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Review Article

A Comprehensive Review Of Water Quality Analysis: Parameters, Analytical Methods, And Emerging Perspectives

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ABSTRACT

Water quality analysis is essential for protecting public health, supporting industrial activities, and maintaining environmental safety. This review discusses different types of drinkable water, including tap, bottled, reverse osmosis, alkaline, and electrolyzed-reduced water. It summarizes major physical, chemical, and biological parameters such as turbidity, pH, total dissolved solids, dissolved oxygen, COD, BOD, bacteria, viruses, and algae. The review also highlights important steps in water analysis, including sampling, preservation, method selection, laboratory testing, and reporting. Common analytical techniques such as spectrophotometry, ion chromatography, atomic absorption spectroscopy, HPLC, electrochemical methods, and microbial testing are described. Special attention is given to alkaline and electrolyzed-reduced water, including their proposed benefits and possible harmful effects. Major limitations include high cost, complex instrumentation, sample instability, calibration requirements, and difficulties in data interpretation. Standardized methods, validated instruments, and proper quality-control practices are therefore necessary for reliable water analysis and safe water management.

INTRODUCTION

Water is a fundamental resource essential for sustaining life, supporting ecosystems, and driving economic activities. However, ensuring the availability of clean and safe water is increasingly challenging due to various anthropogenic and natural factors, including pollution, urbanization, industrialization, and climate change. In recent years, significant advancements have been made in water analysis techniques, driven by the need for more sensitive, selective, and efficient methods for detecting and quantifying contaminants in water. These techniques range from traditional methods such as spectroscopy, chromatography, and electrochemistry to cutting-edge technologies

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such as nanomaterial-based sensors, microfluidic devices, and remote sensing techniques. Each technique offers unique advantages and capabilities for analyzing different types of contaminants, from organic pollutants and heavy metals to pathogens and emerging contaminants. [1]

Water quality analysis is extremely necessary in the sectors of:

- Public Health (especially for drinking water)
- Industrial Use

Key factors of water Analysis :

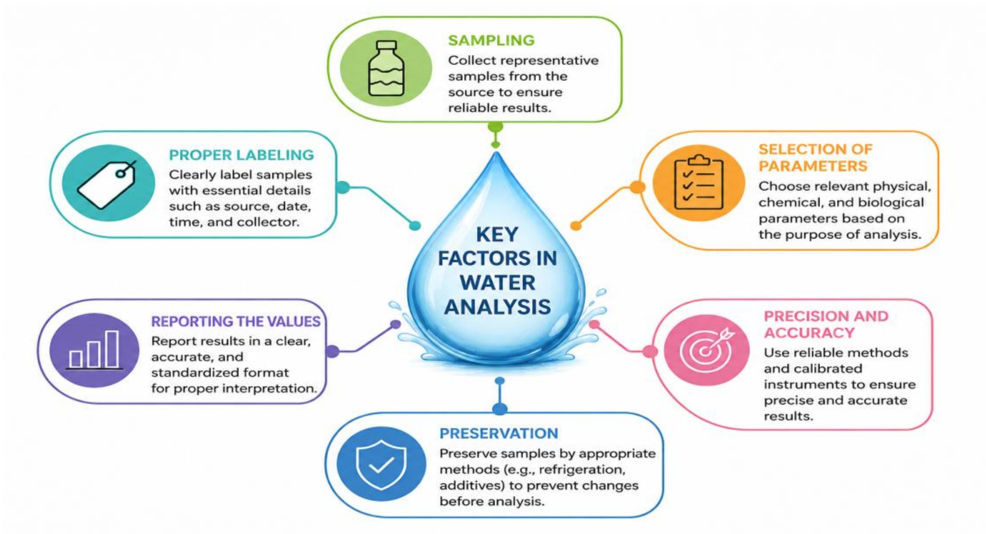

Fig.1 Key Factors of Water Analysis

1.1. Selection of Parameters [2]

The parameters of water quality are selected entirely according to the need for a specific use of that water. Some examples are: Drinking , Irrigation (pH, conductivity, sodium and potassium), Industries, Domestic consumption.

1.2. Selection of method [2]

The methods of water quality analysis are selected according to the requirement. The factors playing key role for the selection of methods are:

I. Volume and number of sample to be analyzed
II. Cost of analysis
III. Precision required
IV. Promptness of the analysis as required

1.3. Precision and Accuracy of method selected as per requirement [2]

What precision and accuracy to be maintained against a particular method is decided according to the objective of the monitoring. The factors influencing this decision includes:

 Budget of Monitoring System

 Parameters to be Monitored

 Use of the Water

1.4. Proper Sampling [2]

Proper sampling is a vital condition for correct measurement of water quality parameters. Even if advanced techniques and sophisticated tools are used, the parameters can give an incorrect image of the actual scenario due to improper sampling.

