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REVIEW ARTICLE

Assessment of Drinking Water Quality in Various Parts of India - A Review

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ABSTRACT

The quality of drinking water is a critical determinant of public health, and its assessment is vital for ensuring safe and adequate water supply. This review article provides a comprehensive evaluation of the current state of drinking water quality across various regions of India, highlighting the diverse challenges and regional disparities. We examined studies and reports from different states, focusing on key parameters. Special attention was given to the impact of industrial activities, agricultural practices, and inadequate sanitation, and infrastructure on water quality. The review also discusses the effectiveness of existing water quality monitoring and management practices, including regulatory frameworks and technological interventions. By synthesizing data from recent research and government reports, this article aims to identify critical gaps in water quality assessment and provide actionable recommendations for policy makers and stakeholders to enhance water safety and sustainability in India.

Keywords: Microbial contamination; Chemical pollutants; Physical characteristics

INTRODUCTION

Access to safe drinking water is a fundamental necessity for human health and well-being. In India around 780 million people do not have access to Clean and safe water. As a result, around 6-8 million people die each year due to water related disease and disaster[1]. The quality of drinking water varies significantly across different regions. This variation is influenced by a myriad of factors, including industrial activities, agricultural practices, and urbanization[1,2]. The intersection of industrialization and agricultural expansion has had profound effects on water resources in India. Industries often discharge pollutants into water bodies, leading to contamination with heavy metals, chemicals, and other hazardous substances[2]. Concurrently, intensive agricultural practices contribute to water pollution through runoff of pesticides, fertilizers, and organic waste[3]. These factors, combined with inadequate waste management and aging infrastructure, exacerbate the challenges in ensuring clean drinking water[4], regional disparities further complicate the issue[5].

This review article aims to comprehensively assess the current state of drinking water quality across various parts of India, examining the impacts of industrial and agricultural practices[6]. By highlighting regional variations and identifying key challenges[5], this study seeks to inform policymaking and drive initiatives towards improved water management and public health outcomes[7].

The assessment focuses on evaluating the physical, chemical, and microbiological parameters of water across different regions[8–10]. It includes identifying contaminants such as heavy metals, pesticides, and pathogens, and understanding their sources[6]. The review also considers regional variations in water quality and public health impacts[7]. Additionally, it may explore policy frameworks and management practices to address water quality issue.

Regional analysis

Geographical variability- urban versus rural areas: Urban areas often face contamination due to industrial waste, untreated sewage, and overpopulation, while rural areas face issues related to agricultural runoff, lack of sanitation facilities, and poor water infrastructure. Regional Differences: Water quality varies across regions, such as fluoride contamination in Rajasthan, arsenic in West Bengal, and nitrates in Punjab, necessitating a region-specific approach to assessment.

- **Natural contaminants-arsenic:** Found in groundwater in parts of West Bengal, Bihar, Uttar Pradesh, and Assam, arsenic poses severe health risks like skin lesions and cancer. Endemic in Rajasthan, Gujarat, and Andhra Pradesh, fluoride contamination can lead to skeletal fluorosis. High iron content in water is common in northeastern states like Assam and parts of Bihar and West Bengal, which affects water taste and causes staining [11].
- **Human-induced contaminants- industrial pollution:** In areas like Delhi, Gujarat, and Tamil Nadu, industrial effluents cause severe water pollution, with heavy metals like lead, mercury, and cadmium posing health hazards. Fertilizers and pesticides contribute to nitrate and phosphate contamination in states like Punjab and Haryana, affecting ground water. Untreated sewage is a major problem in cities like Mumbai, Delhi, and Kolkata, contaminating surface water bodies [12].

Analysis in southern states of India

- **Tamil Nadu and Karnataka:** Both states face issues with groundwater depletion and contamination from excessive use of fertilizers and pesticides. Urban areas also struggle with wastewater management, affecting surface water quality [13].
- **Kerala:** Generally, water quality is good, but localized issues such as pollution from unregulated waste disposal can impact specific areas. The state's focus on sustainable water management has shown positive outcomes [14].

