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WATER QUALITY INDICES IN MÉXICO AND COLOMBIA. EVOLUTION, CRITERIA AND CHALLENGES

Índices de calidad de agua en México y Colombia. Evolución, criterios y cambios

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Resumen

El Índice de Calidad del Agua (WQI) es una herramienta simple y fácil de entender para analizar y reportar tendencias de calidad. La calidad del agua no es estática y depende de múltiples factores, por lo que se han desarrollado varios índices a nivel mundial teniendo en cuenta los criterios locales de calidad del agua. Este documento explora y analiza los pasos de evaluación de la calidad del agua basados en los modelos de índices ampliamente utilizados en el mundo. Estos pasos incluyen la selección de los parámetros, la generación de subíndices, las ponderaciones de los parámetros y la agregación de subíndices. Se identificaron las ventajas y desventajas de cada índice y se detectaron las principales limitaciones que surgen en el cálculo de las diferentes metodologías. Estas limitaciones son la subjetividad en la selección y ponderación de los parámetros y la ambigüedad y enmascarado en la etapa de agregación. Las herramientas metodológicas objetivas para resolver estas limitaciones consideran el uso de técnicas estadísticas y de lógica difusa. El CCMEWQI se identifica como un índice de calidad del agua versátil ya que permite determinar las condiciones temporales y espaciales para los diferentes usos de manera específica, cumpliendo con la normativa, y con base en el análisis de los datos de seguimiento de cada región.

Palabras clave: *Agregación, parámetros, calidad, agua superficial, uso del agua, WQI*

Abstract

The Water Quality Index (WQI) is a simple and easy-to-understand tool for analyzing and reporting quality trends. Water quality is not static and depends on multiple factors, in this sense; globally various indices have been developed based on local water quality criteria. This paper explores and discusses about water quality assessment and their steps taking into account the widely used index models in the world. These steps include selecting the parameters, sub-index generation, weightings of the parameters, and sub-indices aggregation. The advantages and disadvantages of each index identified, and the main limitations that arise in the calculation of the different methodologies detected. These limitations are the subjectivity in selecting and weighing the parameters and the ambiguity and eclipsing in the aggregation stage. Objective methodological tools to solve these limitations consider the use of statistical and fuzzy logic techniques. The CCMEWQI is a versatile water quality index, since it allows the determination of the temporal and spatial conditions for the different uses in a specific way, achieving with regulations, and based on the analysis of monitoring data for each region.

Key words: *Aggregation, parameters, quality, surface waters, water use, WQI.*

1. INTRODUCTION

Water availability is linked directly to human well-being, and at the same time, plays a significant role in the landscape system [1]. Despite its great value, its current patterns of consumption are ecologically and socially unsustainable. The hydrological cycle balance has been altered, with sensitive changes in evaporation rates and consequent alteration of water quality, which ultimately causes its deterioration and accentuates availability problems [2]. Hence, proper management and constant monitoring of quality and quantity of water play an essential role in the integrated management of this resource [3].

Given that natural and anthropogenic activities change the characteristics of water and its different uses do not require the same conditions, water quality represents the condition associated with the physicochemical and biological factors used for its intended purpose. Usually, evaluating the quality of a body of water is carried out by monitoring and analyzing individual parameters of three broad categories: physical, chemical, and biological. However, this is a highly laborious and costly process without providing a whole picture of the water quality. Furthermore, many scientists and researchers often find it challenging to define and present it in a consolidated and straightforward way [4,5] Therefore, different calculation methodologies have emerged whose main objective is to identify the significant parameters for representing water quality according to the uses intended and communicate it to decision-makers.

Water quality indices (WQIs) emerge as simple and easily understandable tools for analysing and reporting quality trends. Through a dimensionless number, they reduce the multivariate nature of the data, allowing them to communicate their status in a more efficient way to stakeholders [5-6]. This valuable tool has proven to be the most effective technique and has played a key role in water resources management. So that currently, developing countries have been actively working on research in this field [7].

Four typical steps have been identified in the WQIs calculation approaches: parameter selection, sub-index generation, weight allocation, and sub-index aggregation for a final index determination [6, 8-9, 5]. However, there is no globally accepted method for implementing these steps, corresponding to the WQI processors applying their expertise and knowledge to select the most appropriate method. Numerous models with variations in their calculation's four typical steps have been developed [10-13]. Exploring and modifying the indices will help to select the most appropriate index to apply in a particular study. This paper aims to present a critical analysis of the different WQIs most commonly used worldwide. Looking specifically at the indices developed and applied in Colombia and Mexico.