1.5. Proper Labelling [2]

Proper labeling prevents sample misidentification and ensures the responsibility and accountability of the collector. The sample container should be labeled properly, preferably by attaching an appropriately inscribed tag or label. Alternatively, the bottle can be labeled directly with a water-proof marker. Barcode labels are also available nowadays.

1.6. Preservation [2]

Usually a delay occurs between the collection and analysis of a sample. The characteristics of the sample can be changed during this period. Therefore proper preservation is required in the way to laboratory after collection, and in the laboratory up to when analysis starts.

1.7. Analysis [2]

The samples, after reaching laboratory, are analyzed, according to the requisite parameters, following standard methods and protocols.

1.8. Reporting [2]

The ultimate procedure of water analysis is to prepare a proper report against the submitted requisition. The report must be authenticated before handing over the authority. All data should be kept in the laboratory log and preferably in laboratory database.

2. Types of Drinkable Water

2.1. Tap Water

2.2. Bottled Wate [10]

2.3. Reverse Osmosis (RO) Water [11]

Industrial & Commercial Uses:

(i) Food & Beverage Production
(ii) Pharmaceutical Manufacturing
(iii) Electronics & Semiconductor Fabrication
(iv) Automotive Manufacturing
(v) Textile Industry
(vi) Wastewater Treatment & Recycling

3. Types Of Water Testing

There are various parameters for water analysis or water testing. Water testing is done for the testing of water at a particular level. So that we understood that the water which we used in ourday to day life like drinking water is safe for our health and hygiene or not. See Fig.2 and Table 2

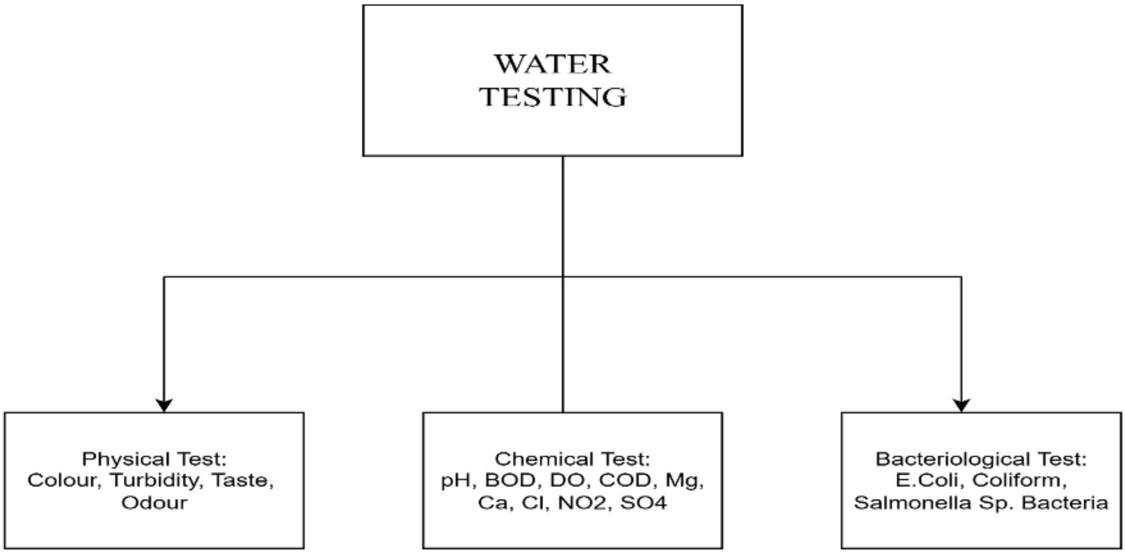

Fig.2 Types of Water Testing

Below given table gives the Detailed parameters of water testing. (See Table 2)

Table:3 Parameters of Water Testing

3.1 PHYSICAL PARAMETERS

3.1.1. Turbidity

Fig.3 Turbidity[12]

3.1.2. Temperature:.[12]

3.1.3. Color

3.1.4. Taste and Odor

TON or TTN = (A + B) / A

where TON is the threshold odor number and TTN is the threshold taste number.[12]

