



WATER POLLUTION ANALYSIS

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ABSTRACT –

Water is one of the most vital resources on Earth, second only to air in importance for sustaining life. Although water covers the majority of the planet's surface, only a small fraction is actually usable for human, agricultural, or industrial purposes—making it an incredibly limited and precious resource. Because of its essential role in daily life and across various sectors, it's critical to evaluate the quality of water before using it. Regular monitoring of water sources is also necessary to ensure they remain healthy and unpolluted. Deterioration in the condition of water bodies not only signals environmental degradation but also poses serious risks to ecosystems and human health. In industrial settings, poor water quality can lead to operational hazards and significant economic losses. Therefore, assessing water quality is important from both environmental and economic perspectives. Over the years, standardized methods and protocols have been developed to guide the process of water quality analysis. These include established procedures for sample collection, preservation, and laboratory analysis. This report provides a concise overview of these standard practices, aiming to support researchers and professionals engaged in water monitoring and quality assessment.

Key Words: Water Quality Monitoring, Water Quality Assessment, Water Quality Analysis, Chain of Custody.

1. INTRODUCTION

1.1 What is Water Quality?

Water quality refers to the chemical, physical, and biological characteristics of water that determine its suitability for a particular use. The intended use may include drinking, recreational activities, agriculture, industry, or ecological habitat, each requiring specific water quality standards. For instance, water intended for human consumption must meet stringent guidelines concerning microbial, chemical, and physical parameters, while water for agricultural irrigation may tolerate a broader range of salinity or nutrient concentrations (Chapman, 1996).

The concept of water quality is dynamic and multifaceted, often reflecting the condition of the water in terms of pollution level, mineral content, microbial contamination, and turbidity. In natural water bodies, the quality also influences and is influenced by aquatic ecosystems, playing a crucial role in maintaining biodiversity and ecological integrity (CCME, 2001). Water quality is measured using a combination of physical parameters (such as temperature and turbidity), chemical indicators (like pH, dissolved oxygen, and nitrate concentration), and biological metrics (such as coliform bacteria counts or the presence of indicator species) (USEPA, 2007).

1.2 What is Water Quality Analysis?

Water quality analysis is the systematic process of sampling, measuring, and evaluating the components of water to assess whether it meets the required standards for a specific purpose. These assessments are done using standard procedures and protocols, often outlined by international bodies such as the World Health Organization (WHO), the United States Environmental Protection Agency (USEPA), and in India, agencies like the Central Pollution Control Board (CPCB) and the Bureau of Indian Standards (BIS) (Sargaonkar & Deshpande, 2003).

The primary goal of water quality analysis is to quantify various parameters — such as pH, total dissolved solids (TDS), biochemical oxygen demand (BOD), heavy metals, and microbial load — and compare them against benchmark values to determine suitability. The procedure involves careful sample collection, labeling, preservation, and analytical testing using tools such as spectrophotometers, titrimetric methods, or even more advanced methods like chromatography and atomic absorption spectroscopy (Jaji et al., 2007).

Modern water analysis also integrates remote sensing, GIS mapping, and the development of Water Quality Indices (WQI) that simplify the interpretation of complex data into single-value indicators that describe the overall condition of a water body (Kannel et al., 2007).

1.3 Why is Water Quality Analysis Required?

Water quality analysis serves multiple critical functions, from safeguarding public health to ensuring compliance with environmental standards and facilitating sustainable industrial development. The key motivations for conducting water quality analysis include:

i. Ensuring Compliance with Water Quality Standards

Water analysis ensures that water complies with regulatory standards for various uses. For drinking water, organizations like WHO provide comprehensive guidelines on permissible levels of various contaminants, such as lead, arsenic, and nitrates, that can pose serious health risks even at low concentrations (WHO, 2017). Regular testing helps in preventing the consumption of contaminated water and reduces the risk of waterborne diseases, especially in developing regions (Bhardwaj, 2005).

ii. Monitoring the Effectiveness of Water Treatment Systems

Water quality assessments also help in evaluating the efficiency of treatment plants, filtration systems, and other purification technologies. For instance, a high turbidity or bacterial load in post-treatment samples may indicate a failure in chlorination or filtration systems, necessitating immediate corrective measures (Li et al., 2019).