Key issues

- **Contaminants:** Water sources in India often face contamination from industrial discharges, agricultural runoff (pesticides and fertilizers), and microbial pathogens. Natural contaminants like arsenic and fluoride are also prevalent in certain regions [14].
- **Regional variability:** Contamination levels and types vary significantly; for instance, arsenic is a major issue in West Bengal and Assam, while fluoride problems are more common in Rajasthan and Gujarat. Coastal areas may face issues with salinity and so on may serve as an issue [5].
- **Infrastructure:** Many regions suffer from inadequate or outdated infrastructure, which affects the effectiveness of water treatment and distribution systems. Issues include insufficient treatment facilities, leaking pipes, and poor storage conditions [15].
- **Management:** Water management is often hampered by fragmented regulatory frameworks, lack of coordination between agencies, and insufficient data for effective planning. Enhancing management practices involves better regulation, improved data collection, and investment in infrastructure.

REVIEW OF LITERATURE

The study of Dattatraya et al., indicated the possible source of contamination in drinking water. A of 15 samples of ground water were collected in the month of August-December, and analyzed for physico-chemical parameters like, pH, TDS, total alkalinity, total hardness, dissolved oxygen, turbidity and chloride by standard procedure mentioned in IS 10500 [16].

During the assessment of water, Jain collected from different city areas and found that dissolved carbon dioxide and dissolved oxygen were in the range of 6.4 and 33. Total dissolved solid of collected water samples showed a range under 1500 ppm and found within the range of BIS. Important and vital minerals like Calcium, Magnesium, Chloride, Sulphate, Barium and Copper were also tested from the collected samples and the results complied with the given range of test for minerals. Alkalinity and total hardness of water samples should be less than or equal to 10 and 300 ppm respectively [16].

Agrawal had undertaken a systematic study to calculate the water quality index of river Ganga in Hardwar District. They collected and analyzed samples for two consecutive years 2007 and 2008. Each parameter was compared with the standard desirable limit of that parameter in river water as prescribed by different agencies. They collected 90 water samples from five sampling stations and investigated for physicochemical parameters [17].

In a study on chemical analysis of drinking water of Sanganer Tehsil, Jaipur District, Sharma et al., found out certain result as describe below the water samples were analyzed for pH, Fluoride (F) Electrical Conductivity (EC), Total Dissolved Solid (TDS), Calcium (Ca), Magnesium (Mg), Total Hardness (TH), Chloride (Cl^-), Carbonate (CO_3^{-2}), Bicarbonate (HCO_3^-), Alkalinity, Sodium (Na^+), Potassium (K^+) and Nitrate (NO_3) using standard techniques in laboratory (APHA, 1985). The results revealed that most of the water samples were below or out of limit; according to the WHO standards [18].

Kumar and Kumar selected 10 different locations for their study and compared groundwater samples of Ambattur town during the post-rainy season in November 2010. Borosilicate glassware, distilled water and E-Merk reagents were used throughout the testing. Samples were collected in sterilized screw-capped polyethylene bottles of one liter capacity and analyzed in laboratory for their physicochemical parameters. After the study they got following results for the selected city.

Parameter value pH 7.2-8.5; Total alkalinity 270-320 mg/L; Total hardness 220-310 mg/L; Chloride within permissible limit; Sulphate 150-230 mg/L; Fluoride 0.8-1.4 mg/L TDS within permissible limit; Conductivity 750-900 μmhos/cm. So, it is concluded that water from the studied area was highly contaminated with TDS and other observed parameters were not in the permissible limit. Thus, if people drink that water, then problem of certain diseases such as stomach diseases, gastric troubles, etc., arise [19].

