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A Study on Traditional Water Quality Assessment Methods

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Abstract

Water quality has been damaged in countries with abundant water resources. They often have significant pollution levels in the rivers. The three most prevalent anthropogenic activities are industrial regions, sewage, agriculture, and animal husbandry. Water pollution can also result from natural calamities like floods and the illegal disposal of chemical waste. Water pollution harms human health, the environment, society, the economy, and wildlife. Hence, water quality assessment is crucial for reducing challenges associated with or caused by water pollution. This study delved into reviewing different traditional water quality assessment methods to identify the most advantageous one. The traditional water quality assessment methods are the single-factor assessment method, numerous pollution index, comprehensive pollution index method, principle component analysis, fuzzy comprehensive evaluation method, and water quality identification index. The strengths and weaknesses of all these methods were examined, and it was discovered that the water quality identification index would be more plausible; however, it is costly.

Keywords: Water, Water pollution, Water quality, Assessment methods, Traditional water assessment.

1 | Introduction

The decline in water quality is a major global challenge that keeps getting worse. Governments, businesses, non-profit organizations, and the general public should all take this harmful issue seriously because water makes up 70% of the globe and more than 60% of the human body [1], [2].

Water that is clean and safe is essential for drinking, domestic use, industry, and health, as dirty water and inadequate sanitation can spread diseases like cholera, diarrhea, hepatitis, skin infections, typhoid, and other health hazards [3]-[5]. It is essential to note that wastes generated from homes, businesses, farms, and public transportation do contaminate water [6]. As a result, citizens' health using polluted water is negatively

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impacted [6], [7]. Water is utilized for washing, drinking, farming, and industrial processes. Aquaculture ecosystems and human health are at risk from contaminated water; thus, it must be safe and clean.

It is mainly caused by cities rising and their populations increasing, endangering drinking water supplies, human and ecological health, and future economic growth [8]. Because surface waterways are easily accessible for wastewater disposal, they are particularly susceptible to contamination [9]. Both natural processes (such as soil erosion and chemical weathering) and human inputs (such as agricultural runoff and the discharge of industrial and municipal wastewater) contribute to the degradation of water quality [10]. Sustainable water resource use in terms of ecosystem health and socioeconomic development, which, more crucially, establishes the groundwork for the prevention and management of surface water pollution, requires a practical and trustworthy evaluation of water quality [7], [11].

To successfully tackle issues surrounding water quality, there is a need to provide a detailed assessment of the water quality challenge and its root causes [12]. A large body of research has examined water quality deterioration using various evaluation techniques during the last ten years. For instance, Huang et al. [13] demonstrated that the main river channel of the Qiantang River had superior water quality than its tributaries using a fuzzy comprehensive assessment and multivariate statistical approach. Similarly, Massoud [14] used the Water Quality Index (WQI) approach to assess the degree of water contamination in the Damour River (southern Lebanon). The findings showed that human activity along the Damour River affected water quality [12].

Similarly, Xu [15] introduced the Complete Water Quality Identification Index (CWQII), a novel instrument for the overall evaluation of surface water quality. The water quality in Taizi River was assessed by Fu et al. [16] in China using the CWQII technique; the findings showed that the water quality declined between 2019 and 2022. The CWQII values of Honghu Lake (China) were also measured by Ban et al. [17], and it was revealed that CWQII increased between 2011 and 2015 and maintained a balance between 2016 and 2021. IT indicated that the water quality had progressively improved since 2016 due to water protection measurements conducted by the local government in 2014. This study entails the review of different traditional water quality assessment methods to identify the most advantageous one.

2 | Literature Review

2.1 | Review of Traditional Methods Used for Water Pollution Monitoring

Water quality has been damaged in countries with abundant water resources due to rapid industrialization, urbanization, and population increase. They often have significant pollution levels in the rivers. The three most prevalent anthropogenic activities are industrial regions, sewage, agriculture, and animal husbandry [18]. Water pollution can also result from natural calamities like floods and the illegal disposal of chemical waste [19].