2. METHODS

This document includes an overview of the concept and history of different models of WQIs developed worldwide. Afterward, the development and methodologies for the most widely used WQIs worldwide summarized, and their main challenges and limitations addressed, including some studies aimed to reduce these limitations. For this purpose, several journal articles and reports from government agencies were reviewed. Some of the terms used to perform this search were: water quality, water quality indices, surface water quality, and water parameters. Bibliographies from these articles were searched to identify any additional relevant studies that were not found or missed through the main research. This research was conducted between August and October 2021.

3. RESULTS

3.1. Importance and evolution of the water quality index

WQIs result from mathematical simplification exercises, based on some physicochemical and microbiological parameters, selected and transformed into a dimensionless number. They describe the state of the water according to its degree of purity or pollution regarding natural water quality, human health, and intended uses, allowing it to be communicated to a target audience or general [8-9, 5].

They are considered critically important tools. The information obtained from WQIs is used for different purposes such as resource management, area classification, regulatory enforcement, and scientific research [14, 4]. They also keep the public informed and help motivate their participation to support awareness and actions to conserve and improve water quality.

The concept of water quality has a long history. Dates back to 1848, when in Germany, some attempts were made to relate it to the presence or absence of specific biological organisms [6, 15]. In 1908, one of the first WQIs, the Saprobic Index (SI), used to estimate the level of easily degradable organic matter in water, being insufficient and leading to the search for better indices in the following decades [15].

In 1965, Horton presented a simple but scientifically defensible mathematical method for rating water quality [8]. This method based on integrating eight significant parameters: wastewater treatment, dissolved oxygen, pH, fecal coliforms, specific conductance, carbon chloroform extract, alkalinity, chlorides. Each parameter was transformed by assigning it a rating scale from 0 to 100 and then a weight from 1 to 4, giving 4 to the most significant parameter based on his judgment and a few associates. The final index score was composed of the weighted sum of the sub-indices, divided by the sum of weights and multiplied by two coefficients, dependent on temperature and water pollution level [16, 8].

Since Horton's first modern WQI, researchers have developed numerous indices applied by different government agencies in studies worldwide. During the 1970s and 1980s, various indices were developed: National Sanitation Foundation Index (NSF-WQI), Dinius Indexes (1972, 1988), the original Oregon Quality Index (O-WQI), Prati Index, Bhargava Index, Bascaran Index, and the Index of the Environmental Company of Sao Paulo State (CETESB) [17-23]. In the 1990s, Smith developed a WQI for four uses of water, which was used in water quality legislation and for the diffusion of water quality information in New Zealand [24]. In Canada, a significant development was the British Columbia Water Quality Index (BCWQI), used to assess water quality in that province [25].

In Colombia, Rojas (1991) proposed an index, adapted to the context of the Cauca River. In the late 1990s; by the other side, in Mexico, the Secretariat of Urban Development and Ecology of Jalisco (INDIC-SEDUE) and the León Index were proposed [26, 27]. In the first decade of the 21st century, the Canadian Council of Ministers of the Environment Index (CCME-WQI) was approved [28]. Recent models correspond to Argentina's Almeida Recreation Index (RWQI), Brazil Bathing Conditions Index (ICB), Malaysian Index, and West Java Index (WJWQI).

3.2. Indices used worldwide

In Table 1, the countries, methodologies, and references of studies using various water quality indices worldwide are presented. Among the variety of WQIs, the application of NSF-WQI in its geometric and arithmetic form, O-WQI and CCME-WQI stand out. Their descriptions are introduced later, and a summary of their advantages and disadvantages (Table 2).

NSF-WQI. This index intended for a general water evaluation. It emerged as an improved version of Horton's index. The professional opinion of a panel of 142 water quality experts for parameter selection used, who also defined the weighting of each parameter and set the classification on a scale, from excellent to very bad. Brown, et al. (1970) proposed the first version of the NSF index by on the arithmetic form; subsequently, in 1973, geometric aggregation considered better, being more sensitive when a single variable exceeds the regulation, because if anyone sub-index exhibits poor water quality, the overall index will display poor water quality.

