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REVIEW ARTICLE

Biochemical Potability of Drinking Water: A Review of Parameters, Health Risks, and Treatment Approaches

Ariba Shahab

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ABSTRACT

Safe drinking water is essential for sustaining health and preventing disease. Biochemical potability refers to the suitability of water for consumption based on its chemical and microbial composition. This review discusses major biochemical factors influencing drinking water quality, including pH, nitrates, heavy metals, microbial content, and organic pollutants. It also compares internationally accepted limits with observed values in contaminated water sources. Furthermore, the paper explores health risks linked to unsafe water and examines available treatment technologies for purification. Ensuring biochemical potability is crucial for achieving public health targets, especially in rapidly urbanizing and industrializing regions such as South Asia and Sub-Saharan Africa. The review integrates insights from chemistry, microbiology, and public health to provide a holistic understanding of water quality challenges and solutions.

KEYWORDS: Biochemical potability, Contaminants, Drinking water, Heavy metals, Microbial load, Waterborne diseases, WHO standards, Water purification.

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INTRODUCTION

Water is fundamental for human survival, yet billions of people lack access to safe drinking sources. While physical characteristics such as clarity or odor can signal contamination, they often fail to capture the biochemical hazards lurking within. Biochemical potability is a comprehensive measure involving the evaluation of chemical, organic, and microbial constituents that may pose serious health risks. More than seven hundred organic and inorganic pollutants along with microbial populations have been reported in water.[7] Among these, some organic and inorganic pollutants due to their high toxicity and carcinogenicity are dangerous. Moreover, some organics and metal ions due to their non-bio transformability or non- biodegradability persist in the environment for a longer time. Most toxic organic pollutants are Polynuclear Aromatic Hydrocarbons (PAHs), Polychlorinated Biphenyls (PCBs), Plasticizers, Phenols, Insecticides, Pesticides, Industrial solvents, volatile organic compounds, Polybrominated Diphenyl ethers (PBDE), Food processing wastes and Drug residues. Inorganic water contaminants include acidity caused by industrial effluents, fertilizers, and metals, among others. Toxic metal ions include platinum, mercury, arsenic, cadmium, antimony, and other heavy metals. These compounds are widely used as contaminants in industrial wastewater, and most are said to be toxic and carcinogenic.

Sources of contamination are also typically industrial effluents, agricultural runoff, inadequate sanitation infrastructure, and natural geological processes. Industrial sources are coal combustion in power plants, metal processing in refineries, nuclear power plants, petroleum combustion, high tension lines, textiles, microelectronics, plastics and paper processing plants.[9] Globally, waterborne diseases remain a significant contributor to morbidity, particularly in low-resource settings. Chronic exposure to certain contaminants, such as arsenic or fluoride, can result in irreversible damage to organs or development. Therefore, it is imperative to regularly assess and ensure the biochemical safety of drinking water.

School of Water, Energy and Environment, Cranfield University, Bedford MK43 0AL, United Kingdom.

Corresponding Author: Ariba Shahab

Email: aribashahab@gmail.com

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Key Biochemical Parameters of Concern

Several chemical and biological indicators determine whether water is fit for human consumption. These parameters often vary depending on local geology, human activity, and treatment infrastructure.

pH Measurement

pH measures alkalinity or acidity of water and affects corrosion potential and chemical reactivity. The range of 6.5 to 8.5 is optimal for drinking water, as suggested by the World Health Organization (WHO).[3] Outside this range, taste and damage to plumbing infrastructure are probable, with potential release of toxic materials like lead or copper from pipes.[1] pH is impaired at extreme levels, impacting aquatic life, biodiversity, and water quality indirectly. Recent studies emphasize that pH also regulates the solubility and behavior of other water quality parameters, including metal concentration and treatment process efficiency.