iii. Evaluating Environmental Impact and Pollution Control

Analyzing water quality is essential for identifying pollution sources, such as industrial effluents, agricultural runoff, and urban sewage, and evaluating their impact on rivers, lakes, and groundwater (Vadde et al., 2018). This is crucial for framing pollution control policies and developing restoration programs for degraded water bodies.

iv. Regulatory and Legal Requirements

In many countries, industries are legally obligated to monitor the quality of effluents they discharge into water bodies. Non-compliance can result in legal penalties, loss of operating licenses, and environmental litigations. In such cases, water analysis serves as a legal document supporting either the regulatory authorities or the polluters, depending on the data integrity maintained through chain-of-custody protocols (USEPA, 2007).

Importance Across Sectors

Public Health

Perhaps the most critical application of water quality analysis lies in the domain of public health. Contaminated water can be a vector for numerous diseases such as cholera, typhoid, hepatitis A, and diarrhea, especially in areas lacking access to treated water. Monitoring and ensuring water quality are thus fundamental to reducing disease outbreaks and improving community health outcomes (Jaji et al., 2007).

Industrial Applications

In industries, water quality can influence product quality, equipment lifespan, and production costs. For example, in the pharmaceutical or food industries, ultra-pure water is required to maintain product standards, whereas in textile industries, water with high hardness or heavy metals can damage machinery and affect dyeing processes. Monitoring quality helps in reducing economic losses and improving process efficiency (Sargaonkar & Deshpande, 2003).

2. PROCEDURES OF WATER QUALITY ANALYSIS

Water quality analysis is a structured process that involves multiple steps, from identifying the purpose of monitoring to delivering validated results. Each step must be conducted with precision to ensure the integrity and usability of the data. The procedures not only help in detecting contamination or compliance but also serve as legal and scientific evidence in regulatory and research contexts. The key components of water quality analysis include parameter selection, sampling techniques, preservation, chain-of-custody, analytical methods, and reporting. Each of these is explained in detail below.

2.1 Selection of Parameters

The first step in water quality analysis is to determine **which parameters** need to be measured. This depends on the intended use of the water—whether for drinking, agriculture, industry, or ecological conservation. For example:

- **Drinking water** must meet stringent microbiological, chemical, and physical criteria defined by standards such as the WHO Guidelines or the Bureau of Indian Standards (BIS 10500).
- **Irrigation water** requires analysis of parameters like pH, sodium adsorption ratio (SAR), salinity, and nutrient content.
- **Industrial water** varies based on the sector but often requires control over hardness, turbidity, heavy metals, and pH.
- **Surface water bodies** (rivers, lakes) are monitored for pollutants, biological oxygen demand (BOD), chemical oxygen demand (COD), and overall ecological health.

Common parameters include:

- **Physical:** Temperature, turbidity, color
- **Chemical:** pH, DO, TDS, nitrates, phosphates, heavy metals
- **Biological:** Coliform bacteria, E. coli, plankton counts

Selection of appropriate parameters ensures that the data generated is relevant and actionable.

2.2 Selection of Analytical Methods

Once parameters are chosen, the next step is selecting the most suitable **analytical methods**. Factors influencing this choice include:

- **Precision and accuracy required**
- **Budget and cost of testing**
- **Available equipment and facilities**
- **Number and type of samples**

Standard methods are often derived from authoritative guidelines such as:

- **APHA Standard Methods for the Examination of Water and Wastewater**
- **BIS, CPCB, and WHO protocols**
- **US EPA-approved analytical techniques**

For example, pH is measured with a calibrated pH meter; turbidity with a nephelometer; metals like lead or arsenic with atomic absorption spectroscopy (AAS) or inductively coupled plasma (ICP) techniques.

2.3 Chain-of-Custody Protocols

To ensure data integrity and credibility—especially for regulatory or legal use—it is essential to maintain a **chain-of-custody (COC)**. COC refers to the documented and secure handling of a sample from collection to analysis and final disposal. The key elements include:

- **Sample Labels:** Proper labeling to identify the source, date, time, and type of sample.
- **Seals:** Tamper-evident seals to ensure the sample is not altered or accessed without permission.
- **Field Logbooks:** Detailed notes including sampling location, method, personnel, and field conditions.
- **Analysis Request Forms:** Accompany the samples to the lab and contain information on tests requested and sample specifics.
- **Documentation:** Waybills and courier records if samples are transported externally.
- **Custodian Logs:** Laboratories maintain logs of receipt, condition, and storage of samples.

