A brief review of water quality indices and their applications

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Abstract. Water Quality Indices (WQIs) refers to a set of water quality parameter data that aggregate to produce a single value to the water quality, reducing the huge amount of data into a simple and easy expression. Also enabling comparisons of water quality status for different locations and at different times, which eventually will help inform of water quality status to management and the public in a simple manner.

Before generating and developing an appropriate mathematical model, there should be a process of evaluating, reviewing, and considering the Challenges and limitations of the existing developed models of similar nature. Therefore, this review paper intends to summarize the scientific literature papers from different countries related to the development of the water quality indices and practical applications. In general, five common steps are used in approaches of WQI calculation: (1) selection of parameter, (2) transform the data from a parametric system to a dimensionless system, (3) creation of subindices, and (4) compute the final WQI score by using the aggregation of subindices.

1. Introduction

Surface water pollution is a major problem worldwide, associated with extensive biological and chemical pollutants [1]. The main pressures on aquatic ecosystems are defined as: (i) hydro-morphological pressures and water extraction, (ii) diffuse sources of pollution—among which the most important are agriculture and atmospheric precipitation, (iii) point sources of pollution—especially industry and energy production [2].

The basic reason for the investigation into hydromorphological conditions is to extend the knowledge about the hydro morphological pressures and impacts caused by natural processes and various human activities [3]. Hydromorphological condition is very important for creating a safe habitat in aquatic system. The assessment of hydromorphological properties closely correlates with biological, physical, and chemical data for assessing ecological conditions of waters [4]. To minimize the potential risks of public health, it is fundamental to recognize the source of pollutions and develop an appropriate management strategy. Water quality can be affected by pollution sources (point and non-point) [5]. The amount and type of impurities present in water are greatly responsible for the suitability of water for any use, where these impurities will in some way affect the desired use. The various impurities in water are classified into physical, chemical and biological, expressed through pollution parameters [6].

To determine the degree and state of the contamination on any river, it must continuously monitor the water quality [7]. Therefore, water sources' suitability for various consumption (public water supplies, irrigation, industrial processes) has been described in water quality indices (WQI). WQI is one of the most effective tools to describe the water status and determine its suitability for different uses. WQI utilizes data on water quality and assists in modifying the environmental policies designed by environmental agencies. The explanation of the water quality parameters for Non-specialists and the common public is not easily understandable. Hence, WQI proved to be an easy way to provide information on citizens and policymakers [8].

The primary aim of WQI is to give a single value for water quality by converting the data on the component and their concentrations in a sample into a unique number. It will be easy to compare different
samples for their quality based on each sample's index value. WQIs work by condensing selected variables into a single unitless score, allowing to notice the changes in water over time or comparisons between different water bodies [9].

There are two way to formulated WOI: (i) indices having increasing scale, in which the index numbers (value) increase with the degree of pollution (water pollution indices). (ii) indices are having decreasing scale, in which the index numbers (value) decrease with the degree of pollution (water quality indices) [10][11]. Water quality (WQ) is a general term in which water pollution indicates undesirable or unfavourable water quality conditions. Generally, WQIs systems are often designed to display a maximum number of 100 (corresponding to unaffected water) and a minimum number of zero (highly polluted or unsuitable water for any use). The index can compare sites and track changes at one site over time [12].

All indexing systems require measurements to be made for a selection of water quality variables. A sub-index rating is taking from these measurements for each variable. Then, the sub-index values are aggregated to generate the final score of the index [10]. Henceforward, this paper briefly reviews the literature relating to the design and development of the water quality indices (Appendix A, B).

2. Selection of water quality parameters

Water quality parameters are the most significant component of any WQI. The generation of the index depends on it. According to Sutadian [13], there are three systems applicable to the parameter selection process. These systems are defined as follows:

(i) Fixed system: In this system, the WQI designer's parameters are the most suitable group necessary for calculating the final index score, where WQI is limited to these fixed parameters only. Because of this limitation, the system is rigid, so that it will be a common problem for most users. The fixed system's rigidity cannot allow new parameters, even if it becomes important and necessary to add a new parameter.

(ii) Open system: the system allows the user to combine their choice and need parameters. This system is more flexible and eliminates rigidity that's occurring in the first system. An open system has a problem in comparing the results of WQI from different monitoring sites. When using a similar parameter that the user imposes, it is then inappropriate to use an open system as comparison tools, especially when generating matrices based on water quality classification and pollution conditions.

(iii) Mixed system is a combination of both fixed and open systems. This system contains the basic fixed parameters required for calculating the final index and new parameters that can be introduced based on user decisions.

2.1. Common steps for development of any WQI

For the development of WQI, the following four steps are applied:

1. Parameter selection.
2. Transformation of the parameters that have different units and dimensions are to a common scale.
3. Weights Assignment for all parameters.
4. The assemblage of sub-indices is to produce an index score [5][14].

2.2. Justification for use of WQI

WQIs are attended to use in the first place to evaluate water quality monitoring data, allowing for significant interpretation of water results, especially when the concentrations of the pollutant are below the standards of water quality. Generally, WQI can completely exclude the sampling frequency importance used in monitoring water quality [15]. WQIs help experts' sites separate monitoring data into a bigger context and allow the administrative decision-makers to assess the regulatory programs' effectiveness and report the
information on water quality understandably and easily to the audience [13]. Indices served almost all the purposes of monitoring programs like; water quality, assessment, treatment, utilization, public information, Research and Development programs and environmental planning [16].