The sub-indices values are obtained by constructing water quality valuation curves for each parameter with a range of 0 to 100 on the vertical axis and the different levels of the variables along the horizontal axis. This index uses the Delphi methodology, an iterative process involving many experts and questionnaire opinion-gathering techniques, allowing feedback to refine assessments and allow consensus [6, 29-30]. It is one of the most widely used WQIs by agencies and institutions in the United States and is commonly used in the world, being validated and adapted in different studies [27], it is applied in countries such as Brazil, Mexico, Iraq, Croatia, Colombia, and Costa Rica, among others [31-33, 15].

Table 1. Water quality indices and countries in which they were developed.

Index	Country	No. of Parameters	Weight	Aggregation	References
NSF index	United States of America	9	Different weights	Geometric and arithmetic	Akkoyunlu and Akiner, 2012; Effendi et al., 2015; Darvishi et al., 2016; Ewaid, 2017; Gupta et al., 2017; Barakat et al., 2018; Fathi et al., 2018; Mena-rivera et al., 2018; Rimoldi et al., 2018; Lopes et al., 2020; Torres et al., 2010; Zotou et al., 2020
Prati Index	Italy	13	Different weights	Arithmetic	Prati et al., 1971
Dinius index (1972)	United States of America	11	Different weights	Arithmetic	Dinius, 1972
CETESB	Brazil	9	Different weights	Geometric	Medeiros et al., 2017; Lopes et al., 2020
Oregon index	United States of America	8	Unweighted	Harmonic square mean	Dunnette, 1979; Cude, 2001; Lumb et al., 2011; Dede et al., 2013; Darvishi et al., 2016; Hamlat et al., 2017; Zotou et al., 2019
Bhargava index	India	According to the use. Four categories: coliform organisms, metals, physical parameters, and organic and inorganic parameters	Different weights	Modified geometric	Bhargava, 1983, 1985
Dinius index (1988)	United States of America	12	Different weights	Geometric	Dinius, 1988

Smith index	New Zealand	4-6-7 (According to the use)	Unweighted	Minimum operator	Smith, 1989, 1990 four suitability-for-use water quality indexes have been developed. The water users are: General, Bathing, Supply, and Fish Spawning although in the Bathing and Supply Indexes protection of aquatic life is also considered. To ensure that they tell us something useful and do not 'hide' important information as current indexing systems tend to do, the Minimum Operator has been employed as the sub-index aggregation mechanism. This is a robust, sensitive, and flexible method and seems more appropriate for this type of index than the more commonly used techniques (e.g. additive and multiplicative
Bascaron index (BWQI)	Spain	26	Different weights	Modified arithmetic	Bascaran, 1979; Lopes et al., 2020
Rojas index	Colombia	6	Different weights	Geometric	Rojas, 1991
INDIC-SEDUE	Mexico	18	Different weights	Arithmetic	Montoya, 1997
Leon index	Mexico	15	Different weights	Geometric	León-Vizcaíno, 1999
Pesce and Wunderlin index	Argentina	3	Different weights	Arithmetic	Pesce and Wunderlin, 2000
CCME index	Canada	Open choice	Unweighted	Mathematical formula composed of 3 factors	Lumb et al., 2006, 2011b; Espejo et al., 2012; Hurley et al., 2012; CCME, 2017; Bilgin, 2018; Chacón et al., 2018; Gikas et al., 2020; Lopes et al., 2020; Zotou et al., 2020
Nagels index	New Zealand	7	Unweighted	Minimum operator	Nagels et al., 2001
ICAUCA River index	Colombia	10	Different weights	Geometric	CVC, 2004; Ocampo-Duque et al., 2013
Department of Environment Malaysia index (DOE-WQI)	Malaysia	6	Different weights	Arithmetic	Suratman et al., 2015; Naubi et al., 2016

