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Water Quality Assessment in Terms of Water Quality Index

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Abstract Water quality index (WQI) is valuable and unique rating to depict the overall water quality status in a single term that is helpful for the selection of appropriate treatment technique to meet the concerned issues. However, WQI depicts the composite influence of different water quality parameters and communicates water quality information to the public and legislative decision makers. In spite of absence of a globally accepted composite index of water quality, some countries have used and are using aggregated water quality data in the development of water quality indices. Attempts have been made to review the WQI criteria for the appropriateness of drinking water sources. Besides, the present article also highlights and draws attention towards the development of a new and globally accepted "Water Quality Index" in a simplified format, which may be used at large and could represent the reliable picture of water quality.

Keywords: *ground water, surface, water quality, water quality index*

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1. Introduction

Water, a prime natural resource and precious national asset, forms the chief constituent of ecosystem. Water sources may be mainly in the form of rivers, lakes, glaciers, rain water, ground water etc. Besides the need of water for drinking, water resources play a vital role in various sectors of economy such as agriculture, livestock production, forestry, industrial activities, hydropower generation, fisheries and other creative activities. The availability and quality of water either surface or ground, have been deteriorated due to some important factors like increasing population, industrialization, urbanization etc.

Water quality of any specific area or specific source can be assessed using physical, chemical and biological parameters. The values of these parameters are harmful for human health if they occurred more than defined limits [1,2,3,4]. Therefore, the suitability of water sources for human consumption has been described in terms of Water quality index (WQI), which is one of the most effective ways to describe the quality of water. WQI utilizes the water quality data and helps in the modification of the policies, which are formulated by various environmental monitoring agencies. It has been realized that the use of individual water quality variable in order to describe the water quality for common public is not easily understandable [5,6]. That's why, WQI has the capability to reduce the bulk of the information into a single value to express the data in a simplified and logical form [7]. It takes information from a number of sources and combines them to develop an overall status of a water system [8-25]. They increase the understanding ability of highlighted water quality issues by the policy makers as well as for the general public as users of the water resources [26]. The present study reviews some of the important water quality indices used in water quality assessment and provides their mathematical structure, set of parameters and calculations along with their merits and demerits, which are being used worldwide.

2. Water Quality Index

Initially, WQI was developed by Horton (1965) [27] in United States by selecting 10 most commonly used water quality variables like dissolved oxygen (DO), pH, coliforms, specific conductance, alkalinity and chloride etc. and has been widely applied and accepted in European, African and Asian countries. The assigned weight reflected significance of a parameter for a particular use and has considerable impact on the index. Furthermore, a new WQI similar to Horton's index has also been developed by the group of Brown in 1970 [28], which was based on weights to individual parameter. Recently, many modifications have been considered for WQI concept through various scientists and experts [29,30].

A general WQI approach [31] is based on the most common factors, which are described in the following three steps:

1. Parameter Selection: This is carried out by judgment of professional experts, agencies or government institutions that is determined in the legislative area. The selection of the variables from the 5 classes namely oxygen level, eutrophication, health aspects, physical characteristics and dissolved substances, which have the considerable impact on water quality, are recommended [32].
2. Determination of Quality Function (curve) for Each Parameter Considered as the Sub-Index: Sub-indices transform to non-dimensional scale values from the variables of its different units (ppm, saturation percentage, counts/volume etc.).
3. Sub-Indices Aggregation with Mathematical Expression: This is frequently utilized through arithmetic or geometric averages.

However, a huge number of water quality indices viz. Weight Arithmetic Water Quality Index (WAWQI), National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), Oregon Water Quality Index (OWQI) etc. have been formulated by several national and international organizations. These WQI have been applied for evaluation of water quality in a particular area [33,34]. Moreover, these indices are often based on the varying number and types of water quality parameters as compared with respective standards of a particular region. Water quality indices are accredited to demonstrate annual cycles, spatial and temporal variations in water quality and trends in water quality even at low concentrations in an efficient and timely manner. On the basis of reviewed literature, available indices have many variations and limitations based on number of water quality variables used and not accepted worldwide [35]. Hence, it needs worldwide acceptability with varying number of water quality variables. Various WQI determination methods have been described herein.