Maintaining a complete chain-of-custody record is critical for data validity and traceability.

2.4 Sampling Techniques

Proper sampling is the cornerstone of reliable water quality analysis. Even with advanced analytical equipment, poor sampling can invalidate results. Sampling must meet the following criteria:

- **Representative:** The sample should reflect the true condition of the water body.
- **Reproducible:** The sampling method should yield consistent results when repeated.
- **Defensible:** The method should be well-documented and scientifically valid.
- **Useful:** The sample must provide data relevant to the study's objectives.

Important considerations include:

- **Sampling location:** Strategic selection based on pollution sources, inflow points, etc.
- **Sampling containers:** Should be clean, inert, and appropriate (e.g., amber bottles for light-sensitive samples).

- **Avoid contamination:** Use gloves, sterilized containers, and proper technique.
- **Sample size:** Depends on the number and type of analyses to be performed.
- **Sample types:** Grab samples, composite samples, or flow-proportional samples.
- **Preservation:** Immediate preservation methods such as refrigeration, acidification, or filtration.

2.5 Sample Preservation and Transport

Between collection and analysis, water samples are vulnerable to physical, chemical, and biological changes. Proper **preservation techniques** must be used to retain sample integrity. Preservation depends on the parameter being analyzed. Common methods include:

- **Refrigeration (4°C):** Used for most biological and nutrient samples.
- **Acidification:** For heavy metal analysis (e.g., adding nitric acid to maintain pH <2).
- **Filtration:** To separate suspended solids when needed.
- **Amber bottles:** For samples sensitive to light, such as chlorophyll or pesticides.
- **Freezing:** For long-term preservation of certain organic compounds.

Transport must occur promptly—usually within **24–48 hours**—especially for microbiological analysis. Delays can cause degradation or growth of organisms, leading to inaccurate results.

2.6 Laboratory Analysis

Upon reaching the laboratory, samples undergo **systematic examination**. The lab team must first:

- Inspect the sample condition
- Cross-check COC forms and labels
- Assign a unique sample ID or barcode

Analytical methods are then applied based on the parameters selected. Laboratories may use:

- **Gravimetric and volumetric techniques**
- **Colorimetric analysis**
- **Spectrophotometry**
- **Titration**
- **Chromatography (GC-MS, HPLC)**
- **Atomic absorption or ICP-MS for metals**
- **Microbiological plating and membrane filtration methods**

Laboratories are expected to follow **Good Laboratory Practices (GLP)** and participate in **inter-laboratory comparisons** or **proficiency testing** to ensure quality.

2.7 Data Validation and Reporting

Once analysis is complete, data is reviewed and validated. This involves:

- **Checking calibration logs**
- **Assessing quality control samples**
- **Repeating suspect results**
- **Statistical validation (RSD, standard deviation, etc.)**

The results are compiled in a report containing:

- Sampling details
- Methods used
- Raw and processed data
- Compliance against regulatory standards
- Observations and recommendations

Often, water quality is summarized using a **Water Quality Index (WQI)**—a single numerical value that integrates multiple parameters for easy interpretation.

2.8 Sample Disposal

After analysis, samples are stored for a **holding period** in case reanalysis is needed. Once data is finalized, samples are disposed of according to:

- **Hazard classification**
- **Environmental norms**
- **Internal lab policies**

Hazardous samples (e.g., heavy metals or organics) require special treatment or incineration.

2.3 Precision and Accuracy of Method Selected as per Requirement

In any scientific analysis, particularly in the assessment of water quality, the concepts of precision and accuracy hold fundamental importance. While accuracy refers to how close a measurement is to the true or accepted value, precision denotes the consistency or repeatability of measurements. Both are essential for ensuring the reliability and credibility of water quality data. The selection of methods for water analysis must therefore be guided by the required level of accuracy and precision, which in turn depends on the purpose of the monitoring program, the sensitivity of the application, and the decisions to be made based on the data.