Buffering capacity is minimum in the pH range 8.3–8.5, and precise pH monitoring is important for water treatment optimization.[4]

Dissolved Oxygen

Dissolved oxygen (DO) is important in maintaining aerobic microbe balance in bodies of water. In drinking water, dissolved oxygen is recommended by the World Health Organization to be at least 5 mg/L.[3] Low dissolved oxygen can be an indicator of too many organic matters, which promotes the growth of anaerobic microbes producing toxic by-products such as methane or hydrogen sulfide.[2] Dissolved oxygen is also a direct indicator of the ability of an aquatic system to support life; dissolved oxygen levels below 1-mg/L are hypoxic and are usually devoid of living organisms.[1]

Chemical Oxygen Demand

Chemical oxygen demand, or (COD), is generally the amount of contaminants in water bodies in most instances. COD is a quantification of the amount of a specific oxidizing agent that reacts with the sample under specific conditions. The quality of the oxidizing agent used is expressed in terms of the equivalence in oxygen. The organic and inorganic constituents of a sample are oxidized. However, in most instances, the organic constituents are more common and deserve more attention.

Nitrates and Nitrites

These nitrogenous compounds often enter water supplies from fertilizer use, septic systems, or animal waste. Elevated nitrate levels are especially dangerous for infants, leading to methemoglobinemia or "blue baby syndrome".[3] Long-term exposure may also increase cancer risk.[4] Nitrate contamination in agricultural regions, with climate-driven rainfall extremes leads to increased leaching into groundwater.

Heavy Metals

Elements like arsenic, lead, mercury, and cadmium are highly toxic, even at low concentrations. Sources include industrial discharges, mining, and natural mineral deposits. Chronic exposure is associated with neurological deficits, kidney failure, and cancer.[5,6]

Fluoride

In trace amounts, fluoride protects against dental decay. However, high concentrations (>1.5 mg/L) cause dental fluorosis and, in severe cases, skeletal fluorosis. Certain regions, such as parts of India and Africa, report naturally high fluoride levels in groundwater.[7]

Microbiological Load

Waterborne pathogens, including Escherichia coli, Salmonella, and Vibrio cholerae, indicate fecal contamination. These organisms are responsible for numerous gastrointestinal diseases and are a key target in public water testing protocols.[8]

Organic Pollutants

Synthetic chemicals like pesticides (including persistent organic pollutants such as DDT and PFAS), detergents, and industrial solvents persist in water systems. Many are endocrine disruptors and are linked to carcinogenicity and reproductive disorders.[9] The growing concern over microplastics and pharmaceuticals as emerging contaminants in drinking water also has potential long-term health impacts.

Additional Parameters

- **Total Dissolved Solids (TDS):** Elevated TDS levels can affect taste and may indicate the presence of harmful substances. WHO recommends a maximum of 500 mg/L for palatability, though higher levels may be tolerated in some regions.[12]
- **Turbidity:** High turbidity can shield microorganisms from disinfection and is often associated with microbial contamination.[12]
- **Temperature:** While not directly harmful, temperature affects chemical reactions and the solubility of gases like oxygen in water.[12]

Guidelines for Biochemical Water Quality

International agencies have developed standards to guide safe water consumption.

WHO Guidelines

The World Health Organization recommends specific limits for biological and chemical contaminants based on risk assessments. For example, arsenic should not exceed 0.01 mg/L, and nitrates should be below 50 mg/L.[10]

US EPA Regulations

The U.S. Environmental Protection Agency categorizes water standards into Primary (health-related) and Secondary (aesthetic) standards. These limits are strictly enforced and regularly reviewed[11].

BIS Indian Standards

India's Bureau of Indian Standards (IS 10500:2012) defines acceptable and permissible limits tailored to regional challenges. These align broadly with WHO values but allow flexibility where treatment access is limited[12].

Representative Data

Table 1: Biochemical Parameters vs. WHO Standards

Parameter	WHO Limit	Common Contaminated Range
pH	6.5–8.5	<6.0 or >9.0
Nitrate (mg/L)	<50	60–120
Arsenic (mg/L)	<0.01	0.05–0.2
Lead (mg/L)	<0.01	0.05–0.2
Fluoride (mg/L)	<1.5	2.0–5.0
Escherichia coli (CFU/100 mL)	0	Up to 1000

