based, scatter plots methods, etc. However, the most simple statistical analysis approach can be used by modifying one factor, at a point to see what changes it creates on the output.

The statistical analysis involves correlation analyses, such as FA and CA, which can be helpful in the process of parameter selection in order to reduce the uncertainty and sensitivity analysis. For instance, many researchers have applied the FA and CA methods to achieve the optimal selection of parameters and its weights for cost-efficient monitoring purposes [160–163]. Moreover, Khalil et al. [164,165] applied the CA to choose the appropriate selection of parameters that can be used for the development of the WQI. Therefore, it is suggested that the view of local water quality developers (through strategies such as the MCDM method) be considered in every one of the steps taken in establishing a WQI. For instance, concerning the NSFWQI in the United States, the presence of WQI developers on water quality parameters is extremely strong and has evolved into a standard method for establishing processes for other indices, such as Smith Index, Ross Index, Dinius Index, SRDD Index, Dunnette Index, Almeida Index, and Vaal Index.

5. Future Developments

The purpose of the WQI method was introduced in the 1960s to evaluate the statuses of water quality. Significant attempts have been made to improve the WQI (for simple calculation) to help minimize efforts, for great precision, and to address a number of challenges in the future using MCDM methods. The use of less rigid and straightforward calculations with flexibility in the selection of parameters and weightage of variables can help in searching for a globally accepted and effective index. WQI developers can use all four steps or a few steps; however, a 100% accurate or objective method in WQI has not been accepted worldwide [166].

Thus, problems, such as rigidity, uncertainty, and eclipsing, will always be a challenge in the development of a WQI [34]. Because the steps of developing a WQI are subjected to subjectivity and ambiguity, it can also be assumed that statistical methods can be useful for reducing uncertainty in steps, such as parameter selection processes. Furthermore, in order to emphasize the importance of the opinion of local experts in developing a WQI, it is crucial to ensure that the parameter weights analysis is carried out via the involvement of major authorities involved in the water quality process. Thus, selecting the most appropriate environmental parameters would be immensely important, and will provide the user with a certain form of the algorithm. Such selection should also be related to the potential aspects of water body pollution, the economic implications, and the description of technical staff in the methods to calculate these parameters.

Many government agencies and individuals implemented the WQI method, mainly based on parameter selection and the usage of water resources for different purposes, including understanding water contamination and clean water. Water use, according to each legislation and the search for the relevant water purification, will also be more effective depending on these factors (uncertainty and eclipsing). Moreover, this method contributes to useful information of the concentration of physical, chemical, and biological parameters in water resources, which is straightforward and easy to understand and can also be utilized by water agencies and the wider community. This method provides information on the type of water consumption, and its various purposes according to the location, time, and particular specific water quality parameters. Zahedi [166] attempted to correlate the index introduced by Meireles et al. [167] to that established in his work through many statistical methods, and to identify potential conflicts between the use of water for public supply and irrigation purposes.

MCDM methods can give accurate values, with less effort, in the WQI development. Still, the problem is that each water quality index uses various selection parameters and different weights of parameters. Additional parameters for essential factors can be implemented in related studies through the involvement of local experts. AHP and MACBETH may be used to identify more essential factors if this is considered in the future. In addition, questions on essential factors can be included in the questionnaire utilizing AHP for acquiring parameter weights. Combining research through local experts on specific important factors with weights would lead to more efficient time management. Therefore, this study discusses the proposed WQI method for monitoring the quality of water resources based on the MCDM (AHP and MACBETH) approach, considering the importance of the different criteria based on the four important water uses: drinking, industrial, irrigation, and domestic purposes.

6. Conclusions

Water quality depends on human consumption, area, and specific parameters. The WQI method plays a crucial role in the determination of significant water analysis multi-parameter values in single-digit scores. Thus, WQI is a mathematical technique to measure the overall status of surface water and groundwater quality at certain times and places. This study reviewed and addressed 46 usable WQI methods, in terms of the four steps to establish WQI, from the 1960s to 2020. Moreover, the WQI calculation procedure, based on the four basic steps, is a prolonged process to measure the water quality. Therefore, this

study aimed to address the easy and simple procedure of calculating WQI for the assessment of water quality of water resources, based on two methods of MCDM: MACBETH and AHP. MCDM techniques can easily calculate WQI with less work and great precision and allow flexibility and error reduction based on the weighting values of parameters. MCDM is a process to define and select alternatives based on the decision-makers priorities and values, with individual criteria or with multiple criteria.

MACBETH and AHP methods are mainly based on four steps: selecting criteria based on demand from users, selecting alternatives to make decisions, the classification of criteria and alternatives based on the value from consumers, and a comparison of alternatives and criteria. MACBETH is an advantageous way to evaluate the weight of the criteria and rank alternatives based on qualitative judgments. Furthermore, this study recommends that every step of the development process quantify and identify the sources of rigidity, eclipsing, and uncertainty. Moreover, it is recommended that the selection of parameters have a fixed set of water quality parameters for both surface water and groundwater, for drinking, domestic, irrigation, and industrial purposes. The quantification of uncertainty and a fixed set of parameters will improve an index's overall credibility and help index developers. Their users will better understand the strengths and limitations of a WQI. The study will also help provide valuable information for the use or customizing existing indicators to water resource authorities globally, and contribute to future WQI development for successful planning and studies.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/w13070905/s1>. The WQI method is used for unequal weights to achieving the final index, discussed in Table S1, and some of the methods used equal weights, as described in Table S2 in the Supplementary Materials.

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