For instance, if water analysis is being conducted for a regulatory purpose, such as compliance with national or international water quality standards (e.g., WHO guidelines or CPCB norms), high accuracy is indispensable. Even slight deviations from the true values may lead to regulatory violations or misinterpretation of compliance status. On the other hand, if the analysis is intended for a preliminary screening, a less rigorous method may be acceptable, provided that it offers reasonable reproducibility. Precision becomes particularly important in trend analysis, where repeated sampling over time is used to observe changes in water quality. In such cases, even if the absolute values are slightly off, consistent precision allows researchers to identify meaningful trends and deviations.

The choice of analytical method—whether manual, instrumental, or automated—should be evaluated for its method detection limit (MDL), limit of quantification (LOQ), linearity, and reproducibility. For parameters like pH and conductivity, simple portable meters can yield precise and accurate results if calibrated regularly. However, for trace metals or pesticide residues, high-end instruments such as atomic absorption spectrophotometers (AAS), gas chromatographs (GC), or high-performance liquid chromatographs (HPLC) are required to meet stringent performance standards.

Moreover, the precision and accuracy achievable also depend on operator training, calibration of equipment, quality of reagents, and laboratory environment. Standard Operating Procedures (SOPs) should be in place to guide each step, from sample handling to data entry, reducing the chance of human error. Laboratories should participate in inter-laboratory comparison programs and undergo regular audits to assess their performance in achieving expected accuracy and precision levels.

Budget constraints can also influence the level of precision achievable. In many resource-limited settings, the balance must be carefully maintained between cost-effectiveness and analytical robustness. In such cases, less expensive but validated field kits may be used for certain parameters like residual chlorine or fluoride, while more critical or sensitive parameters can be sent to certified laboratories for analysis.

In summary, selecting methods based on required precision and accuracy involves careful assessment of monitoring objectives, regulatory needs,

technical capabilities, and economic constraints. It also demands ongoing quality assurance and control measures to ensure that the data generated is both scientifically valid and decision-worthy.

2.4 Chain-of-Custody Procedures

The chain-of-custody (COC) procedure is a critical yet often underappreciated aspect of water quality monitoring, particularly when the data is to be used in regulatory assessments, environmental litigation, or public health investigations. It refers to a formalized, documented protocol that ensures the security, integrity, and traceability of water samples from the point of collection to the final stage of data reporting. A properly maintained chain-of-custody system protects the sample from unauthorized handling, contamination, tampering, or loss, thereby preserving the credibility of the analytical results.

The chain-of-custody begins at the point of sample collection, where the field technician is responsible for ensuring that each sample is accurately labeled, sealed, and documented. Labels must contain essential information such as the sample code, location, date and time of sampling, the name of the collector, and any preservation methods applied. It is crucial that the label remains legible and securely attached throughout the sample's journey. In addition, sample seals—usually tamper-evident tapes or tags—are used to physically protect the sample containers. These seals must be unbroken upon receipt at the laboratory, as any breach could compromise the sample's validity.

Field personnel are also required to maintain a field logbook, a comprehensive record that includes details about the sampling purpose, site conditions, GPS coordinates, weather at the time of sampling, field observations, and contact details of responsible parties. This documentation supports transparency and accountability and becomes particularly vital in case of disputes or reanalysis.

Each sample is also accompanied by a Sample Analysis Request Form or Chain-of-Custody Form, which serves as a control document. This form includes both field and laboratory sections. The field section records information similar to that in the logbook, while the laboratory section captures details such as sample receipt time, condition upon arrival (e.g., temperature, container status), laboratory-assigned sample ID, and the tests to be performed. This form is signed by each individual who handles the sample, thereby creating an audit trail. The form ensures that at every transition point—collection, transport, storage, and analysis—the person taking custody is accountable for maintaining the integrity of the sample.

When samples are transported, especially over long distances or through third-party courier services, additional documentation such as shipping receipts or waybills must be attached to the chain-of-custody form. These records provide proof of transit and help track sample movement. During transportation, care must be taken to maintain the required storage conditions—usually refrigeration in insulated coolers—to prevent any alteration in sample composition. Delays in transport can lead to degradation, especially for microbiological and nutrient parameters, and must be avoided or noted in the records if unavoidable.