3.1.5. Solids (TDS)

Solids occur in water either in solution or in suspension. This material is usually called total dissolved solids or TDS.[12]

Total solid (TS) = Total dissolved solid (TDS) + Total suspended solid (TSS)

Water can be classified by the amount of TDS per liter as follows:

• freshwater: <1500 mg/L TDS;

• brackish water: 1500–5000 mg/L TDS;

The residue of TSS and TDS after heating to dryness for a defined period of time and at a specific temperature is defined as fixed solids. Volatile solids are those solids lost on ignition (heating to 550°C).[12]

3.2. CHEMICAL PARAMETERS

3.2.1. pH

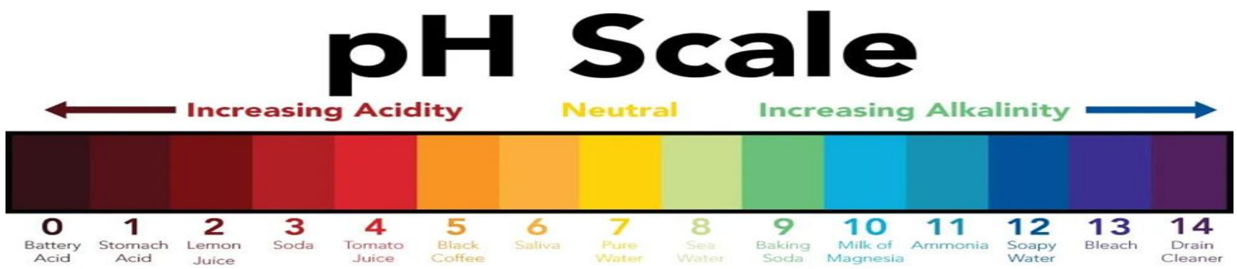

Fig.4 pH scale [13]

3.2.2. Acidity

Acidity is the measure of acids in a solution. The acidity of water is its quantitative capacity to neutralize a strong base to a selected pH level. Acidity in water is usually due to carbon dioxide, mineral acids, and hydrolyzed salts such as ferric and aluminum sulfates..[12]

3.2.3. Alkalinity

The alkalinity of water is its acid-neutralizing capacity comprised of the total of all titratable bases. Alkalinity of water is mainly caused by the presence of hydroxide ions (OH^-), bicarbonate ions (HCO_3^-), and carbonate ions (CO_3^{2-}), or a mixture of two of these ions in water. As stated in the following equation, the possibility of OH^- and HCO_3^- ions together are not possible because they react together to produce CO_3^{2-} ions. [12,13]

$$OH^- + HCO_3^- \rightarrow CO_3^{2-} + H_2O$$

Alkalinity is determined by titration with a standard acid solution (H_2SO_4 of 0.02 N) using selective indicators (methyl orange or phenolphthalein).[14]

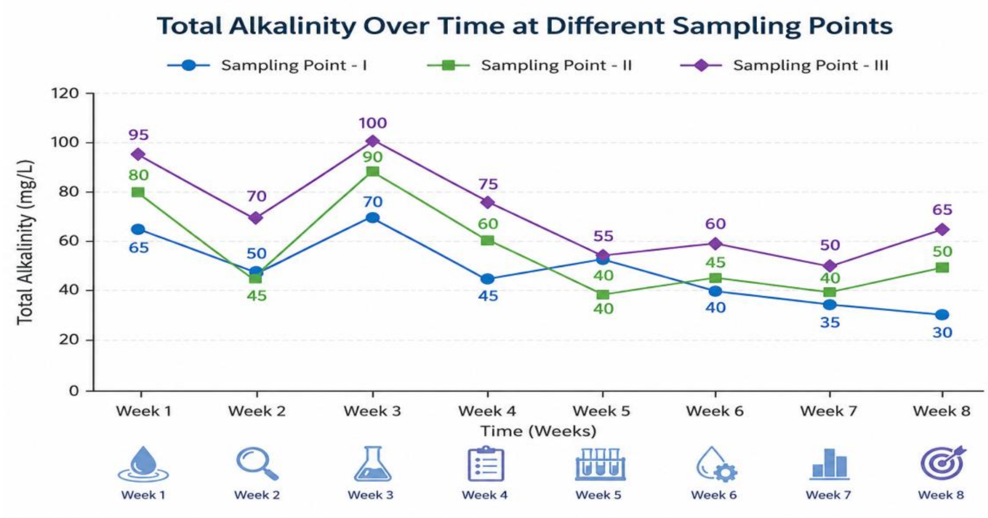

Fig.5 Alkalinity Comparison By Sampling Point

3.2.4. Chloride

Chloride occurs naturally in groundwater, streams, and lakes, but the presence of relatively high chloride concentration in freshwater (about 250 mg/L or more) may indicate wastewater pollution..[14]

