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A review of water quality index (WQI) assessment methods

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Abstract
The assessment of water quality is of paramount importance in ensuring the health and sustainability of aquatic ecosystems and safeguarding human well-being. The Water Quality Index (WQI) has emerged as a comprehensive and effective tool for quantifying the overall quality of water by integrating multiple physicochemical, biological, and ecological parameters. This review aims to provide an in-depth analysis of the Water Quality Index as a valuable metric for evaluating water quality, its development over time, its application in various contexts, and its limitations. This review seeks to contribute to a deeper understanding of the Water Quality Index's utility, accuracy, and relevance in modern water quality management practices. Ultimately, this review underscores the vital role of the Water Quality Index in aiding policymakers, researchers, and environmental practitioners in making informed decisions to protect and improve water resources worldwide.

Keywords: WQI, Sustainability, Ecosystem, various parameters

Introduction

Water, often referred to as the "lifeblood of our planet," is an indispensable resource for all living organisms. It plays a pivotal role in sustaining ecosystems, supporting human societies, and driving economic activities. Water is a vital natural resource crucial for various sectors like agriculture, industry, power generation, economic advancement, societal well-being, and individual health [1]. However, the quality of this precious resource is under constant threat due to various natural and anthropogenic factors. Regrettably, various regions around the globe encounter issues of contaminated drinking ground water sources and declining surface water quality stemming from diffuse and diverse pollution source [2]. Degrading water quality reduces the available clean water supply while demand remains high. Humans have developed treatment processes, but animals lack such options. Many water bodies now serve as both freshwater sources and untreated wastewater disposal points, causing mass contamination and disrupting aquatic ecosystems. It is estimated that nearly two-thirds of all nations will experience water stress by the year 2025 [3]. This predicament, a blend of environmental and human health concerns, is exacerbated by human-induced factors and intertwined natural processes such as hydrology, topography, climate, precipitation, and geological features [4]. Its degradation due to factors like population growth and industrialization has led to the need for assessing its quality through comprehensive management strategies.

Water Quality Index (WQI)

To effectively assess and manage the quality of water bodies, scientists and environmentalists have developed a vital tool known as the Water Quality Index (WQI). It helps in monitoring, managing, and improving water resources by providing a clear picture of water quality conditions, highlighting areas of concern. The WQI is a quantitative and comprehensive measure used to evaluate the overall health and suitability of water for various purposes, including drinking, industrial use, agriculture, and aquatic ecosystems. The primary purpose of a WQI is to provide a simple and accessible way for researchers, environmentalists, to assess and the state of water quality in a particular given area for communicating water quality conditions, helping to guide actions aimed at improving and protecting water resources.

The Water Quality Index (WQI) was first developed by Horton [5] and presents a mathematical method of calculating a single value to represent water quality from multiple water quality parameters.

WQIs consider a range of water quality parameters, which can include physical properties (e.g., temperature, turbidity), chemical constituents (e.g., pH, dissolved oxygen, nutrients, heavy metals), and biological indicators (e.g., presence of specific organisms or species) into a single numerical value, making it accessible and understandable to a wide range of stakeholders, from policymakers to the general public [6].

WQIs may incorporate specific thresholds or water quality standards established by regulatory agencies or international bodies. Exceeding these standards can lead to a lower WQI score.

These indices undergo five stages of development, including parameter selection, sub-index generation, weight assignment, sub-index aggregation, and classification schemes. Recent efforts focus on improving WQIs to enhance accuracy, reliability, and acceptance while reducing subjectivity in their development. By simplifying and summarizing water quality data, WQIs provide an effective means for managing and safeguarding water resources. Water Quality Index also includes the protection of human health, aquatic ecosystems and wildlife. This study reviews various water quality indices, parameter sets, and advantages/disadvantages which are used worldwide.