3. HISTORY OF WATER QUALITY INDEX CONCEPT
In 1965 [17], a panel of the president's science consultative committee of Environmental Pollution recommends stimulating the development of a scientific method for appointed a numerical index for detecting chemical water pollution. A panel declares that the method must be sensitive to a wide variety of chemical pollutants. Its result is almost proportional to the undesirable effects of water pollution on a human being or aquatic life. The index will allow the many following changes in water quality. This statement led Horton to publish the first water quality index (WQI) in the same year [18]. Since that's the day, WQIs has become a popular and effective tool in assessing the water quality of different water bodies worldwide [19]. After Horton, Brown et al. [20] developed a WQI similar in structure to Horton's index (18). Still, with much rigidity in selecting parameters, the work of Brown et al. [20] was supported by the National Sanitation Foundation (NSF). For this reason, Brown's index is also referred to as NSFWQI.

In 1971 PATRI et al. [21] proposed an index based on a water quality classification system. The index has a numerical expression of the degree of pollution. It takes into account the various pollutants present at the same time. However, the measure of each pollutant in a separate way, PATRI index, unlike the Horton index and NSFI, has an increasing scale with pollution. The index scale ranged from 0 for good quality (or no pollution) to 15 or more for poor quality.

Dinius [22] designed WQI to evaluate water pollution control expenditures as a part of the social counting system. This index uses straightforward equations for calculating subindex functions. The sum of weighted subindices then computes the index score.

Stoner 1978 [23] uses two broad water-use categories, public supply and irrigation, to develop the index. The index can accommodate the two water uses by applying the subindex functions and weightings into the final index aggregation. Stoner index can be appropriate to other water uses as well.

Dinius' second index in 1987 [24] proposed A multiplicate index used to bring the pollutant together into one system. The Delphi method includes seven-panel of water quality scientists, the formulate index can be used to assess the level of pollution in freshwater.

Smith's index 1990 [25] addresses four water usage, which includes contact and non-contact use (i) General, (ii) Regular public bathing, (iii) Water supply, (iv) Fish spawning. The index's formulation includes using the Delphi method, selecting parameters for each water type, developing subindices, and assigning weights for the selected parameter.

CCMENWQI: Canadian Council of Ministers of Environment Water Quality Index 2001 [26] provides a mathematical framework for assessing ambient water quality conditions relative to water quality objectives. The index consists of three essential elements: (i) scope refer to the number of variables that were not meeting the objectives of water quality; (ii) frequency refer to the number of times were the objectives are not met; (iii) amplitude represent the amount by which the objectives are not met. The index's output ranges from 0 indicate the worst water quality, and 100 indicate the best quality. These numbers are divided into five classes to facilitate presentation.

4. Review of some WQI
Horton 1965: Horton [18] defined a WQI as "overall a rating reflecting the composite influence as the quality of several individual quality characteristics." Horton index is still used for monitoring surface water as an alternative theoretical method of classification. The index includes 10 common measured water-quality variables (Appendix A). The final index score is calculated with a linear sum aggregation function. The mathematical function aggregates the all subindices $I_i$ (Appendix
B) divided by the sum of the weights $W_i$ (ranged from 1 to 4) and multiplied by two coefficients $M_1$ and $M_2$: Each coefficient takes on either of two values 1 or 1/2, depending on temperature and extent of obvious pollution (if the T is above the critical level, $M_1 = 1/2$ otherwise, $M_1 = 1$, if obvious pollution is present $M_2 = 1/2$; otherwise $M_2 = 1$). This function makes the Horton index open to criticism where Coefficients $M_1$ and $M_2$ subject to personal judgment. Also, arithmetic weighted mean application makes the index not sensitive to lowering some important parameters' values. The Horton index's advantage is that it is a simple and easy method for calculating the index from the different parameters' weights and ratings.

NSFWQI 1970: Brown et al. in 1970 [20] presented WQI similar in structure to Horton Index. The resulted index is known as the National Sanitation Foundation's Water-Quality Index (NSFWQI). NSFWQI was designed using the Delphi method to combine the opinions of a large panel of water experts from throughout the US, where members of the panel were polled by mail using questionnaires. A three-round of questionnaires delivered to a panel of 142 expertise. During the first questionnaire, the respondents were asked to consider 35 water pollutant parameters for possible inclusions in the new WQI. In the second questionnaire, each member was asked to review his initial rating and modify his response if he desired. The feedback process's purpose was to obtain greater convergence opinion regarding each variable's significance for overall water quality; using expert opinion obtained from the initial stages, the investigators identified nine individual variables (Appendix A). In the third questionnaire, the respondents were asked to develop a rating curve for every nine variables. The experts were asked to compare relative overall water quality using a scale of 1 (high importance) to 5 (low importance). The disadvantage of the index lay in choosing the arithmetic mean. Using it does not permit sufficient lowering of the index if any variable is of a low quality.