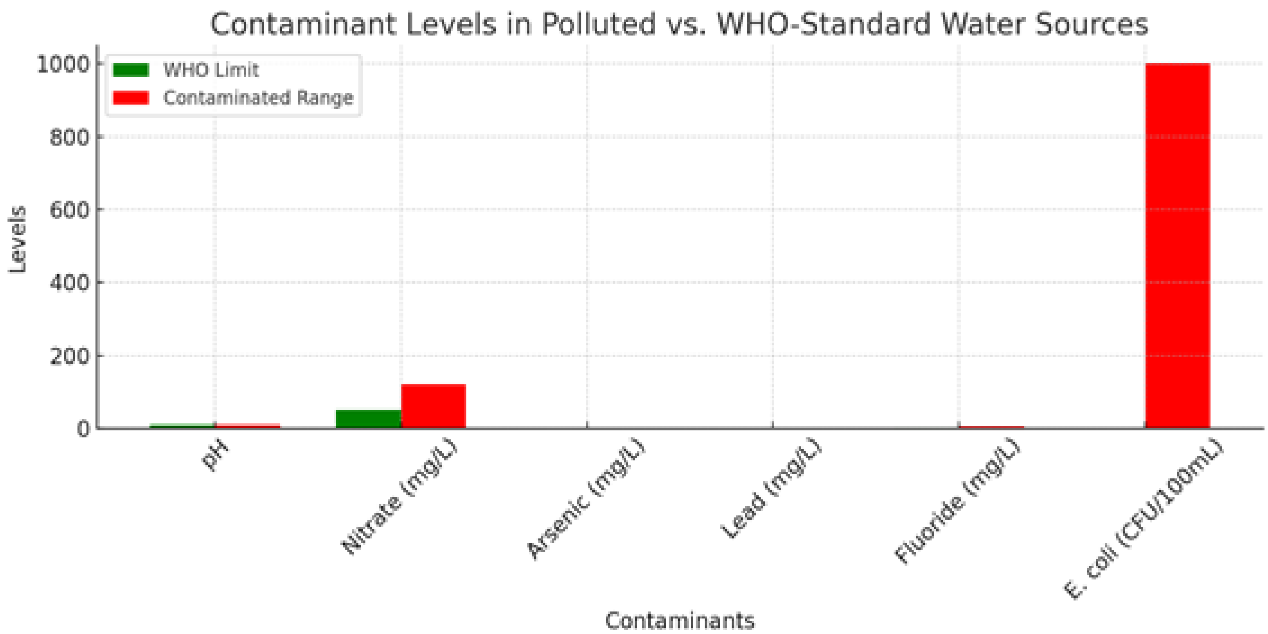

Figure 1: Contaminant levels in polluted vs. WHO-standard water sources.

Health Impacts of Contaminated Water

Unsafe water remains a primary cause of disease and mortality worldwide. Contaminants impact health in both acute and chronic ways:

- Microbial pathogens cause diarrhoea, cholera, typhoid, and hepatitis, especially in developing countries where access to clean water is limited.[13]
- Arsenic ingestion has been linked to skin lesions, cardiovascular disease, and cancers of the lung, bladder, and kidney.[5]
- Lead exposure is particularly harmful to children, impairing brain development and increasing behavioural disorders.[6]
- High fluoride levels result in joint stiffness, calcification of ligaments, and visible tooth mottling.[7]

Preventing such outcomes requires rigorous water monitoring, community education, and proactive regulation enforcement.

Monitoring and Treatment Technologies

Water Quality Monitoring

Modern water testing uses technologies such as:

- Colorimetric kits for field nitrate and fluoride detection.
- PCR and immunoassays for microbial identification.
- Real-time sensors and IoT platforms for continuous monitoring.[14]

Colorimetric Kits

Colorimetric kits are a handy means for rapid on-site determination of nitrate and fluoride levels in water. They work on the principle of the addition of reagents to a water sample, which brings about a chemical reaction that causes a color change. The intensity of the color change is then compared with a standard calibration chart to estimate the concentration of the pollutants, thereby yielding semi-quantitative and quantitative results.[14] For instance, the Fluoride Detection Kit (FDK) designed by BARC allows quick categorization of water as safe, borderline, or dangerous on the basis of fluoride concentration, which is highly useful in far-flung and disadvantaged communities. Likewise, portable detection kits for nitrate and nitrite in water allow quick analysis in field conditions, thereby allowing communities to make highly educated choices about the safety of water.[14]