Water pollution is an evil that may harm people's health, as well as the environment, society, economy, and wildlife. Water quality monitoring is crucial for reducing problems with water pollution, and the best way to offer early evaluations of toxins in water is through a water quality monitoring system [20].

The government typically monitors water quality, with assistance from the business sector, in many industrialized nations such as the United States, the United Kingdom, Malaysia, Germany, Japan, China, and others. It includes weekly groundwater inspections of rivers and lakes [11]. Some of these nations will face a water crisis by 2025 if the significance of good water management is not sufficiently understood [21]. Because 79% of people in ten Southeast Asia and the Pacific countries use groundwater, it is one of the most essential household drinking water sources. However, there are common concerns about pollution from improper sanitation, which can result in shortages during the dry season, among other things [22].

Furthermore, physical, chemical, and biological qualities can be used to identify pollutants that cause water contamination. Chemical parameters include pH level, ammonia, salinity, hardness, organic compounds, metals, Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and so on [23]. Among their biological characteristics are viruses, bacteria, and algae. Turbidity, temperature, color, taste, odor, suspended particles, and metals are examples of physical attributes. It is crucial to consider specific water quality characteristics to assess whether water is suitable for human consumption and ecosystem health.

Based on the National Water Quality Standards (NWQS), the WQI is used to assess the water quality and show the degree of contamination. DO, Total Suspended Solids (TSS), ammonia, COD, BOD, and pH value are the water quality parameters that are used to calculate the WQI [24], [25].

WQI is measured through different water quality parameters. The commonly used parameters are discussed as follows:

pH of water: this specifies how acidic or alkaline the water is. The acidic range lies between 0 and 6, while the alkaline range lies between 8 and 14. 6.5–8.5 is the most acceptable range of pH. It is measured through electrometry and pH electrodes. It significantly correlates with Electrical Conductivity (EC), Total Hardness (TH), sulfates, and TSS [26].

Turbidity of water: this is the measurement of nonfilterable, divided solids in the water. It may also interfere with the treatment of water. It is primarily measured in Nephelometric Turbidity Units (NTUs). It is measured through a nephelometer or turbidimeter. It correlates significantly with hardness, EC, sulfates, Total Dissolved Solids (TDS), and COD [27].

Temperature: this is one of the most critical parameters, and it considerably affects aquatic life. It also affects gas transfer rates and the amount of DO. It may alter the form of some of the elements or their concentration. It is mainly measured in Celsius. Its measurement is carried through a thermistor or thermometry in the field. It is highly correlated with EC and loosely associated with pH [28].

Chloride (Cl): it is naturally present in water, and while its excess is not normally harmful to humans, the water's taste grows towards the saltier range if it increases to more than 250 mg/l, which may be detrimental to agricultural activities. It is mostly measured through titration and measured in mg/l. It is highly correlated with TH, EC, TDS, and biological and COD [29].

EC indicates the water's potential to conduct electric current. It is not directly applicable in terms of water quality. Nevertheless, it helps more in terms of water's ionic content, which in turn determines the hardness, alkalinity, and some of the dissolved solids. The conductivity varies with the water source and is also correlated with pH, temperature, turbidity, chlorides, sulfates, DO, TDS, and COD. It is measured through the electrometric method [28].

Dissolved oxygen (DO): this indicates oxygen's solubility in water. Water primarily absorbs oxygen from the atmosphere or produces it through photosynthesis. It is pretty essential for aquatic life. It is mainly measured through an electrometric meter or Winkler titration. It is highly correlated with EC, BOD, and sulfates [30].

Total Hardness (TH): this is an important parameter to determine water's suitability for domestic and industrial use. It is primarily the amount of concentrations of calcium and magnesium present in the water. Their concentrations in rocks lead to significant hardness levels in water. It significantly correlates with pH, turbidity, chloride, TDS, and biological and COD. It is measured through titration with EDTA and in mg/l CaCO3 [26].

Total Solids (TS): this is the amount of suspended and dissolved solids in the water. It indicates the remains in the water, such as sulfur, phosphorus, calcium, etc. It is measured using the gravimetric (dried at stated temperature) method and in mg/l [27].