Different methods for WQI determination

Horton developed the first WQI model in the 1965 based on 10 water quality parameters like sewage treatment, dissolved oxygen (DO), pH, coliforms, electroconductivity (EC), carbon, chloroform extract (CCE), alkalinity, chloride, temperature and pollution for rating water quality through index numbers, offering a tool for water pollution abatement, since the terms “water quality” and “pollution” are related. After the proposed WQI method by Horton, the numbers of WQI methods have been developed for various purposes by numerous organizations across the globe, such as the National Sanitation Foundation Water Quality Index (NSFWQI) [7], Scottish Research Development Department (SRDD) [8], River Status Index (RSI) [9], Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) [10], British Columbia Water Quality Index (BCWQI) [11], Overall Index of Pollution (OIP) [12], Oregon Water Quality Index (OWQI) [26], Bhargava Method Water Quality Index (BMWQI) [14] Malaysia Water Quality Index (MWQI) [15], Water Contamination Index (WCI) [16], Vaal Water Quality Index (Vaal WQI) [17], etc.

Measuring the Water Quality Index (WQI)

It involves a systematic assessment of various water quality parameters to generate a numerical value that represents the overall quality of a water body. The specific methodology for calculating WQI can vary, but here is a general process commonly used:

Selection of Parameters

A set of water quality parameters to be measured are identified and selected. Parameter selection is crucial, where variables are chosen based on both management objectives and environmental characteristics. These parameters typically fall into three categories: Physical, Chemical, and Biological. Examples include temperature, pH, Dissolved oxygen, Turbidity, Nutrient concentrations (e.g., nitrogen and phosphorus), Heavy metals (e.g., lead, mercury), and indicators of Biological health (e.g., faecal coliform bacteria) [18].

Data Collection

Data is gathered for each selected parameter through water sampling and laboratory analysis. The frequency and locations of sampling may vary depending on the objectives of the assessment, but they should be representative of the water body being evaluated. The result is a non-dimensional scale, and subindices are generated to quantify and represent water quality effectively.

Parameter Normalization

Data is normalized for each parameter to bring them onto a common scale using various statistical approaches. This is typically done to ensure that parameters with different units and measurement ranges can be combined into a single index such as ppm, saturation, or percentage. Normalization often involves transforming the data into a range of 0 to 100 or a similar scale [19].

Weighting

In water quality assessment, weights are assigned to each parameter based on its relative importance in determining overall water quality. The weighting process reflects the significance of each parameter for the intended use of the water (e.g., drinking, swimming, ecological health). Parameters with greater importance receive higher weights [20]. Expert opinions are often sought to assign these weights, considering guidelines set by international and national agencies for drinking water quality [21].

Sub-Index Calculation

Sub-indices for each parameter is calculated using the normalized data and their respective weights. The sub-indices reflect the quality of each individual parameter. Aggregation of sub-index values is done to obtain the final. To enhance accuracy and reduce subjectivity, statistical techniques like factor analysis (FA), principal component analysis (PCA), discriminant analysis (DA), and cluster analysis (CA) are employed in some indices. These approaches help refine the index by objectively identifying the most influential parameters, thereby improving the assessment's reliability and robustness.

Overall WQI Calculation

All the sub-indices are combined to calculate the overall Water Quality Index. This can be done using various mathematical methods, such as the arithmetic mean, geometric mean, or weighted sum, depending on the chosen WQI model.

Classification

Overall WQI value is classified into different water quality categories or classes. These classes can range from "Excellent" to "Poor" or use a numerical range to indicate the water quality status.

Communication

Calculated WQI value is communicated and its associated water quality class in a format that is easily understandable to the target audience. This often involves using Color-coded maps, Graphs, or Verbal descriptions.

Water Quality Index in India

Water Quality Index (WQI) in India, like elsewhere, relies on collecting 500 mL-1000 mL samples from various sources such as tap water, wells, rivers, lakes, and groundwater to assess drinking water quality. For industrial water, effluent and treated wastewater samples are analysed to ensure compliance with environmental standards. Due to regional variations, it's essential to assess water quality on a location-specific basis.