Polymerase Chain Reaction (PCR)

The Polymerase Chain Reaction (PCR), and quantitative PCR (qPCR), and immunoassays, among other technologies, have revolutionized microbial water quality analysis. PCR and PCR-based methods amplify the target DNA or RNA sequences of the pathogens, and thus make very sensitive and specific detection possible—even at very low levels and within hours.[18] The latest technologies are multiplex and real-time PCR tests, which can identify several pathogens at the same time using a given sample, and microfluidic chips that further reduce detection time and sample volume requirements.[18] Immunoassays, such as enzyme-linked immunosorbent assays (ELISA), use antibodies to detect microbial antigens, and thus another rapid and accurate way of detecting waterborne pathogens. These molecular and immunological tests are now the norm for microbial source tracking and risk assessment for water quality monitoring.[18]

Real-time Monitoring through Sensors And Iot Platforms

The integration of real-time sensors with Internet of Things (IoT) platforms has transformed water quality monitoring such that continuous, remote, and automated monitoring of crucial parameters such as pH, temperature, turbidity, dissolved oxygen, and pollutant concentrations is feasible.[19] IoT-enabled systems employ a network of connected sensors that transmit data in real time to centralized databases or cloud platforms, where it can be analyzed for trends, anomalies, or threshold breaches. This approach allows for immediate detection of contamination events and supports proactive management of water resources. Recent developments include low-cost, energy-efficient sensor arrays and user-friendly dashboards for real-time data visualization and decision-making, significantly enhancing the capacity for timely public health interventions.[19]

Treatment Techniques

Effective purification depends on the type of contamination:

- Reverse Osmosis (RO): Removes heavy metals and salts
- Activated Carbon: Adsorbs organic pollutants and odors
- UV Sterilization: Eliminates microbial pathogens
- Bio-sand and Ceramic Filters: Affordable solutions for low-income areas.[15]
- UV/Cl-cyanurates: Advanced Oxidation process is proposed as a novel and effective alternative.[23]

Reverse Osmosis

Reverse osmosis water purification technology has been advancing at a rapid rate in the last few years. The process is founded on the separation of the solvent and the solute through pressure-driven water molecules that cross a potent reverse osmosis membrane. The process has made tremendous progress due to its efficiency to enhance efficiency, whereas in parallel, reverse osmosis water filtration technology has attained a mature development level.[25] The theoretical model indicates that the reverse osmosis process is capable of efficiently removing suspended particles, organic matter, colloids, bacteria, viruses, as well as salts and other ionic substances.[25] Nevertheless, it should be noted that only water can pass through the reverse osmosis membrane, thus safeguarding the water against contamination. Thus, the drinking water purification technology which can maximum possibly eliminate the disinfection by-products and trace organic pollutants to be recognized by more and more people. And it has become an effective method to guarantee the safety of drinking water, and has been extensively used to enhance drinking water quality, increase drinking water sources and guarantee emergency water supply.[25]

Activated Carbon

Activated carbon is a vital part of the water treatment process, with the ability to eliminate a broad range of organic impurities, including pesticides, herbicides, volatile organic compounds (VOCs), and industrial chemicals. Because of its large pore volume, generally over 1000 m^2/g in surface area, it has the ability to adsorb organic molecules and odor-causing substances through physical and chemical processes.[24] Activated carbon can eliminate chlorine, chloramines, and taste- and odor-causing chemicals, making water potable for drinking.[24] Laboratory tests have proved that powdered and granular activated carbon is effective in decreasing biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS) by a very large amount, making it an effective tool for municipal water treatment plants and household water treatment systems.[24] Several factors, including pore size, contact time, temperature, and pH levels, affect the efficacy of activated carbon. While effective in eliminating organic impurities and odors, activated carbon is not as effective in eliminating inorganic impurities, including heavy metals or microbial pathogens; as such, it should be supplemented with auxiliary means of treatment to completely purify water.[24]