Total Suspended Solids (TSS): this is the amount of remains of inorganic and organic solid material suspended in the water. The increase in TSS makes the water prone to the high absorption of light, which increases the water temperature and, in turn, decreases the water's ability to hold oxygen. It highly affects aquatic life. It is measured through gravimetric (filtration, with drying at stated temperature) method and measured in mg/l. It significantly correlates with pH and TDS [27].

Total Dissolved Solids (TDS): the amount of remains of inorganic and organic soluble solids in the water. It is highly correlated with salinity, increasing the water's saline. It is highly correlated with turbidity, chlorides, EC, TH, TSS, and COD. It is measured using the gravimetric (dried at stated temperature after filtration) method and in mg/l [26].

Biological Oxygen Demand (BOD): this is the amount of oxygen consumed by biological activities in the water, particularly protozoa and bacteria. If the BOD level is relatively high and surpasses DO, other organisms die due to a shortage of oxygen. It is quite an essential factor in water quality and is significantly correlated with chloride, DO, and TH. It is measured through the incubation technique with oxygen determinations by oxygen meter or Winkler method and measured in mg/l [31].

Chemical Oxygen Demand (COD): this is the amount of oxygen consumed during the breaking down of organic material and during oxidation of present inorganic material. Like BOD, it is also a vital factor representing water quality and is highly correlated with turbidity, chlorides, EC, TH, and TDS. It is measured in mg/l [27] through micro-digestion, colorimetry, and reflux distillation with acid potassium dichromate followed by titrimetric.

Fecal Coliform (FC): these bacteria are found in human and animal waste and mainly originate in the intestines of warm-blooded species. They indicate possible fecal contamination of water. They are measured through the membrane filtration method, and the most probable number is the multiple tube method, which is measured in the number of organisms/100 ml. It is loosely correlated with ammonia and significantly associated with Total Coliform (TC) [30].

Total Coliform (TC): FCs and other similar non-fecal bacteria are mostly found in soil. The total coliforms reflect the possible presence of pathogenic micro-organisms and are correlated with FCs. They are measured through the membrane filtration method, and the most probable number is the multiple tube method, which is measured in the number of organisms/100 ml [32].

2.2 | Comparison of Various Water Quality Monitoring Methods

Water Distribution Systems (WDSs) and treatment plants each have specialized instruments for monitoring water quality to identify impurities and determine if the water is fit for human consumption. Over the past few decades, much research has been done on sensing and monitoring analyses to produce reliable and effective approaches with the least energy and running expenses. Pollution detection tools still have some limitations. Thus, it is necessary to update the present water quality examinations. A Raspberry Pi-based hardware platform was used in the water monitoring system [20] suggested. The system used fuzzy logic for decision-making and a Python framework to create a Graphical User Interface (GUI). Another method [33] employed Wireless Sensor Networks (WSNs) to check water quality in distant locations continually.

Three components comprise the WSN system: a distant monitoring station, a database station, and data monitoring nodes. MATLAB was utilized by the software design to communicate with the remote monitoring station's hardware. Arduino was used to develop a water monitoring system that interfaced with LabVIEW to adjust temperature, turbidity, and pH levels. A GUI shows the data [2]. Bernama [34] installed water quality monitoring sensors in a WDS. Water sources, tanks, and connections are represented as nodes in the WDS system, while boundaries show the pipelines that link the nodes.

The system's implementation might benefit numerous applications, including the health monitoring sector, smart buildings, location, estimate and prediction, and fault detection [34]. The approach may, however, present some challenges, such as the possibility of highly complicated data being acquired, which might result in costly and unpredictable outcomes. Water quality characteristics were detected using a variety of water quality monitoring sensors, and an Arduino board was utilized to interface with the sensors and effectively present the data [35]. In this approach, every sensor's reading value was obtained using Arduino, and the Raspberry Pi received the data via the Internet [35].