PRATI Implicit Index of Pollution 1971: PRATI [21] depends on water-quality classifications to establish a classification of surface water quality adopted from different countries: England, Germany, New Zealand, Poland, USA and reported in Water Quality Criteria. The index intends to determine a mathematical expression to transform pollutants' concentrations into pollution levels, expressed in new units (measurement unit of pollution). The numerical value of each polluting factor is no longer proportional to its concentration but the polluting effect relative to other factors. The index is only indicated to the substances and parameters that are most commonly measured. Toxic substances have not been included in the PRATI index because, the authors thought, their presence in concentrations higher than the generally accepted results in the water being classified as the lowest category (heavily polluted).

To formulate the index, mathematical expressions were formed to transform each value of the pollutants into subindices. The transformation process considers the parameters polluting capacity related to a selected reference parameter [21].

Dinius first Index 1972: Dinius index [22], like Horton's index and the NSFWQI, which had a decreasing scale, and the index values are expressed as a percentage of perfect water quality, which corresponds to 100%. The index Design for a rudimentary social accounting system that is shown to apply to actual data, the index's advantage can measure the costs and impact of pollution control efforts. However, the index has limited variables that reflect the actual status of the water quality. This index includes 11 variables for six water uses; public water supply, recreation, fish, shellfish, agriculture and industry (Appendix A). On a basic scale of importance, the weights ranged from 0.5 to 5; 1= very little importance, 2= little, 3= average, 4= great, 5= very great importance, the weighted sum was 21.

Stoner's Index 1978: Stoner [23] develops WQI for public water supply and irrigation, but the index could be applied to any water use. Subindices included two types of variables; Type I toxic
variables, which were treated as step functions at their recommended limit by EPA [27], and Type II aesthetic or "nontoxic" variables, which were treated as mathematical functions. The rationale for the function approach for toxicity was the difficulty in assessing responses to deficient and subcritical concentrations. Instead of graphical descriptions, a mathematical function was chosen to describe the effect of the water-quality properties, was the linear function \((a + bx)\), the parabolic function \((a + bx^2)\) and the parabolic function \((a + bx + cx^2)\) was the only function used. The Subindices then aggregated by adding the type I subindices (values \(=-100\) at the critical level) to the weighted sum of the type II variables (ideal values \(=100\), criteria limit \(=0\)).

Bhargava 1983: This is the first index reported by an Asian author [28]. He wanted to develop WQIs for various water grades for the different beneficial uses. The author classifies the water uses in the major group based on more or more minor similar water quality requirements: (i) Bathing, swimming, (ii) Public water supplies, (iii) Agriculture, (iv) Industry, (v) Fish culture, wildlife, boating and other non-contact recreation. The author pointed to that not all quality parameter is detrimental to all beneficial uses. Any parameter may have great importance for only one use but could not be important for other beneficial use. Bhargava illustrates the Relevant WQ parameter for Various Beneficial Uses (appendix A). In the Bhargava index, each parameter's effect is included in the sensitivity function values for various parameters relevant to a particular use. All parameters' sensitivity functions for a specific use would have equal.

Dinus Second Index 1987: For the development of the Dinus second index, Delphi Method was chosen with seven-member scientists from a different specialty in water pollution through refined water quality standards to assess the detrimental effects of various pollutant substances present in the water. To bring the pollutants substances together into one system, a multiplicative index was used [24].

Developing of the index include three steps: (i) for each of the six water uses, the seven-panel members' final evaluations combining into one subindex; (ii) all subindices were combining for the six water uses (public water supply, recreation, fish, shellfish, agriculture and industry) into one subindex for general water use; (iii) finally, the formulating each subindex of pollutant's function. To express each subindex in a numerical approach, each subindex was computed, where each subindex is given on an identical scale ranging from 100 to 0.

The disadvantage of the Dinus second index is that the author has been biased to a set of variables that he imposed on the experts, where the numbers of the variables were 11 (appendix A). The experts added Nitrate, so the author did not give the experts the free will to choose the variables.

Smith 1990: Smith [25] attempt to produce an indexing system that would be useful and not hide vital information simultaneously (non-eclipsing). Depend on the approach used to create the NSF [20]. Smith developed his index to produce an indexing system for water managers based on specific, meaningful, and definable politicians. The system covered four streams and river uses (water supply, bathing, general use, and fish spawning).

Smith [25] used the Delphi method to obtain and moderate the expert opinion. This method attempts to gain a higher degree of convergence of expert opinion (the anonymity between the panel members is preserved and communication between them is by mail), five-round of questionnaires has been applied, and the Index Development has three-stage; (i) Variables Selection; the appropriate and most desirable variables for each of the water use; (ii) Sub-index curve development; blank graph formats were sent to the panel, the x-axis represents the expected range of the variable, while y-axis \((I_{sub})\) ranged from 0 to 100 which represent the suitability use.