Upon arrival at the laboratory, samples undergo initial inspection by a designated sample custodian, who verifies the label and seal condition against the accompanying documentation. Any discrepancies must be immediately reported and resolved before analysis proceeds. Once accepted, the samples are logged into the Laboratory Information Management System (LIMS) or a manual logbook, assigned a unique lab ID, and stored under appropriate conditions until analysis begins.

At the point of analysis, the responsibility of the sample shifts to the laboratory analyst or supervisor. Analysts are trained to handle samples as per SOPs and are responsible for maintaining sample integrity throughout the analytical process. After the required tests are completed, the data is reviewed, validated, and reported as per the laboratory's data quality objectives.

After data analysis, samples are usually retained for a prescribed holding period, depending on the project or regulatory guidelines. Once the retention period ends, samples must be disposed of using environmentally safe methods. Hazardous samples—those containing heavy metals, pathogens, or toxic chemicals—must follow proper waste disposal procedures in compliance with environmental protection regulations.

In conclusion, a well-documented chain-of-custody system provides legal defensibility, data credibility, and scientific reliability. It reduces the risk of sample tampering, ensures accountability, and enhances the integrity of the overall water quality monitoring process. Particularly in the context of regulatory enforcement, court proceedings, and public health emergencies, maintaining an unbroken chain-of-custody is not just best practice—it is a non-negotiable requirement for ensuring the trustworthiness of water quality data.

2.5 Proper Sampling

Sampling is the foundation of any accurate and meaningful water quality analysis. Without appropriate sampling techniques, even the most advanced instruments and sophisticated methodologies can produce misleading or invalid results. Proper sampling involves the systematic collection of water that is truly representative of the source being analyzed—whether it's a river, lake, groundwater well, or industrial effluent. Key factors to consider in sampling include sampling location, frequency, sample type (grab or composite), sampling depth, and timing.

To ensure reliability, sampling procedures must be planned to meet the objectives of the monitoring program. For example, sampling from a river to detect upstream industrial discharge requires strategic placement of sampling points both upstream and downstream. The number of samples and their volume must also be adequate for all the parameters being tested. For microbial analysis, sterile containers are essential, while metal analysis may require acid-washed polyethylene bottles.

There are several critical conditions for proper sampling:

- **Representativeness:** The sample must reflect the actual condition of the water body or effluent. Stagnant zones or uncharacteristic patches should be avoided unless specifically targeted.
- **Reproducibility:** Sampling protocols should be standardized so that different personnel or teams can replicate the process with consistent results.
- **Defensibility:** Detailed documentation should support the sampling procedure to ensure legal and scientific integrity.
- **Safety and contamination control:** Field personnel must use appropriate protective gear and avoid sample contamination through improper handling or cross-contamination between sites.

Ultimately, the sampling process must align with standardized protocols such as those from APHA, WHO, CPCB, or ISO guidelines, ensuring the data produced is valid for both research and compliance purposes.

2.6 Proper Labeling

Labeling is a seemingly simple but critically important aspect of water sampling. Each collected sample must be clearly and permanently labeled to avoid misidentification, cross-contamination, or administrative errors. Improper labeling can result in confusion during analysis or, worse, invalidate the results entirely, rendering them unusable for decision-making.

A proper label should include at minimum:

- Sample identification code (e.g., WQ-01)
- Date and time of sampling
- Sampling location (coordinates or site name)
- Source type (e.g., groundwater, surface water, effluent)
- Preservation method used
- Collector's name and contact

Labels should be waterproof and smudge-resistant, and should be placed securely on the container. In addition to physical labeling, each sample should be recorded in a field notebook or digital log, and corresponding details should match exactly with the chain-of-custody and analysis request forms.

Failing to maintain consistent labeling can lead to data rejection, legal liability (in compliance monitoring), or loss of credibility in research. Hence, meticulous attention to labeling is not just administrative—it is a scientific necessity.

2.7 Preservation

Once collected, water samples begin to undergo physical, chemical, and biological changes almost immediately. Exposure to light, temperature fluctuations, oxidation, microbial activity, and reaction with container surfaces can alter the composition of the sample. Preservation refers to the set of actions taken to slow or stop these changes, thereby maintaining the integrity of the sample until it can be analyzed in the laboratory.