Universal Water Quality index (UWQI)	Turkey	12	Different weights	Arithmetic	Boyacioglu, 2007; Dede et al., 2013 salts and total parameters were selected as index components. Threshold values were assigned to seven water-quality classes as defined by the legislation and were used to develop mathematical equations to convert observed values to index scores. Depending on the ecological importance of the parameters, weights were assigned to each variable and then a weighted sum method was performed to aggregate sub-indices. The applicability of the method was demonstrated in two basins located in Turkey. Factor analysis was applied to optimize the index component selection process. Several alternatives were tested to comprise at least one variable from each defined factor class (e.g. salinity content
RWQI	Argentina	9	Different weights	Geometric	Almeida et al., 2012
Overall Index of Pollution (OIP)	India	13	Unweighted	Arithmetic	Sargaonkar and Deshpande, 2003; Hamlat et al., 2017
ICB	Brazil	4	Unweighted	Minimum operator	Azevedo Lopes et al., 2016 especially where the climate is favorable. Water resources with appealing conditions for primary contact recreational activities include rivers, waterfall plunge pools, dams and lakes, as well as sea coasts. Recreational use has specific demands forwater quality, particularly as regards risks to human health such as exposure to pathogenic organisms, toxic substances, and submerged hazards. In Brazil, there is insufficient monitoring of bathing water conditions and currently used methodology has some limitations particularly the lack of guidance on interpretation of variables other than faecal bacterial indicators. The objectives of this studywere: (1).

Medeiros index	Brazil	11	Different weights	Geometric	Medeiros et al., 2017
WJWQI	Indonesia	13	Different weights	Geometric	Sutadian et al., 2018
Ecosystem specific water quality index (ES-WQI)	Mexico	14	Different weights	Arithmetic	Gradilla-Hernández M.S et al., 2020which is frequently used to assess chemical, physical, and microbiologic features of waterbodies in temperate latitudes. In this work, a well-structured method, completely based on multivariate statistical methods and historical data distributions, was used to develop an ecosystem specific water quality index (ES-WQI)
Santiago- Guadalajara River index (SGR-WQI)	Mexico	17	Different weights	Arithmetic	Casillas-García et al., 2021; Gradilla-Hernández M.S. et al., 2020

OWQI. This index supports the assessment of water quality for general recreational uses. Its first version was a branch of the NSFWQI, developed by the Oregon Department of Environmental Quality, United States of America (USA), and it is used in various documents to report water quality status and trends. The Delphi methodology used to select six parameters, non-linear transformations for sub-index generation, and an arithmetic average aggregation formula weighted in the final index calculation. It was updated in 1995 using logarithmic transformations to calculate sub-indices and add temperature and total phosphorus parameters. The aggregation method was modified through the unweighted harmonic square mean formula (Table 4) [20-34].

Table 2. Advantages and disadvantages of the most widely used indices around the world.

NSFWQI	
Advantages	**Disadvantages**
Simple and concise method, easy to understand. Allows evaluation between areas and identifying changes in water quality. Facilitates and enhances communication with users who have limited technical capabilities. It is one of the most used indices by agencies and institutions in the United States.	Some information is lost when multiple water quality parameters are included. Fixed established parameters. Cannot determine water quality for specific uses Cannot evaluate every single health risk. Sensibility and subjectivity issues present in complex. environmental issues.

OWQI	
Simple and concise method, easy to understand. Allows evaluation between areas and to identify changes in water quality. Facilitates and enhances communication with users who have limited technical capabilities . It has been used in several briefs and reports to inform about the state and tendencies of water quality in Oregon. Enables the expression of water quality for recreational uses in general, including fishing and swimming. Its formula allows the most deteriorated variable to impart the most significant influence on the water quality index and recognizes that the different water quality variables will have a different meaning for overall water quality at other times and places.	Some information is lost when multiple water quality parameters are included. Fixed established parameters. Cannot determine water quality for specific uses, e.g., irrigation or potable. Cannot evaluate every single health risk. Precaution required if applying to other geographical zones or different water bodies. Subjectivity issues present in complex environmental issues.
CCMEWQI	
Flexible in terms of the type and number of water quality parameters, application period, and type of water body. Allows the evaluation of water quality for general uses as for specific uses. Flexibility in the absence of parameter data. Compares observations with a benchmark (water quality standards); therefore, there is no sub-index generation, or weighting put in place. Identifies parameters that do not meet the set levels and frequency of occurrence. Easy to calculate. A simple mathematical framework for adding the value of the final index. It can be used both to track changes at a site over time and for direct comparisons between sites.	Some information is lost when multiple water quality parameters are included. It is solely up to the user's professional judgment to determine what and how many variables should be included in the index. It requires a period of at least three years for the calculation The selection of regulations influences the results. Therefore, the regulations must be equivalent for comparisons to be valid . Factor F1 has a more significant influence on the final value of the index, creating a sensitivity problem. It is recommended to use at least eight but no more than 20 parameters.