2.1. National Sanitation Foundation Water Quality Index (NSFWQI)

A usual water quality index method was developed by paying great rigor in selecting parameters, developing a common scale and assigning weights. The attempt was supported by the National Sanitation Foundation (NSF) and therefore as NSFWQI in order to calculate WQI of various water bodies critically polluted. The proposed method for comparing the water quality of various water sources is based upon nine water quality parameters such as temperature, pH, turbidity, fecal coliform, dissolved oxygen, biochemical oxygen demand, total phosphates, nitrates and total solids [28,36]. The water quality data are recorded and transferred to a weighting curve chart, where a numerical value of Qi is obtained. The mathematical expression for NSF WQI is given by

$$WQI = \sum_{i=1}^{n} QiWi$$

Where,

Qi = sub-index for ith water quality parameter;

Wi = weight associated with ith water quality parameter;

n = number of water quality parameters.

For this NSFWQI method, the ratings of water quality have been defined by using following Table 1:

Table 1. Water Quality Rating as per different Water Quality Index methods

National Sanitation Foundation Water Quality Index (NSFWQI)	
WQI Value	**Rating of Water Quality**
91-100	Excellent water quality
71-90	Good water quality
51-70	Medium water quality
26-50	Bad water quality
0-25	Very bad water quality
Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI)	
95-100	Excellent water quality
80-94	Good water quality
60-79	Fair water quality
45-59	Marginal water quality
0-44	Poor water quality
Oregon Water Quality Index (OWQI)	
90-100	Excellent water quality
85-89	Good water quality
80-84	Fair water quality
60-79	Poor water quality
0-59	Very poor water quality

2.2. Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI)

CCME WQI provides a consistent method, which was formulated by Canadian jurisdictions to convey the water quality information for both management and the public. Moreover, a committee established under the Canadian Council of Ministers of the Environment (CCME) has developed WQI, which can be applied by many water agencies in various countries with slight modification [37,38,39]. This method has been developed to evaluate surface water for protection of aquatic life in accordance to specific guidelines. The parameters related with various measurements may vary from one station to the other and sampling protocol requires atleast four parameters, sampled atleast four times [40,41]. The calculation of index scores in CCME WQI method can be obtained by using the following relation:

$$WQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}$$

Where,

Scope (F_1) = Number of variables, whose objectives are not met.

F_1= [No. of failed variables /Total no. of variables]*100
Frequency (F_2) = Number of times by which the objectives are not met.
F_2 = [No. of failed tests/Total no. of tests]*100
Amplitude (F_3) = Amount by which the objectives are not met.
(a) $excursion_i$ = [Failed test $value_i$ /$Objective_j$]-1
(b) normalized sum of excursions (nse) = $\sum_{i=1}^{n}$ $excursions_i$ /No of tests
(c) F_3 = [nse/0.01nse+0.01]

Therefore, five categories have been suggested to categorize the water qualities which are summarized in Table 1.

2.3. Oregon Water Quality Index (OWQI)

OWQI creates a score to evaluate the general water quality of Oregon's stream and the application of this method to other geographic regions, which combines eight water quality variables into a single number. The parameters covered in this method are temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), pH, ammonia and nitrate nitrogen, total phosphorus, total solids and fecal coliform [32,42]. The original OWQI was designed after the NSFWQI where the Delphi method was used for variable selection. It expresses water quality status and trends for the legislatively mandated water quality status assessment. The index is free from the arbitration in weighting the parameters and employs the concept of harmonic averaging. The mathematical expression of this WQI method is given by

$$WQI = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{SI_i^2}}}$$

Where,
n = number of subindices
SI = subindex of ith parameter
Furthermore, the rating scale of this OWQI has also been categorized in various classes, which are given under Table 1 [43].

2.4. Weighted Arithmetic Water Quality Index Method

Weighted arithmetic water quality index method classified the water quality according to the degree of purity by using the most commonly measured water quality variables. The method has been widely used by the various scientists [44,45,46,47] and the calculation of WQI was made [48] by using the following equation:

$$WQI = \sum QiWi / \sum Wi$$

The quality rating scale (Qi) for each parameter is calculated by using this expression:

$$Qi = 100[(Vi - Vo/Si - Vo)]$$

Where,
Vi is estimated concentration of ith parameter in the analysed water
Vo is the ideal value of this parameter in pure water
Vo = 0 (except pH =7.0 and DO = 14.6 mg/l)
Si is recommended standard value of ith parameter
The unit weight (Wi) for each water quality parameter is calculated by using the following formula:

$$Wi = K/Si$$

Where,
K = proportionality constant and can also be calculated by using the following equation:

$$K = \frac{1}{\sum (1/Si)}$$

The rating of water quality according to this WQI is given in Table 2.