After the computing subindex ratings from determined values, the major problem is how to aggregate these subindices to produce a final index score. The author depends on many complicated mathematical functions were it mainly based on equations \(I = \Pi_{l=1}^{n} I_{sub_l}^{wl}\) and \(I = \frac{1}{100} \sum_{l=1}^{n} I_{sub_l}^{wl} \) but proved disappointing because of the eclipsing problem. depended on a minimum operator equation that's are
straightforward and easy system was finally chosen $I = \min(I_{sub1}, I_{sub2}, ..., I_{subn})$. Smith points to a real fact that declares "the poorest feature greatly dominates that water's suitability, so it can be used to generate the index score." Ott 1978 [29] recommend the use of the minimum operator system and declare that's none of the published ecological indices adopted this system. Its potential remains unexplored until yet".

CCME WQI: The Canadian Council of Ministers of the Environment CCME, represented by Canadian jurisdictions, modified the British Colombia WQI to create a CCMEWQI, which could be applied by many water agencies in many different countries [30]. The calculating CCMEWQI not involved sub-index generation for the variables, establishment of weights, and classical index aggregation [26].

According to (26), CCMEWQI depends on three factors; (i) scope ($F_1$), (ii) Frequency ($F_2$), (iii) amplitude ($F_3$) to produce a single unitless number that eventually indicates the overall water quality through using an expected value for each variable chosen for computed the index.

Van et al. 2020 [30] modify CCMEWQI; the aggregation method in CCMEWQI was done by combining the three factors ($f_1, f_2, f_3$) root mean square. In comparison, the modified CCMEWQI was calculated by combining the three factors using the geometric mean function. CCME, 2006 [33] found that saving the plus sign in the equation of CCME WQI (root-mean-square aggregation) did not change the situation. After this thought, a new WQI is has been introduced based on the modification of CCMEWQI.

The new WQI will be called a Modified Water Quality Index (MWQI) [30]. The main idea of MWQI takes into account the three factors ($F_1, F_2, F_3$) as different views of water quality but still behaves similarly to CCMEWQI. MWQI provides a fairer judgment status in cases where the statistical factors of CCME WQI draw a skewed image.

SAID WQI 2004: Said index [31] was designed to describe the overall WQ status using multiple variables and expressed as a single number. The proposed index has a fixed parameter system and consists of 5 variables: DO, SC, TURB, TP, and FCol. Said's index was developed in two steps; (i) according to their significance, the water quality variables are ranked, (ii) dissolved oxygen (DO) give the highest weight value, followed by FCol and TP. In contrast, the least influence was given to Specific conductance and Turbidity.

The index was kept in a simple mathematical formula. The logarithm system was easily understood by the small number of stakeholders, decision-makers, and audience.

The powers of all the parameters chosen in the Said index depend on each parameter's environmental effect on general water status. For example, FCol and TP's higher values will be seriously harmful to human health and aquatic life, where the index design gives strong responses to these two parameter effects. Furthermore, Turb and SC have a less acute effect on changing the parameter values because they would not be harmful unless correlated with a higher level of biological contamination caused by pathogens that will make FCol higher, likewise the index (Appendix B).

Iraqi WQI 2020: In 2020, a group of Iraqi research designed an Iraqi WQI [14] to evaluate the River's suitability for drinking. This index is considered a first step to create an overall water quality index for Iraqi surface water. a Delphi method was used. The questioner includes 44 water quality management expertise and asked them to rate only 10 parameters from 27 water quality parameters. According to the panel's recommendation, only 6 parameters were chosen for the index: Total Dissolved Solid, Chemical Oxygen Demand, Dissolved Oxygen, Total Hardens, Total Coliform and Chloride, and also according to their opinion, the weights was given for each parameter. The subindex for each parameter was taken by the average curve representing the water quality level variation on a scale of 0-100.

Next step includes the aggregation of the all subindices by weighted average. The final formula for the Iraqi WQI as the following: 

\[ IraqiWQI = \left( (-0.019 TDS + 84.587) \times 0.2 \right) + \left( (-0.006 TC + 86.231) \times \right) \]
0.2] + [10 DO × 0.2] + [(-0.119 TH + 113.68) × 0.15] + [-5.886 COD + 99.846] × 0.1] + 
[(-0.12 CI + 106.58 × 0.15]

Like said index, this index has a fixed parameter system that cannot allow for a new parameter. Also, metal and Toxic substances have not been included and are restricted for only water use.

5. Application of WQI

Sutadian et al. [13] reviewed 30 WQIs developed and used in different regions worldwide based on the common four steps utilized in the past to develop a WQI. At the same time, this study reviewed the most applied indices in a different country, focusing on the Iraqi papers in the last 4 years (Table 1). The CCME is the most indices selected to evaluate water quality in different cities in Iraq. It can include many variables and its flexibility in selecting standards or criteria and has low sensitivity to missing data [32].