3.2.5. Dissolved Oxygen

Dissolved oxygen (DO) is considered to be one of the most important parameters of water quality in streams, rivers, and lakes. For example, the saturation concentration at 20°C is about 9 mg/L and at 0°C is 14.6 mg/L. [15,17]

3.2.6. Chemical Oxygen Demand (COD)

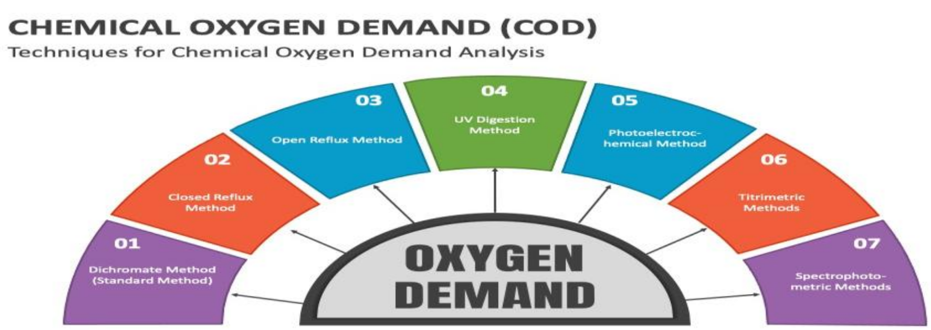

Fig.6 Techniques for COD Analysis

Chemical Oxygen Demand (COD) is a water quality parameter that quantifies the amount of oxygen needed to chemically oxidize organic substances.

COD testing is vital for assessing the quality of wastewater and the efficiency of water treatment processes, as well as for evaluating the potential environmental impact of discharges. The most commonly used method for measuring COD is the Dichromate Method (Closed Reflux Method), which involves the use of a strong oxidizing agent, potassium dichromate ($K_2Cr_2O_7$), in an acidic solution to oxidize organic compounds.[18]

3.2.7. Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) is a critical water quality parameter that measures the amount of dissolved oxygen required by microorganisms to break down organic material in a water sample over a specified period, typically five days (BOD_5).[19]

3.3. BIOLOGICAL PARAMETERS

3.3.1 Bacteria

Bacteria are considered to be single-celled plants because of their cell structure and the way they ingest food [12]