Another improvement was made by Taru and Karwankar [2], who created a system that interfaced with LabVIEW and Arduino to improve data-collecting performance. The system was simple to install, use, and adaptable. Khatri et al. [20] established fuzzy logic in decision-making, developing the fuzzy method in MATLAB and calculating the WQI using a Python framework. In addition, optical methods based on light propagation theory are critical for determining the exact locations and times of sewage contaminations in real-time field settings with low costs, a simple procedure, and excellent accuracy outcomes.

By employing optical spectroscopy, one may leverage statistical relationships between the optical characteristics of water samples, such as reflection, refraction, fluorescence, and absorbance spectra, to calibrate and find sewage pollution. For example, vibrational spectroscopy is an optical method employed recently. Infrared (IR) and Raman spectrometers are the devices used in vibrational spectroscopy [36]. Two popular vibration spectroscopy methods for chemical and biological investigation are IR and Raman Spectroscopy, providing quick and easy non-destructive evaluation of several parameters [37]. Because it relies on the sample's physical condition, this method is frequently used to analyze water's liquid and gas phases.

To preserve water quality, a fluorescence spectroscopy approach is also necessary to quickly and accurately identify three common pathogenic bacteria, including K. pneumonia, S. aureus, and E. coli [38]. A UV laser was utilized as an excitation light source to stimulate bacterial dilutions in LIF (laser-induced fluorescence) experiments, and fluorescence emission spectra were simultaneously recorded using a spectrometer. The analysis of several gradients of bacteria concentration in this study demonstrated a strong linear correlation between the bacteria concentration and the fluorescence peak's height. Compared to active E. coli, inactive E. coli does not affect the fluorescence peak location.

Because dormant bacteria cannot grow continuously, there are differences in the peak height of fluorescence. The five key factors that require consideration are salt levels, pH, DO, EC, and water temperature. A wireless multi-sensor system was then presented to monitor the water quality parameters of freshwater aquaculture. This system incorporated an ESP 32 WiFi module and a WiFi Access Point (AP) and displayed the results on the ThingSpeak IoT platform. It was said that data on the EC level was obtained from the EC sensor to determine the salinity level. High-sensitivity sensors were employed to deliver dependable and accurate data. From the perspective of smart sensor aquaculture, the method offers a more straightforward setup and upkeep, a more economical option, simultaneous on-site monitoring, and overall very dependable operation.

3 | Traditional Methods

Water quality may be observed using traditional methods. It is predicated on on-site sample collection and laboratory-performed chemical, physical, and microbiological examination. This approach is labor- and money-intensive [20]. Modern approaches can generate output in real-time, whereas conventional procedures often yield results after a few days. Central Water Commission operates as an example of a traditional technique. Certain places gather water samples within the processing and distribution system, examined in state-of-the-art laboratories. Water quality indicators, including pH, turbidity, and DO, were assessed using lab-based equipment after analyzing raw, filtered, and treated water samples [39].

Errors resulting from field sampling and miscalibrated equipment might cast doubt on results. Aside from that, the sampling method's intricate procedure might make it highly time-consuming. Since human energy is required to complete tasks, the conventional method's drawbacks include its lack of continuity, reliability, and potentially shallow testing frequency [39]. A competent individual typically completes the analytical tasks with high accuracy parameter detection outcomes. In addition, the cost of maintaining laboratory facilities is high [40]. Traditional laboratory techniques are more expensive, time-consuming, and need chemical reagents; they can also not provide measurements in real-time [36]. As a result, the study does not include ongoing system monitoring.

3.1 | Comparing Traditional Methods with Modern Methods

A comparative survey was conducted by Mercy Amrita and Babiyola [41] on the traditional and modern methods for water quality analysis. Since modern techniques can give output data and analyze water quality characteristics in real time, they offer more advantages than conventional methods. Immediate detection of low water quality allows for prompt remediation of unwanted materials in the water. Traditional approaches have the potential to result in delays and human mistakes during procedures [42]. The conventional methods primarily involve collecting and tracking water samples, with laboratory analysis conducted [41]. Mistakes might happen when preparing samples in the lab.