| Table 1: List of Reviewed WQIs with their Applications |
|------------------------------------------------------|
| WQI name | Location | Numbers of parameters | Purpose of application | Ref. |
| Weighted arithmetic mean (Brown index) | | | | |
| India | 5 | Surface water | [33] |
| Bengal | 9 | Drinking and health risk assessment | [34] |
| Egypt/Lake Qarun | Irrigation = 12 Aquatic Life = 7 | Irrigation and aquatic life | [35] |
| Kenya | 9 | Human use | [36] |
| Nigeria | 12 | Drinking | [37] |
| Iraq/Al Hammar marsh | 12 | Surface water quality | [38] |
| Iraq/Springwater/Duhok | 11 | Drinking-water | [8] |
| Iraq Shatt-Al Kufa in Najaf | 11 | Irrigation | [39] |
| Iraq/Baghdad/Tigris River | 11 | Drinking | [40] |
| NSF WQI | Nigeria | 9 | Drinking | [41] |
| Iran | 7 | Irrigation | [42] |
| Indonesia | 9 | Drinking-water | [43] |
| Lower Zab river | 8 | Surface water | [44] |
| CCME WQI | All states in Canada | 28 | Versions use | [45] |
| Hungarian | 8 | Groundwater | [10] |
| Algeria | 7 | Irrigation | [46] |
| Romania | 13 | Drinking | [32] |
| Egypt Lake | 30 | Irrigation and aquatic life | [47] |
| Turkey | 12 | Surface water | [48] |
| Iraq/Mosul/Tigris River | 13 | Drinking | [49] |
| Iraq/Mosul/wells | 11 | Drinking and civilian purposes | [50] |
| Iraq / Anbar/Euphrates River | 14 | Drinking-water quality | [51] |
| Iraq/Baghdad/Tigris | 10 | River | [52] |
| Iraq/Diyala river | 8 | Aquatic life | [53] |
| Iraq/Diwanyah River | 9 | Aquatic life | [54] |
| Iraq/Garmat Ali | 5 | River water quality | [55] |
| Bhargava | | | | |
| Shatt-Al Kufa in Najaf | 11 | Irrigation | [39] |
| Iraq/Diyala River | Irrigation= 6 Drinking= 7 | Irrigation and drinking | [56] |

6. Conclusion

Water quality index is a useful and easy technique used to report the data on water quality. It has proven to be an effective method to evaluate temporal and spatial water changes in any region worldwide. Water quality indices can convert huge amounts and complex water quality data to a single value in a simple and
reproducible way. This process demonstrates the wide and successful application of WQIs over the past 60 years. They help to conclude large amounts of complicated scientific data and clearly describe water quality status to the public and political decision-makers. Even non-technical stakeholders will understand the simple dimensionless index score.

References

[1] Al-Janabi ZZ, Zaki SR, Alhassany JS, Hameed A, Al-Obaidy MJ and Awad ES, Maktoof A A 2019 Geochemical Evaluation of Heavy Metals (Cd, Cr, Fe, and Mn) in Sediment of Shatt Al-Basrah, Iraq. *Engine. And Techn. J.* 37 2 237–41.

[2] Dedić A, Gerhardt A, Kelly MG, Stanić-koštroman S, Šiljeg M, Stroil BK and et al. 2020 Innovative methods and science and policy to fill knowledge gaps in approaches for WFD: ideas. *Wat. Solu.* 3 30–42.

[3] Wątor K and Zdechlik R 2021 Application of water quality indices to the assessment of the effect of geothermal water discharge on river water quality – a case study from the Podhale region (Southern Poland). *Ecol Indic.* 121 1–14.

[4] Poikane S, Salas Herrero F, Kelly MG, Borja A, Birk S and van de B W 2020 European aquatic ecological assessment methods: A critical review of their sensitivity to key pressures. *Sci Total Environ.* 740:1–12. Available from: https://doi.org/10.1016/j.scitotenv.2020.140075

[5] Vadde KK, Wang J, Cao L, Yuan T, McCarthy AJ and Sekar R 2018 Assessment of water quality and identification of pollution risk locations in Tiaoxi River (Taihu Watershed), China. *Water* 10 1–18.

[6] Kanga I S, Albachir S Ni, Mustapha N, Chikhaoui Mo, Keith S, Stephanie L and Naeem N S 2019A Systematic Review and Meta-Analysis of Water Quality Indices. *J Agric Sci Technol.* 9 1 1–14.

[7] Hussein KM, Al-Bayati S A and Al-Bakri S A 2019 Assessing Water Quality for Al-Diwaniyah River, Iraq Using GIS Technique. *Enginee and Techn J.* 3 7 256–64.

[8] Ameen HA 2019 Springwater quality assessment using water quality index in villages of Barwari Bala, Duhok, Kurdistan Region, Iraq. *Appl Water Sci.* 9 176 1–12. Available from: https://doi.org/10.1007/s13201-019-1080-z

[9] Nowicki S, Koehler J and Charles KJ 2020 Including water quality monitoring in rural water services: why safe water requires challenging the quantity versus quality dichotomy. *npj Clea Wat.* 3(14):1–9. Available from: http://dx.doi.org/10.1038/s41545-020-0062-x

[10] Mester T, Balla D and Szabó G 2020 Assessment of Groundwater Quality Changes in the Rural Environment of the Hungarian Great Plain Based on Selected Water Quality Indicators. *Water Air Soil Pollut.* 231 536 1–14. Available from: http://dx.doi.org/10.1007/s11270-020-04910-6

[11] Banda TD and Kumarasamy MV 2020 Development of water quality indices (WQIs): A review. *Polish J Environ Stud.* 29 3 2011–21.

[12] Li D and Liu S. 2018 Water quality monitoring and management: Basis, technology and case studies. Water Quality Monitoring and Management: Basis, Technology and Case Studies. Academic Press, 368.