CCMEWQI. Through the Canadian Environmental Sustainability Indicators (CESI) initiative, the government focused on key environmental indicators of great concern in Canada. Water quality is one of them, address through CCMEWQI [35]. This index is based on a different concept from those of NSFWQI and OWQI. Developed from BCWQI by the Canadian Council of Ministers of the Environment, it was oriented to assessing the ecological quality of water based on measures to comply with or divert from established water quality standards. The model adds the index through a three-component non-linear formula (1, 2, 3): scope (F1); Which represents the percentage of parameters that do not meet the guidelines, at least once during the considered period, relative to the total number of measured parameters, frequency (F2). In addition, it represents the percentage of individual tests that do not meet the guidelines, and amplitude (F3), which means the value by which failed test values do not meet the above guidelines. The specific parameters, policies, and periods used in the CCMEWQI are not specified and may vary from region to region, depending on local conditions, purpose of index use, and water quality problems [36, 37].

The formulas for calculating F1, F2, and F3 are as follows:

$$F_1 = \left(\frac{\text{Number of parameters which did not meet desirable levels}}{\text{Total number of parameters}} \right) \times 100 \qquad (1)$$

$$F_2 = \left(\frac{\text{Number of tests that did not meet desirable levels}}{\text{Total number of tests}} \right) \times 100 \qquad (2)$$

$$F_3 = \left(\frac{nse}{0.01\ (nse) + 0.01} \right) \qquad (3)$$

(*nse)* represents the magnitude which water quality diverts from the conformity criteria. It is calculated dividing the sum of the magnitude of each of the deviations observed in the tests that were out of conformity (nse), by the total number of tests:

$$nse = \frac{\sum_{i=1}^{n} nse_i}{\text{Total number of tests}} \qquad (4)$$

For cases in which the test values should not exceed the desirable level:

$$nse_i = \left(\frac{\text{Value of the comformity level}_i}{\text{Desirable level}_i} \right) - 1 \qquad (5)$$

For cases in which the test values should not go below the desirable level:

$$nse_i = \left(\frac{\text{Desirable level}_i}{\text{Out - of - conformity test value}_i} \right) - 1 \qquad (6)$$

3.3. Indices developed in Mexico

In Latin America, the development and implementation of WQIs boomed in Mexico [38]. Different studies have developed and applied WQIs in groundwater and surface water bodies. Most studies have focused on surface water bodies, such as rivers, lakes, and dams [39-42]. However, recent studies have applied WQIs in groundwaters [43-44].

Moreover, the indices developed in Mexico, the first and most notorious works are the WQIs developed by Montoya (1997) and León (1999) [45, 31]. Both indexes based on the Dinius work [19, 46]. Dinius (1972). This index can be considered the predecessor of the planning or decision-making indexes. The sub-indices of the index were developed from a review of the published scientific literature. The following categories were established for the selection of 11 parameters: amount of organic material, coliform bacteria, ionic material, and physical characteristics. Eleven parameters were selected. Equations were generated for the sub-indexes. Finally, the index was calculated as the weighted arithmetic average of the subindices.

Subsequently, Dinius (1988) developed a new WQI under reference water quality standards defined by a panel of seven experts under the Delphi methodology instead of the reference values used in the first index. It uses a multiplicative index and incorporates nitrates as an additional parameter. Evaluate the water quality considering six water uses: public water supply, recreation, aquatic life (fish), aquatic life (shellfish), agriculture, and industry.

INDIC-SEDUE. The Montoya index (INDIC-SEDUE) was the first to be developed and applied in Mexico and Jalisco [47]. It was based on the work of Dinius in 1972; it is made up of 18 physicochemical and microbiological parameters, uses functions for generating the sub-indexes, assigns weights from 0.5 to 5 on a scale of relevance, additive aggregation formulas, and considers six water uses. CONAGUA used the INDIC-SEDUE to evaluate water quality at the national level between 1990 to 2001 [27] León Index.