Ultraviolet Disinfection

Ultraviolet (UV) sterilization is a chemical-free, efficient method of water disinfection that can kill a range of microbial pathogens including bacteria, viruses, and hardy protozoa like Cryptosporidium and Giardia, which are known to be resistant to regular chlorination.[26] Utilizing UV-C light of 200–280 nm wavelength, this process inactivates microbial DNA, thus disallowing them to be reproductive and making them non-pathogenic.[26] Promoted by regulatory bodies like the US EPA and FDA, UV systems can destroy up to 99.99% of microorganisms without altering the taste, odor, or mineral content of water. UV treatment does not affect chemical contaminants and has no residual disinfection but allows water to recontaminate if it is exposed to pathogens post-treatment. UV sterilization effectiveness depends on the intensity of UV light, contact time, transparency of water, and regular equipment maintenance.[26]

Biosand and Ceramic Filters: Biosand and ceramic filters are low-cost, long-lasting domestic water treatment technologies suitable for low-income and rural populations.[27] Biosand filters use sand and gravel layers as physical barriers to pathogen removal, turbidity, and dissolved metal removal, and a bioactive layer (biofilm) on the sand surface increases removal of microbes by natural predation and competition. Biosand filters have been demonstrated to remove greater than 97% of bacteria and maintain performance with little maintenance.[27] Ceramic filters, usually made from locally available clay, provide comparable bacterial reduction and are valued for their simplicity and low cost. Both technologies greatly improve water safety in communities without centralized treatment plants, but performance also depends on design, user compliance, and maintenance practice. Addition of materials like zeolites to biosand filters can enhance chemical contaminant removal, for example, arsenic and iron.[27] 8.5 UV/Cl-cyanurates The UV/Cl-cyanurates is a new advanced oxidation process (AOP) designed to enhance drinking water treatment and facilitate water reclamation. The process utilizes ultraviolet (UV) irradiation and chlorinated cyanurates, such as sodium dichloroisocyanurate (NaDCC), to create strong oxidizing species.[23] The operating mechanism of the process is as follows:

- UV irradiation interacts with chlorinated cyanurates in water, initiating photolysis that generates reactive species, including hydroxyl radicals (·OH) and reactive chlorine species (RCS).
- These reactive agents effectively degrade persistent organic micropollutants, pharmaceuticals, and trace contaminants that resist conventional treatment approaches.
- Additionally, the process neutralizes microbial pathogens, contributing to improved water safety.

This AOP stands out for its ability to target a broad spectrum of contaminants while providing residual disinfection, making it a forward-looking solution for ensuring high-quality drinking water.[23]

Future Challenges and Opportunities

Providing safe water remains a global priority under the UN's Sustainable Development Goals. The Key obstacles include:

- Limited funding for infrastructure
- Lack of awareness and education in rural areas
- Weak policy implementation
- Emerging contaminants such as microplastics and pharmaceutical residues

Innovations in decentralized treatment, community-level filtration, policy reforms, AI-driven sensors and decentralized filtration systems offer scalable pathways to meet SDG 6 targets that are essential to ensure universal access to clean water.

CONCLUSION

The biochemically compatibility of drinking water is a core aspect of public health all over the world and environmental conservation. The present review has addressed the basic interaction of chemical, microbial, and organic parameters that determine the quality of water, and the crucial health risks posed by the contamination with heavy metals, nitrates, and microbes. Comparative examinations of international recommendations, especially those set up by the WHO, US EPA, and BIS, highlight the need for robust, context-specific regulations to address local concerns, particularly in risk-prone areas like South Asia and Sub-Saharan Africa. Advances in tracking technologies—from colorimetric kits to IoT-based sensors—along with successful treatments like reverse osmosis, activated carbon filtration, UV sterilization, and novel UV/Cl-cyanurates processes, offer promising approaches to reduce contamination. However, persistent challenges, including inadequate infrastructure, emerging pollutants like microplastics, and weak policy enforcement, highlight the urgency of integrated solutions. By prioritizing innovation, community engagement, and equitable access to clean water, stakeholders can bridge the gap between current limitations and the ambitious targets of the UN's Sustainable Development Goals. This holistic approach not only safeguards human health but also fosters resilient ecosystems, paving the way for a future where safe drinking water is a universal reality.

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Orcid ID:

Ariba Shahab - https://orcid.org/0000-0002-5358-2441