[13] Sutadian AD, Mutti N, Yilmaz A and Perera C 2016 Development of River Water Quality Indices - A Review. *Environ Monit Assess.* 188 58 1–33.

[14] Ewaid SH, Abed SA, Al-Ansari N and Salih RM 2020 Development and evaluation of a water quality index for the Iraqi rivers. *Hydrol.* 76 1–14.

[15] Brown R M, McClelland NI, Deininger R 1973Validating the WQI. Paper presented at the National Meeting on Water Resources Engineering of the American Society for Civil Engineers, Washington, DC.

[16] Li P 2014 Abbasi T and Abbasi SA: Water Quality Indices. *Environ Earth Sci.* 71 4625–8.
[17] Revelle R 1965 Restoring The quality of our Environment. Report. The White House.
[18] Horton R K 1965 An index number system for rating water quality. J. of Wat. Pollut. Cont. Feder. J Wat Pollut Cont Feder. 1965; 37(3): 300e306.
[19] Kulkarni AR. Water Quality Indices For Panchaganga River Basin. Poll Res. 2020; 39(2): 424–8.
[20] Brown M R, McClellan NI, Deininger R A and Tozer G R 1970 Water quality index—do we dare?, Water Sew Work. 117 10 339–43.
[21] Prati L, Pavanello R and Pesarin F 1971 Assessment of surface water quality by a single index of pollution. Water Res. 5 741–51.
[22] Dinius S H 1972 Social accounting system for evaluating water resources. Water Resour Res. 8 5 1159–77.
[23] Stoner J D 1978 Water-Quality Indices for Specific Water Uses. Geological Survey Circular 770.
[24] Dinius S H 1987 Design of an Index of Water Quality. Water Resour. Bulle. 23 5 833–43.
[25] Smith D G 1990 A better water quality indexing system for rivers and streams. Water Res. 24 10 1237–44.
[26] CCME 2001 Canadian water quality index 1.0 technical report and user’s manual. Canadian Environmental Quality Guidelines Water Quality Index Technical Subcommittee, Gatineau, QC, Canada. Can Water Qual Guidel Prot Aquat Life 1–5. Available from: http://www.ccme.ca/files/Resources/calculators/WQI User’s Manual (en).pdf
[27] EPA 1976 Toxic Substances Control Act. Pub. L. 94–469 Approved 1976-10-11, Washington, DC: US Environmental Protection Agency.
[28] Bhargava S D 1983 Use of water quality index for river classification and zoning of Ganga river. Environ Pollution Ser. 6 51–67.
[29] Ott W R 1978 Environmental indices: theory and practice. Environmental indices: theory and practice. Ann Arbor, Mich.: Ann Arbor Science, 371 p.
[30] Dao V, Urban W and Hazra B 2020 Introducing the Canadian Water Quality Index modification. Groundw Sustain Dev. 11 100457. Available from: https://doi.org/10.1016/j.gsd.2020.100457
[31] Said A, Stevens D and Sehlke G 2004 An innovative index for evaluating water quality in streams. Environ Manage. 34 3 406–14.
[32] Ismail AH, Robescu D and Hameed MA 2018 Application of CCME WQI in the Assessment of the Water Quality of Danube River, Romania. Engineer. and Techno. 36 2 142–6. Available from: http://dx.doi.org/10.30684/etj.36.2C.8
[33] Nihalani S and Meeruty A 2020 A Water quality index evaluation for major rivers in Gujarat. Environ Sci Pollut Res Int. Aug 19. doi: 10.1007/s11356-020-10509-5.
[34] Pattnaik P and Bhowmick PK 2020 Determination of Water Quality Index of Drinking Water Sources and Health Risk Assessment of Arsenic-Contaminated Rural Areas in Basirhat-1 Block of West Bengal. Int J Innov Technol Explor Eng. 9 3 677–84.
[35] Afify A D, Tahoun U M and Abdo M H 2019 Egyptian Journal of Aquatic Biology & Fisheries. Egypt J Aquat Biol Fish 23 1 341–57. Available from: http://www.elsevier.com/locate/scp
[36] Robert G K, Onyari C N and Mbaka J G 2020 Determination of Water Quality Assessment Index for Kenya’s Chania River. African J Aquat Sci. 45 1–11.
[37] Emeka D A and Chinonyerem S E 2019 Application of Water Quality Index in the Drinking Water Quality. Quality Assessment of a Southeastern Nigeria River. J. of Facu. of Food Enginee. eXVIII 4 308 – 314
[38] Al-Musawi NO, Al-Obaidi SK and Al-Rubaie FM 2018 Evaluating water quality index of al Hammar Marsh, south of Iraq with the application of GIS technique. J Eng Sci Technol. 13(12): 4118–30.
[39] Kizar M F 2018 Using Arithmetic Weighted and Bhargava Methods to Classify Irrigation Water Quality Index for Shatt-Al Kufa in Najaf Province, Iraq. Int J Eng Technol. 7 4.20 431–7.
Appendix A. Some details of the reviewed water quality indices: Advantage and Disadvantage

| Index | Use | Parameters | Advantages | Disadvantages | Ref. |
|-------|-----|------------|------------|---------------|------|

[40] Al-Obaidy A M J, Awad ES and Zahraw Z 2016 Impact of Medical City and Al-Rasheed Power Plant Effluents on the Water Quality Index Value of Tigris River at Baghdad City. *Eng & Tech J.* **34** 715–24.