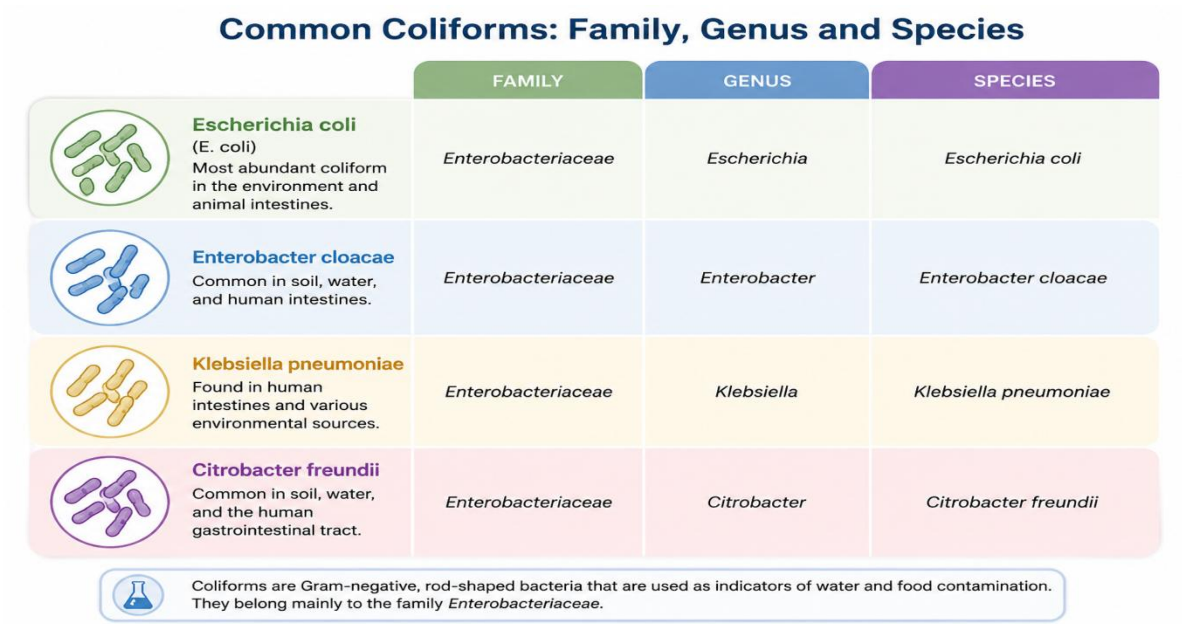

Fig.9 Family, Genera and species of some common coliforms

Bacterial testing in water analysis is essential to evaluate the microbiological quality of water and ensure its safety for human consumption, recreational use, or environmental discharge. One of the most widely used methods to detect bacteria in water is the membrane filtration (MF) method, where a known volume of water is passed through a sterile membrane filter that traps bacteria Bacterial testing plays a crucial role in water quality assessment by identifying potential microbial hazards and ensuring compliance with public health standards.[20]

3.3.2. Viruses

Viruses are the smallest biological structures known to contain all genetic information necessary for their own reproduction. [12]

Testing for viruses in water is a vital component of water quality analysis, particularly for drinking water and recreational waters, as viruses can cause serious diseases such as hepatitis, gastroenteritis, and poliomyelitis. Unlike bacteria, viruses are much smaller, cannot multiply outside a host, and often occur in very low concentrations, making their detection more complex and sensitive. [21]

3.3.3. Algae

Algae are microscopic plants, which contain photosynthetic pigments, such as chlorophyll.

They are autotrophic organisms and support themselves by converting inorganic materials into organic matter by using energy from the sun, during this process they take in carbon dioxide and give off oxygen. [12, 21]

4. Challenges of Water Analysis:

While advanced analytical techniques offer numerous benefits, they also come with challenges and limitations that researchers must consider. Some of the key challenges include:

4.1. Complexity and Cost: [1]

4.2. Data Interpretation [1]

4.3. Method Validation and Standardization

4.4. Instrument Downtime and Maintenance [1]

4.5. Regulatory Compliance [1]

5. Limitations of Water Analysis:

5.1. Instrumentation Limitations: Despite technological advancements, analytical instruments may have inherent limitations in terms of sensitivity, resolution, dynamic range, and detection limits. Instrument performance may vary depending on factors such as sample type, matrix effects, and experimental conditions. [1]

5.2. Data quality and Statistical limitations [22]

5.3. Geographic & Capacity Inequities [23]

6. Alkaline Water

Acidity is most important and ignored reason in development of different diseases like hypertension, skin diseases, hyperthyroidism, hyperlipidemia, cancer, diabetes and related diseases etc. In allopathy physician only work on sign and symptoms of the diseases after performing various expensive diagnosis test like ECG, Kidney function, Blood test etc., but the root of this disease condition is completely ignored. The Natural alkaline water is one the solution to cure root of this diseases.[24]