The Mexican Institute of Water Technology adapted the model proposed by Dinius (1988). The León index considers 15 water quality parameters, uses functions to generate the sub-indices, weights between 0 and 1, multiplicative aggregation formulas. This index classifies water uses into five groups: drinking water, agriculture, fishing and aquatic life, industrial, and recreational [27].

CONAGUA currently determines water quality in Mexico through surface and groundwater monitoring networks. There are 3,493 monitoring sites for surface water and 1,068 for groundwater. The analysis of surface water quality considers eight indicators: BOD5, COD, TSS, fecal coliforms (FC), Escherichia coli (E COLI), Enterococci (ENTEROC), oxygen saturation percentage (OD%), and toxicity (TOX). The results of these indicators are integrated to determine three colors: green, yellow, and red CONAGUA, 2021) [49]. Failure to comply with one or more of the BOD_5, COD, TOX, and ENTEROC indicators automatically qualifies the water as red, classifying it as polluted or heavily polluted. For groundwater, fourteen indicators are considered: fluorides (F^-), fecal coliforms (CF), nitrate-nitrogen (N-NO3), total arsenic (As), total cadmium (Cd), total chromium (Cr), total mercury (Hg), total lead (Pb), alkalinity (ALC), conductivity (CONDUCT), hardness (DUR), total dissolved solids (TDS), total manganese (Mn) and total iron (Fe). Failure to comply with one or more of the indicators of F-, CF, $N\text{-}NO_3$, As, Cd, Cr, Hg, and Pb automatically qualifies the water as red [49].

The water quality index for specific uses is determined with the historical information available from the monitoring networks to assess the degree of contamination and, if necessary, restoration measures. An example of this is the Santiago River index (SGR-WQI), developed as an integral part of the study carried out for the restoration and protection of the aquatic life of this river and proposed as a calculation methodology [50]. The index was developed based on 11 years of data from 13 monitoring stations. It is based on the NSF index and the CCME criteria. The methodology includes Principal Component Analysis (PCA) and consideration of the maximum permissible limits reported in Mexican regulations for selecting 17 parameters with the highest relevance for the intended use. In the generation of sub-indices, rating curves were developed based on the historical distributions and considering the permissible limits of these parameters. Subsequently, the weighting is assigned using multivariate statistical methods (PCA and Discriminant Analysis). Aggregation is performed using the additive method [30, 50].

Most of the methodologies used for developing and determining WQIs for the specific uses of public supply, agricultural irrigation, and protection of aquatic life have been based on the Dinius, NSF, and CCME models. Statistical methods based on Principal Component Analysis (PCA) and Pearson correlations were considered to reduce the subjectivity of traditional methodologies [42, 44, 30].

3.4. Water quality indicators in Colombia

In Colombia, there is also a great variety of indicators proposed to measure the quality and contamination of water. It was proposed by several authors that include multivariate analysis methods of principal components by using mainly in monitoring of the oil industry [51-52]. Also, these include indicators of contamination by mineralization -ICOMI-, by organic matter -ICOMO-, by suspended solids -ICOSUS-, by trophy -ICOTRO-, by temperature -ICOTEMP-, by pH -ICOpH [53], as well such as the creation of specific indicators for oil activity [54]. Among which the Aromatic Hydrocarbon Pollution Index in fish and sediments-ICOARO, the aliphatic hydrocarbon contamination index in pees and sediments-ICOALRE, the Pollution index by unresolved aliphatic hydrocarbons in fish-ICOALNORE-P [53].

Currently, the Institute of Hydrology, Meteorology and Environmental Studies-IDEAM- as the government entity in charge. This Institution adopts a system of water indicators to explain the status of the quantity and quality of water [55]. At the same time, includes indicators associated with the natural regime (Aridity index IA, water retention and regulation index -IRH, to anthropic intervention (IUA water use index, vulnerability index to shortage IVH, the Potential Threat index due to alteration to water quality-IACAL and index of Water Quality-ICA.

The Water Quality Index -ICA- is a numerical expression obtained from a calculation formula that includes the weighting of six parameters: dissolved oxygen -OD- Total suspended solids -SST, Chemical Oxygen Demand - COD, Electrical Conductivity-CE, Nitrogen Total and pH [56-57]. Each variable is calculated using reference equations that enter the concentration of the water quality variable in the corresponding functional curve to estimate its corresponding value [58].