[41] Kalagbor I A, Johnny V I and Ogbolokot I E 2019 Application of National Sanitation Foundation and Weighted Arithmetic Water Quality Indices for the Assessment of Kaani and Kpean Rivers in Nigeria. *Am J Water Resour.* **7** 1 11–5.

[42] Misaghi F, Delgosha F, Razzaghamanesh M and Myers B 2017 Introducing a water quality index for assessing water for irrigation purposes: A case study of the Ghezel Ozan River. *Sci Total Environ* **589** 107–16. Available from: http://dx.doi.org/10.1016/j.scitotenv.2017.02.226

[44] Ichwana I, Syahrul S and Nelly W 2016 Water Quality Index by Using National Sanitation Foundation-Water Quality Index (NSF-WQI) Method at Krueng Tamiang Aceh. *Int Conf Technol Innov Soc.* **3** 110–7.

[45] Khan F, Husain T and Lumb A 2003 Water quality evaluation and trend analysis in selected watersheds of the Atlantic region of Canada. *Environ Monit Assess* **88** 1–3 221–48.

[46] Bouhezila F, Hacene H, Aichouni M 2020 Water quality assessment in Réghaïa (North of Algeria) lake basin by using traditional approach and water quality indices. *Kuwait J. Sci.* **47** 4 57–71, Available from http://helios-eie.ekt.gr/EIE/handle/10442/13107

[47] Goher M E, Mahdy E S, Abdo M H, El Dars F M, Korium M A, Elsherif A 2019 Water quality status and pollution indices of Wadi El-Rayyan lakes, El-Fayoum, Egypt. *Sustain Water Resour Manag.* **5** 2 387–400.

[48] Bilgin A 2018 Evaluation of surface water quality by using Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) method and discriminant analysis method: a case study Coruh River Basin. *Environ Monit Assess* **190** 544 1–11.

[49] Ramadhan O, Al-Saffawi A, Al-Mashhdany M 2018 Application of water quality index [CCME WQI] to assess surface water quality: A case study of Khosar and Tigris rivers in Mosul, Iraq. *Intern. J. of Enha. Rese. in Scie. Technol. & Enginee.* **7** 12, 1-8.

[50] Al-Saffawi A A 2019 Water quality of Nimrud District wells southeast of Mosul city for drinking and civil purpose using the Canadian model of water quality. *Pakistan J Anal Environ Chem.* **20** 1 75–81.

[51] Saod W M, Al-Heety E A and Mohammed M M 2020 Spatial and temporal variation of water quality index of Euphrates River in Anbar Governorate, Iraq. *AIP Conf Proc.* **2213** 1–8.

[52] Ahmed Q N and Gubashi R K 2020 Water Quality index in Tigris River within Baghdad City. *J Eng Sustain Dev.* **24** 80–90.

[53] Hassan F M, Al-Jibouri K D and Hakman A A 2017 Water quality assessment of Diyala river in Diyala province, Iraq. *Mesop environ j.* **4** 41 52–61.

[54] Abbas A A and Hassan F M 2018 Water quality assessment of Euphrates river in Qadisiyah Province (Diwaniyah River), Iraq. *Iraqi J Agric Sci.* **49** 2 251–61.

[55] Mohamed A-RM, Younis KH and Hameed EK 2017 the Ecological Condition of the Garmat Ali River, Iraq. *Glob J Biol Agric Heal Sci.* **6** (3):13–21.