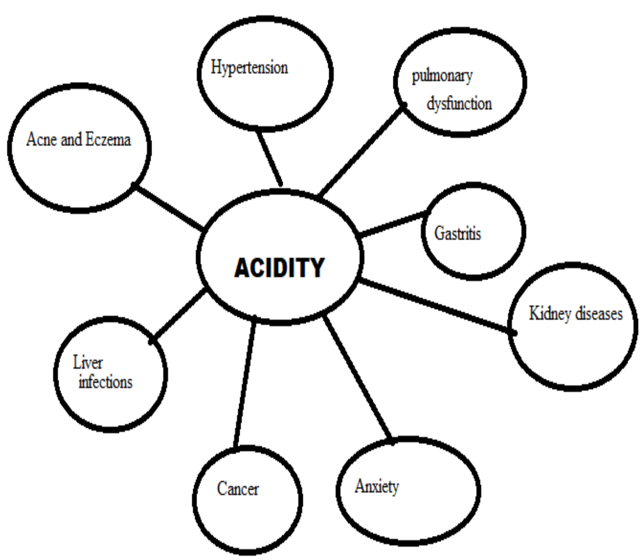

Fig.12 Diseases Cause Due To Acidity

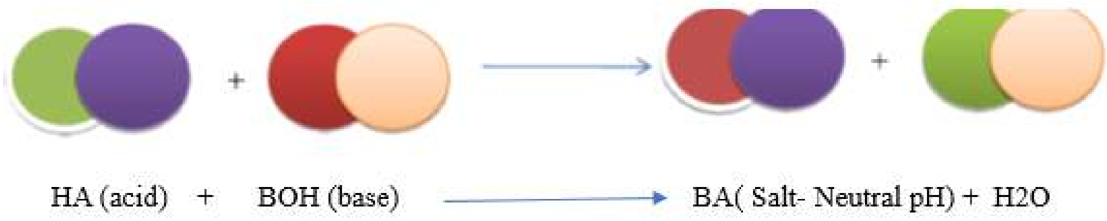

Fig.13 Mechanism of alkaline water

The "basic" in alkaline water alludes to its pH level. A pH level is a number that estimates how acidic or soluble a substance is on a size of 0 to 14. For instance, something with a pH of 1 would be acidic and something with a pH of 13 would be basic. Basic water has a higher pH level than standard drinking water.[24]

Different methods exist for creating alkaline water within the home environment.[25]

(i) Using Baking Soda
(ii) Lemon Water Method
(iii) Alkaline Drops
(iv) Water Ionizers.
(v) Adding pH Boosting Minerals

Home-made alkaline water offers affordable benefits to consumers but alkaline water products at stores differ substantially in price from both bottled and ionized water versions.[25]

Below given table summarizing the key methods for making alkaline water at home, with ingredient ratios, expected pH outcomes, and pros/cons:

7. Electrolyte Reduced Alkaline Water [32].

7.1. The Health Effects of Drinking electrolyzed-reduced alkaline water

The impact on health of drinking a particular type of water called “electrolyzed-reduced” water and show observations from the blood.[33]

7.2. Health Benefits of Alkaline Ionized Water [AIW][34]

7.2.1. Antioxidants: [34]

7.2.2. Effects of AIW in diabetes [34]

7.2.3. Effects of AIW on cancer cells: Apart from making the hydration status of the human body better, AIW also promotes health in the long run..[34]

7.2.4. Effects of AIW in the renal system [34].

7.3. Potential Harmful effects from ingesting high pH alkaline ionized water.

8. Analytical methods for Water Analysis:

Table: 7 Different Analytical Methods for Water Analysis

Sr. No:	Methods	Description	Parameters Analyzed	References
1	Gravimetric Analysis	Based on the measurement of mass of precipitate after filtration and drying.	Total Suspended Solids (TSS), Chlorides, Sulfates	44
2	Spectrophotometry	Measures the absorbance of light at specific wavelengths to identify water contaminants.	Nutrients (Nitrate, Phosphate, etc.), Chlorine, Heavy Metals (e.g., Lead, Copper)	45
3	Ion Chromatography (IC)	Separates ions based on their interaction with a resin, then quantifies them.	Anions (e.g., Nitrate, Sulfate), Cations (e.g., Sodium, Potassium)	46
4	Atomic Absorption Spectroscopy (AAS)	Measures the absorption of light by free atoms to quantify metals.	Heavy Metals (Lead, Cadmium, Zinc, Iron)	47
5	High-Performance Liquid Chromatography (HPLC)	Separates mixtures based on interactions with a column, identifying organic compounds	Organic Contaminants (Pesticides, VOCs), Disinfection Byproducts	48
6	Electrochemical Methods (pH, ORP, Conductivity)	Measures electrical properties to detect various parameters	pH, Conductivity, Oxidation-Reduction Potential (ORP)	49
7	Microbial Biomonitoring (Bioassays)	Evaluates the response of living organisms (e.g., algae, fish) to contaminants	Toxicity, Ecotoxicology	50

CONCLUSION:

Water analysis plays a vital role in ensuring the safety, quality, and suitability of water for human consumption and various other applications. With the increasing demand for clean drinking water, understanding the different types of water—such as tap, bottled, alkaline, and electrolyte-reduced water—has become increasingly important. Each type comes with unique properties and health implications, making accurate testing essential. Various analytical methods, ranging from traditional techniques to advanced instrumental approaches, help assess physical, chemical, and microbiological parameters. However, challenges such as sample contamination, detection limits, and access to high-end testing technologies persist, particularly in resource-limited settings.

Furthermore, while alternative waters like alkaline and ERW (electrolyte-reduced water) offer potential health benefits and potential harmful effects. In conclusion, continued advancement in water testing technologies and the implementation of standardized protocols are essential to address current limitations. Promoting awareness about water quality and encouraging regular analysis can help protect public health and support sustainable water management practices.

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