Different parameters require different preservation methods. Some common preservation techniques include:

- Refrigeration (4°C): Used to slow microbial growth and chemical reactions for most general water quality parameters (e.g., nutrients, BOD, COD).
- Chemical addition: For example, nitric acid is added to samples meant for heavy metal analysis to maintain a low pH and prevent precipitation or adsorption.
- Filtration: Used to remove suspended solids, particularly for dissolved constituents.
- Use of opaque or amber containers: To protect light-sensitive analytes (e.g., chlorophyll, certain pesticides).
- Freezing: Employed in select cases where long-term storage is needed, such as for organic compounds.

Preservation must be done immediately after collection, ideally in the field. Holding times—the duration for which a preserved sample remains valid for analysis—vary depending on the parameter and must be strictly adhered to. Improper or delayed preservation can result in inaccurate data, making the analysis unreliable.

2.8 Analysis

The analytical phase is the core of the water quality assessment process. It involves the precise measurement of selected parameters using validated methods under controlled laboratory conditions. The laboratory environment, instruments, and human expertise all contribute to the accuracy, precision, and reliability of results.

Before analysis begins, the laboratory staff inspects the samples to ensure they have been preserved correctly and that seals are intact. Each sample is then logged into the Laboratory Information Management System (LIMS) or a manual registry and assigned a unique laboratory ID. Depending on the parameters, the appropriate standard methods are selected.

Common laboratory techniques include:

- Titrimetry: For chloride, alkalinity, hardness
- Spectrophotometry: For nitrates, phosphates, color, turbidity
- Gravimetric methods: For total suspended solids
- Atomic Absorption Spectroscopy (AAS): For heavy metals such as lead, mercury, and cadmium
- Gas Chromatography (GC) or HPLC: For organic compounds, including pesticides
- Membrane filtration: For microbial parameters like total coliforms and *E. coli*

Strict quality control protocols must be followed, including the use of blanks, standards, and duplicates, as well as routine calibration of instruments. Laboratory analysts must be trained in Good Laboratory Practices (GLP), and periodic audits should be conducted to maintain certification and reliability.

2.9 Reporting

After analysis, the results must be compiled, reviewed, and reported in a clear, accurate, and actionable manner. The reporting phase transforms raw data into useful information for decision-makers, regulatory authorities, or researchers. A proper water quality report includes:

- Basic details: Date of sampling, site location, and purpose of testing
- Methods used: Standard procedures, instruments, and reagents employed
- Results table: Measured values of each parameter along with relevant units
- Standards comparison: Values compared against applicable standards (e.g., WHO, BIS, CPCB)
- Comments/interpretation: Indicating compliance or deviation, potential health/environmental risks
- Signature and authentication: By the laboratory in-charge or an authorized expert

An important tool used in reporting is the Water Quality Index (WQI), which converts complex water quality data into a single numerical score. This makes it easier for stakeholders, including policymakers and the public, to understand the overall condition of the water source. Additionally, results should be archived digitally and physically for future reference, regulatory review, or legal defense if required.

3. CONCLUSION

Water quality analysis plays a pivotal role in ensuring the safe and sustainable use of one of our planet's most essential natural resources. As water is used across diverse sectors—ranging from domestic consumption and agriculture to industrial processing and ecological preservation—it becomes imperative to assess its suitability for the intended purpose. Through a structured and standardized approach involving proper sampling, labeling, preservation, analysis, and reporting, reliable data can be obtained to support informed decision-making. The establishment of precision and accuracy protocols, along with chain-of-custody procedures, safeguards the integrity and traceability of samples throughout their handling. Moreover, by adhering to internationally recognized methods and regulatory guidelines, analysts and researchers can ensure that water monitoring efforts are both scientifically valid and legally defensible. In an era of increasing water scarcity and pollution, such comprehensive assessments are not only beneficial but essential for maintaining public health, protecting ecosystems, and enabling responsible water resource management. This report aims to provide a concise yet practical overview of water quality assessment procedures, contributing to the knowledge base of students, analysts, and environmental professionals engaged in this critical field.

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