[56] Al-Musawi N 2018 Evaluation of water quality of Diyala River in Iraq using Bhargava method. *MATEC Web Conf.* **162** 1–7. https://doi.org/10.1051/matecconf/201816205001
| Index                | General water                     | DO, pH, coliform, EC, Alk, Cl, Carbon Chloroform. | In a simple method of computing, only 10 variables can be used | -Coefficients M1 and M2 adapting for individual situations  
- Arithmetic mean makes index not sensitive. | [18] |
|---------------------|----------------------------------|--------------------------------------------------|---------------------------------------------------------------|----------------------------------------------------------------|--------|
| NSF WQI             | Surface water                    | DO, Fcoli, pH, BOD, NO₃, PO₄, WT, Turb, TS       | A simple method of calculation, only 9 variables can apply    | - If any variable is of low quality, the arithmetic mean does not permit sufficient lowering of the index. | [20] |
| Prati's Implicit Index | Surface water                  | pH, DO, BOD, COD, SS, NH₃, NO₂, Cl, Fe, Mn, alkylbenzene sulfonates, and carbon chloroform | All variables are considered with unequal weights adding to a total sum of 1 | - Toxic substances have not been included | [21] |
| Dinius first Index  | Surface water                    | DO (% sat), BOD, coliform, coli, pH, Alk, Hardness, Cl, EC, Temp, Colour | Measure the costs and impact of pollution control. | Limit variables | [22] |
| Dinius second Index | Freshwater                       | DO, EC, pH, BOD₅, temp., alk, F, hardness, EC, Colour, NO₃ | Utilize to evaluate four uses water quality. | Biased to a set of variables | [24] |
| Stoner's Index      | Public and irrigation            | -13 public water variables: Cl, MBAS, phenols, NO₃, NH₃, Colour, pH, Cu, FC, F, Fe, ZI, SO₄  
-16 irrigation variables: EC, SAR, SC, Mn, B, As, Cd, Be, Al, Co, Cr, V, Ni, Cu, ZI, and F | - Variables are directly taken as sub-indices.  
- Can apply to any water uses. | Index applied for two water uses only | [23] |
| Bhargava index      | Drinking water                   | 4 different groups: organic and inorganic, coliform, physical and metals. | A different number of variables. Used for different purposes | It is only for one water use. | [28] |
| Smith Index         | Specific water uses              | - 4 variables for fish spawning: BOD, WT, Turb, SS  
- 7 variables for water supply: DO, BOD₅, Turb, SS, NH₄, WT, and FCol | Useful and showing vital information | Opinion of 18 panel experts of water quality were gathering. Which is not enough to cover the different water uses | [25] |
| CCME WQI            | General water                    | - At least 4 parameters  
- Maximum number of parameters involved in the index is not specified. | It is easy to compute and utilize for different uses.  
- Use neither sub-indices nor weights.  
- Low sensitivity for missing data. | - All variables included in the index have the same importance.  
- It cannot include other indicators or biological data.  
- Factor (F1) does not work appropriately if too few parameters are taken. | [26] |
| MWQI                | General water                    | - At least 4 parameters  
- Max. Variable number is not specified. | Provides a fairer judgment situation in cases where the statistical factors draw a skewed image. | - All variables have the same importance.  
- It cannot include biological data.  
- F1 does not work appropriately if too few parameters are taken. | [30] |
| Said WQI            | Surface water                    | DO, Turb, TP, FC, and EC | Easy to calculate, no need to standardize the variables. | - Restricted for particular variables  
- Assess water quality beneficially uses. | [31] |

**Appendix B: WQI technique, Standardization, Weighting, Aggregation and interpretation**

| Index | Technique | Standardization | Weighting | Aggregation | Interpretation | Ref. |
|-------|-----------|-----------------|-----------|-------------|----------------|-----|
|       |           |                 |           |             |                |     |
| Index Type | Method | Literature | Rating curves | Experts’ experience | Aggregation | Mathematical Formulation | References |
|------------|--------|------------|---------------|---------------------|------------|--------------------------|------------|
| Horten index | Delphi | Delphi technique | Experts (weights from 1 to 4) | Arithmetic mean | $Q_I = \sum_{i=1}^{n} W_i M_i M_2$ | 0: very bad, 100: excellent | [18] |
| NSFWQI | Delphi | Delphi technique | Experts’ opinions | Arithmetic mean | $WQI(M) = \prod_{i=1}^{n} Q_i^{w_i}$ | 0: very bad, 100: excellent | [20] |
| Prati’s Implicit Index | Literature | Linear and parabolic function | No | Additive | $I = 1/13 \sum_{i=1}^{13} I_i$ | 1: excellent, 8: heavily polluted | [21] |
| Dinius Delphi technique | Linear and nonlinear function | Delphi technique | Weighted | $DWQI = \frac{1}{21} \sum_{i=1}^{21} l_i^{w_i}$ | 0: not acceptable, 100: acceptable | [22] |
| Dinius second Delphi technique | Linear and nonlinear function | Delphi technique | Geometrical average | $IWQ = \prod_{i=1}^{n} l_i^{w_i}$ | 0: not acceptable, 10: acceptable | [24] |
| Stoner’s Index | No | Limits classes: nonlinear functions | Researchers’ experience | Additive | $I = \sum_{i=1}^{m} l_i + \sum_{j=1}^{n} W_j j$ | 0: unfit water for uses, 100: perfect water | [23] |
| Bhargava index | No | Formulas | Weighted product | Additive aggregation | $WOI = \left[ \left( \prod_{i=1}^{n} \frac{f_i (P_i)}{l_i} \right) \right]^{1/n}$ | Less than 10: Severe polluted, 100: excellent | [28] |
| Smith Index | Expert opinion | Rating curves: experts' opinion | No | | $I = \min_{\{ I_{sub} \}_{1}, I_{sub} \}_{2}, \ldots, I_{sub} \}_{n}$ | 0: unsuitable for several uses, 100: suitable for all uses | [25] |
| CCME WQI | No | Standards values | No | Arithmetic average | $CCMEWQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}$ | 0: bad, 100: excellent | [26] |
| MWQI | No | Standards values | No | Minimum operator | $MWQI = 100 - \frac{\sqrt{F_1 + F_2 + F_3}}{100}$ | 0: bad, 100: excellent | [30] |
| Said WQI | Literature | No need | Ranking | No aggregation method | $SAID WQI = \alpha \log (Do) \times 1.5 / ((3.8)^{0.15}) \times (TP) \times (T_{turb}) \times 0.14 \times (SC) \times 0.5$ | 0: poor, 3: acceptable | [31] |