Mercy Amrita and Babiyola [41] determined water quality parameters in conventional ways using the titration technique. Since the titration procedure cannot be completed in a single day, it takes time. The titration technique measures the amount of carbon dioxide in a solution using sodium hydroxide. When ions are exchanged between the H+ ions in the emf and the swollen layer, pH may be measured via potentiometric analysis. When the glass electrode was submerged in water, the outer layer of the glass bulb became hydrated, and the swelling layer developed [41]. The technique for monitoring water quality was created utilizing wireless sensor nodes. Ten parameters were monitored inside node boxes as part of the system, linked to the wireless sensor node via WiFi.

The farmers might get data through an AP. The concerning pattern was used if an issue arose [41]. The manual approach to monitoring water quality in aquaculture is labor-intensive and time-consuming, and it cannot yield consistent findings like the current method, which uses sensors to check water quality parameters more rapidly and with better results. The contents of the water sample may alter due to the laborious and complicated setup, producing less valuable data for tracking water quality [43]. Thus, adding additional sensors can increase the system's ability to monitor water quality, which can assist authorities in promptly improving the water quality.

3.2 | Methods of Monitoring Water Quality in Various Countries

Numerous techniques for monitoring water quality have lately been developed in multiple nations. For instance, Burbery et al. [44] developed a fully automated nitrate monitoring station utilizing an optical sensor, introducing UV optical nitrate sensors on surfaces and groundwater. Based on leaching from agricultural land in New Zealand, the results indicated that most of the variance in nitrate had been detected at or near the water edge, with yearly maxima occurring in late winter/early spring between August and November [44]. In addition, to address problems with regional water quality assessment, [45] developed a novel multistage decision support system with a complicated Multi-Criteria Decision-Making (MCDM).

There were three steps to the system. The initial phase included 21 distinct water quality indicators, excluding temperature indicators, and processed vast amounts of monitoring data using the Probabilistic Linguistic Term Set (PLTS) approach. Regression-based Decision-Making Trial and Evaluation Laboratory (DEMATEL), for example, provided relative weight for the second and third stages that considered the interplay of indicators. A single-factor weight was then balanced to make a combined weight. To offer evaluation results for the last stage, a new LTS measure was presented with an extension of the fuzzy approach. The water quality status of sixteen administrative districts in Shanghai, China, was then examined using the suggested methodology [45].

An extensive study of Lake Palic's water quality was conducted by Horvat et al. [46] in Serbia. Measurements of the water quality were taken for nine years, from 2021 to 2019, as part of the analysis. A seasonal water quality characteristic was identified using Principal Component Analysis (PCA) and machine learning classification techniques; water quality parameters were then determined by fitting a model using multivariate regression [46]. Hasan et al. [47] also utilized the multivariate analytic approach to assess the groundwater quality in Bangladesh's northeast. The method employed multivariate analysis to analyze the water quality of particular pumps and provide significant findings that were impossible with a superficial review of the data.

To meet drinking water requirements, Khatri et al. [48] measured the pollution levels in the Sabarmati River in Gujarat, India, and evaluated the levels of many indicators. The system employed water quality metrics, including pH, turbidity, TDS, alkalinity, hardness, chloride, ammoniacal nitrogen, DO, conductivity, and Biochemical Oxygen Demand (BOD). The correlation analysis matrix demonstrated that these water quality characteristics impacted the fundamental ionic chemistry, especially pH, EC, TDS, K+, Na+, Mg2+, and SO42− [47].

The Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) and the Weighted Arithmetic Water Quality Index (WAWQI) were used to provide an overall result of pollution in the River Sabarmati. The findings showed differences between two indices: the CCMEWQI's water quality ranged from "fair to marginal," while the WAWQI's showed the River Sabarmati was severely contaminated, unfit for human consumption, and in even worse condition during the post-monsoon season [48].