The Index of Potential Alteration of the Quality of the Water (IACAL) is also a numerical value that qualifies in one of five categories. The existing ratio between the pollutant load in a hydrographic subzone, in a period of time and the surface water supply for mean year and dry year [58] and indicates the vulnerability to contamination to which a hydrographic subzone may be subjected.

The indicator is calculated from variables such as Biochemical Oxygen Demand -DBO- Chemical Oxygen Demand (COD), Total Suspended Solids (SST9, Total Phosphorus (PT) and Total Nitrogen-NT [55-58].

Likewise, the monitoring of the average of Total Phosphorus, Total Nitrogen, Dissolved Oxygen, Hydrogen Potential and Total Suspended Solids is used [58].

3.5. Specific uses of indices

In developing an index, it is necessary to consider their specific purpose since the different objectives will lead to a diverse selection of parameters and permissible threshold concentrations. Some indices currently do not consider the end-use of water, which are commonly used, and those where water is directed to a specific type of demand such as drinking, recreation, irrigation, etc. Among the indices reviewed, those are developed to applicate into specific water uses include: RWQI [59], the Nagels Index [60], the ICB [61], and the index for Colina Lake in Mexico [39] which assess suitability for recreational use of freshwaters. UWQI [62] and the Bhargava Index [63] used to determine the suitability of drinking water supplies; IWQI [64], and the Misaghi Index [65], allow water to be evaluated for agricultural irrigation use. The CCMEWQI, which uses standards as a benchmark, estimates the general water quality and different specific uses, such as agricultural use, water supply, recreational, protection of aquatic life among others [66, 67].

3.6 Different methodologies in water quality indices

In the selection and weighting of parameters of traditional indices, usually, the Delphi methodology is used. However, statistical methods such as Principal Component Analysis (PCA), Factorial Analysis (FA), and Hierarchical Cluster Analysis (HCA) have been used to reduced subjectivity in several studies [68-69,42,64,30,70-71], as they allow to group parameters that have similar characteristics and thus reduce the number of parameters for the index.

The Analytical Hierarchy Process (AHP) is a multicriteria, mature, easy-to-understand, and implement decision analysis method. Studies such as those of Misaghi et al. (2017) have used this method to establish the weights of parameters (individual and grouped) in the water quality index. In the case of the CCMEWQI, to address the increased contribution of frequency to the final value, studies have been made modifying its original aggregation formula [72]. Finally, fuzzy logic allows combining qualitative and quantitative data, so that researchers have used this approach to develop new water quality indices [73-76].

4. CHALLENGES AND PERSPECTIVES OF THE USE OF WATER QUALITY INDICATORS

The use of indicators to visualize the quality of a body of water has great advantages, among other aspects, to show the temporal and spatial variation of quality, identify quality trends and visualize contamination problems, as well as prioritize areas for evaluations, more detailed and help to define priorities for integral water management purposes. However, they are still not enough to reflect the complexity of the phenomena and give a more precise vision of the state of the water.

The use of various statistical methods, as well as the inclusion of qualitative and quantitative parameters weighting, contribute to reduce the subjectivity of the indicators, but they are still insufficient to reflect the state of water quality.

At a general level, the indicators have evolved over time, and the trend includes integrating variables that allow not only the use of physicochemical parameters, but also, biological parameters and recently hydromorphological indices such as those established by the Water Framework Directive –DMA. Moreover, the integration of biological indicators, it is also necessary to have indicators for different approaches to water quality: planning, statistical and use indicators, among others.

Among the challenges to be achieved is to obtain indicators that reduce or eliminate subjectivity in such a way that they allow to assess the real state of the water, diagnose, and carry out adequate planning aimed at protecting and recovering the ecosystems dependent on these water bodies.

5. CONCLUSIONS

Concluding this review, it is recognizable that to date, there is difficulty in defining a single water quality index as a definitive solution. Biological and physicochemical evaluations are necessary and are not interchangeable, insofar as the biological evaluations show the degree to which the ecological balance has been disturbed, meanwhile, the physicochemical variables show the chemical measurement of the concentrations of the pollutants used to identify the sources. However, institutions, agencies, as well as water safety researchers, should try to develop an unique method.

Developing, arranging and maintaining an index can be costly and time consuming, yet it is the best opportunity to succeed in water management and administration.

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