The Government of India has set an ambitious goal of providing clean and piped drinking water to all Indian households by 2024 through the Jal Jeevan Mission, announced in 2019. This target is challenging given the current water availability situation. To ensure water quality, the Water Quality Index is instrumental in assessing water quality across India. If the water quality falls below acceptable standards, appropriate measures can be taken to purify and treat the water. This index is crucial in ensuring safe and accessible drinking water, aligning with the government's commitment to improving water quality and accessibility for all citizens.

In a 2019 study conducted by the Bureau of Indian Standards (BIS), the quality of piped drinking water in Indian cities was assessed using 19 parameters, under the guidance of the Ministry of Consumer Affairs Food and Public Distribution. The study revealed that the Bombay Municipal Corporation provided the highest quality water in India, while Delhi ranked the lowest, with none of its samples meeting BIS standards. Cities like Hyderabad, Bhubaneshwar, Ranchi, Raipur, and Amravati followed closely behind Mumbai in terms of water quality, while Delhi, Kolkata, Chennai, Dehradun, and Jaipur had the poorest water quality.

Furthermore, a report from the World Bank highlighted a significant issue of Non-Revenue Water in India, accounting for more than 40% of good quality water being lost before reaching consumers. This problem not only represents a substantial waste of resources but also exacerbates issues such as water contamination, water theft, and more, primarily due to pipe leakages. Addressing these challenges is crucial not only for public health but also for the overall economy of the country, as efficient water management is essential for sustainable development [22].

Merits and Demerits of Water Quality Index

Merits of the water quality index [23]

The development and utilization of water quality indices offer numerous advantages in managing and communicating information about water quality.

Simplicity

WQI simplifies complex water quality data into a single number, making it easier for policymakers, researchers, and the general public to understand the overall condition of water bodies.

Communication

It provides a simple and effective way to communicate water quality information to the public, which can be crucial for raising awareness and promoting action.

Comparability

WQI allows for the comparison of water quality across different locations and time periods, facilitating trend analysis and identifying areas that may require attention.

Multi-parameter assessment

WQI considers multiple parameters such as pH, dissolved oxygen, turbidity, and pollutant concentrations, providing a holistic view of water quality.

Decision-making

It can aid decision-making processes related to water resource management, pollution control, and environmental protection.

Demerits or Limitations of the water quality index [24, 25]

Simplification oversimplifies

While simplicity is a merit, it can also be a demerit because it reduces the complex nature of water quality to a single number, potentially oversimplifying the true state of water quality.

Weighting and index formula

The calculation of a WQI involves assigning weights to different parameters, and the choice of weighting can be subjective. Different formulas can yield different results, leading to potential bias or misinterpretation.

Data availability

WQI calculations require data on various water quality parameters, and in many cases, such data may be limited or unavailable, making it challenging to compute an accurate index.

Limited biological parameters

WQI primarily focuses on physical and chemical parameters, which may not adequately reflect the ecological health of aquatic ecosystems. Biological parameters like the presence of specific indicator species can be crucial but are often excluded.

Temporal and spatial variability

Water quality can change rapidly over time and space. A single WQI value may not capture these fluctuations adequately.

Subjectivity

The interpretation of WQI values and the classification of water quality categories can vary among individuals or organizations, leading to inconsistencies in assessments.

Lack of predictive capability

WQI provides a snapshot of current water quality but doesn't predict future changes or address the root causes of water pollution.

In summary, while a Water Quality Index is a useful tool for summarizing and communicating water quality information, it has limitations, particularly in its simplification of complex systems and the subjectivity involved in its calculation and interpretation. It is essential to consider these merits and demerits when using WQI to make informed decisions about water resource management and environmental protection.

Conclusion

It's essential to note that different regions and organizations may use different WQI models and parameters depending on local water quality objectives and available data. The specific calculation method and parameter selection should align with the goals of the assessment and the regulatory or management framework in place. Regular monitoring and assessment using the Water Quality Index are vital for ensuring the health of aquatic ecosystems, protecting public health, and guiding water resource management decisions.

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