Moreover, heavy metal contaminations were investigated in the water quality of the River Netravati, another river in India [1]. The methodology employed was akin to that of Horvat et al. [46] and Hasan et al. [47], who employed multivariate analysis. 2019, during the pre-monsoon season, water and sediment samples were gathered from 10 places in the Netravati River basin. Following this, hydrogeochemical properties were examined. The hydrogeochemical characteristics of water play a crucial role in identifying the kinds used for irrigation, industry, and residential usage. Environmental indicators and multivariate approaches were used to analyze metal contaminations. The use of environmental indicators indicates the state of the water quality.

The whole WQI approach was used to assess the river's water quality. Ten sample stations' water quality indicators were used to compute WQI. The examination of overall heavy metal concentrations and distributions demonstrated that sediments had a little heavy metal contamination, likely due to increased urbanization and agricultural practices that altered the hydrological regimes of rivers. Aquatic life is seriously threatened by chronic exposure to pollutants, even at low concentrations, since it can alter metabolic processes and the structure of river communities [1].

4 | Findings

4.1 | Strengths and Weakness of Traditional Methods

The strengths and weaknesses of the traditional methods are appraised as follows to help understand the process:

Single-factor assessment method: the maximum membership grade concept guides the determination of this approach [17]. This technique only considers the most significant contributing factor or the most contaminated water quality parameter; as a result, all other factors were not considered in the evaluation results [49].

Weakness: Mei et al. [50] note that DO, chemical and BOD, and numerous other metrics were also severely compromised. Therefore, when several contaminants are contributing, this technique does not correctly portray the total water quality [51], and it is challenging to compare with water quality evaluations from other places that may have distinct pollution challenges [14].

Nemerow pollution index: this method considers the average contribution of all components and the dominating parameter [52], [53].

Weakness: according to Simeonov et al. [54], this approach tends to overemphasize the impact of the maximal evaluation factor, or the most crucial polluting component. Accordingly, the comprehensive score will be raised when one assessment factor's index value exceeds the others [55]. Therefore, there is a chance that the assessment's findings won't match the state of the water's quality overall [9].

Comprehensive pollution index method: Hope et al. [56] state that this technique thoroughly assesses the water quality.

Weakness: Yang et al. [52] argue that the approach's foundation is the idea that every assessment criteria contributes equally to the overall quality of the water, but this idea isn't necessarily realistic in real-world situations [57], [58]. One issue with water quality monitoring is the difficulty in interpreting the vast array of observed variables [58].

Principle component analysis: this method facilitates the interpretation of intricate data matrices, hence improving comprehension of the water quality [8], [59]. This approach offers effective separation for higher water quality categories in addition to taking water quality into account [60].

Weakness: according to Helena et al. [61], two limitations of principle component analysis are its inability to analyze nonlinear data and its disregard for the degree of data dispersion. As a result, according to Shin et al. [10], PCA may not have excellent accuracy and dependability.

Fuzzy comprehensive evaluation method: this method can objectively depict the overall state of water quality and describe the fuzzy nature of classification boundaries for water quality [62], [63].

Weakness: extreme water quality values are overemphasized [64]. In this instance, some data is lost, and it's not always evident what the weighting factor's scientific foundation is [10].

Water quality identification index: when it comes to the thorough field assessment of water quality conditions, the water quality identification index is well regarded for its dependability and remarkable accuracy [65], [66]. According to Dalal et al. [67], it is the most incredible option for figuring out how the water quality in highly contaminated areas is doing. According to Xu [15] and Bu et al. [59], the benefits include:

- *Evaluating general water quality using a set of assessment items.*
- *Comparing general water quality with the same classification and successfully classifying water quality conditions as inferior.*
- *Depicting water quality and assessing the overall water quality conditions both qualitatively and quantitatively.*

The only weakness is that it is costly.

5 | Conclusion

This study delved into reviewing different traditional water quality assessment methods to identify the most advantageous one. The traditional water quality assessment methods are the single-factor assessment method, numerous pollution index, comprehensive pollution index method, principle component analysis, fuzzy comprehensive evaluation method, and water quality identification index. The strengths and weaknesses of all these methods were examined, and it was discovered that the water quality identification index would be more plausible; nonetheless, it is costly.

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