Table 2. Water Quality Rating as per Weight Arithmetic Water Quality Index Method

WQI Value	Rating of Water Quality	Grading
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very Poor water quality	D
Above 100	Unsuitable for drinking purpose	E

3. Merits and Demerits of Selected Water Quality Index Methods

A comparison of all these water quality indices is also performed under the study considering their merits and demerits. Table 3 explains about the merits and demerits of WQI methods.

4. Conclusions

After the study of different water quality indices, it may be inferred that the aim of WQI is to give a single value to water quality of a source alongwith reducing higher number of parameters into a simple expression resulting into easy interpretation of water quality monitoring data. Moreover, this is an effort to review the important indices used in water quality vulnerability assessment and also provides information about indices composition and mathematical forms. These indices utilize various physico-chemical and biological parameters and have been resulted as an outcome of efforts and research and development carried out by different government agencies and experts in this area globally. In spite of all the efforts and different discussed indices being used globally, no index has so far been universally accepted and search for more useful and universal water quality index is still going on, so that water agencies, users and water managers in different countries may use and adopted it with little modifications.

Table 3. Merits and Demerits of Selected Water Quality Indices

Merits	Demerits	References
National Sanitation Foundation (NSF) WQI		
1. Summarizes data in a single index value in an objective, rapid and reproducible manner. 2. Evaluation between areas and identifying changes in water quality. 3. Index value relate to a potential water use. 4. Facilitates communication with lay person.	1. Represents general water quality, it does not represent specific use of the water. 2. Loss of data during data handling. 3. Lack of dealing with uncertainty and subjectivity present in complex environmental issues.	[49,50]
Canadian Council of Ministers of the Environment (CCME) WQI		
1. Represent measurements of a variety of variables in a single number. 2. Flexibility in the selection of input parameters and objectives. 3. Adaptability to different legal requirements and different water uses. 4. Statistical simplification of complex multivariate data. 5. Clear and intelligible diagnostic for managers and the general public. 6. Suitable tool for water quality evaluation in a specific location 7. Easy to calculate 8. Tolerance to missing data 9. Suitable for analysis of data coming from automated sampling. 10. Combine various measurements in a variety of different measurement units in a single metric.	1. Loss of information on single variables. 2. Loss of information about the objectives specific to each location and particular water use. 3. Sensitivity of the results to the formulation of the index. 4. Loss of information on interactions between variables. 5. Lack of portability of the index to different ecosystem types. 6. Easy to manipulate (biased). 7. The same importance is given to all variables. 8. No combination with other indicators or biological data 9. Only partial diagnostic of the water quality. 10. F_1 not working appropriately when too few variables are considered or when too much covariance exists among them.	[51,52]
Oregon WQI		
1. Un-weighted harmonic square mean formula used to combine sub-indices allows the most impacted parameter to impart the greatest influence on the water quality index. 2. Method acknowledges that different water quality parameters will pose differing significance to overall water quality at different times and locations. 3. Formula is sensitive to changing conditions and to significant impacts on water quality.	1. Does not consider changes in toxics concentrations, habitat or biology. 2. To make inferences of water quality conditions outside of the actual ambient network site locations is not possible. 3. Cannot determine the water quality for specific uses nor can it be used to provide definitive information about water quality without considering all appropriate physical, chemical and biological data. 4. Cannot evaluate all health hazards (toxics, bacteria, metals, etc.).	[43,53]
Weight Arithmetic WQI		
1. Incorporate data from multiple water quality parameters into a mathematical equation that rates the health of water body with number. 2. Less number of parameters required in comparison to all water quality parameters for particular use. 3. Useful for communication of overall water quality information to the concerned citizens and policy makers. 4. Reflects the composite influence of different parameters i.e. important for the assessment and management of water quality. 5. Describes the suitability of both surface and groundwater sources for human consumption.	1. WQI may not carry enough information about the real quality situation of the water. 2. Many uses of water quality data cannot be met with an index. 3. The eclipsing or over-emphasizing of a single bad parameter value 4. A single number cannot tell the whole story of water quality; there are many other water quality parameters that are not included in the index. 5. WQI based on some very important parameters can provide a simple indicator of water quality.	[6,54]

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