Pandey and Tiwari monitored groundwater quality. A fluorinated plastic bottle of capacity 2 liter has been used to collect the sample. Before sampling evacuation of the stored water in the pipelines has been made to take the fresh ground water sample, all the parameters were analyzed by standard procedure mention in APHA [20–24] .

Table 1: Results of Pandey and Tiwari study [20]

pH	6.8-8.3
TDS	145-245mg/dL
Total hardness	235-304mg/dL
Calcium hardness	99-158 mg/dL
DO	3.4-5 mg/L
Chloride content	78-100 mg/L
Alkalinity	110-149 mg/L
Carbon dioxide	7.02- 7.92 ppm

Major terminologies related to the study [12]*:*

- **pH:** The effect of pH on the chemical and biological properties of liquids makes its determination very important. It is one of the most important parameters in water chemistry and is defined as -log [H^+] and measured as intensity of acidity or alkalinity on a scale ranging from 0-14. If free H+ are more it is expressed acidic (i.e., pH<7), while more OH^- ions is expressed as alkaline (i.e., pH> 7). In natural waters pH is governed by the equilibrium between carbon dioxide/bicarbonate/carbonate ions and ranges between 4.5 and 8.5 although mostly basic. It tends to increase during day largely due to the photosynthetic activity (consumption of carbon- di-oxide) and decreases during night due to respiratory activity. Wastewater and polluted natural waters have pH values lower or higher than 7 based on the nature of the pollutants [12].
- **Total dissolved solids (TSD)**: Dissolved solids are solids that are in dissolved state in solution. Waters with high dissolved solids generally are of inferior palatability and may induce an unfavorable physiological reaction in the transient consumer. The difference in the weight of total solids and the total suspended solids expressed in the same units gives the total dissolved solids. The difference in the weights of Total Solids (W1) and Total Suspended Solids (W2) expressed in the same units gives Total Dissolved Solids [12].
- **Dissolved oxygen (DO)**: Oxygen dissolved in water is a very important parameter in water analysis as it serves as an indicator of the physical, chemical and biological activities of the water body. The two main sources of dissolved oxygen are diffusion of oxygen from the air and photosynthetic activity. Diffusion of oxygen from the air into water depends on the solubility of oxygen and is influenced by many other factors like water movement, temperature, salinity, etc., Photosynthesis, a biological phenomenon carried out by the autotrophs, depends on the plankton population, light condition, gases, etc., Oxygen is the major limiting factor in water bodies with organic materials. Dissolved oxygen is calculated by many methods [12].
- **Alkalinity**: Alkalinity is the capacity of water to resist acidification. It should not be confused with basicity which is an absolute measurement on the pH scale. Alkalinity is the strength of a buffer solution composed of weak acids and their conjugate bases. Total alkalinity is measured by collecting a water sample, and measuring the amount of acid needed to bring the sample to a pH of 4.2. At this pH all the alkaline compounds in the sample are "used up". The result is reported as milligrams per liter (mg/L) of calcium carbonate [12].
- **Electrical conductivity (EC):** The electrical conductivity (EC) of water is a measure of the ability of a solution to carry or conduct an electrical current. Since the electrical current is carried by ions in solution, the conductivity increases as the concentration of ions increases. Therefore, it is one of the main parameters used to determine the suitability of water for irrigation and firefighting [12].
- **Turbidity:** Turbidity in drinking-water is caused by particulate matter that may be present from source water because of inadequate filtration or from resuspension of sediment in the distribution system. It may also be due to the presence of inorganic particulate matter in some groundwaters or sloughing of biofilm within the distribution system. The appearance of water with a turbidity of less than 5 NTU is usually acceptable to consumers, although this may vary with local circumstances. Particulates can protect microorganisms from the effects of disinfection and can stimulate bacterial growth. In all cases where water is disinfected, the turbidity must be low so that disinfection can be effective. Turbidity is also an important operational parameter in process control and can indicate problems with treatment processes, particularly coagulation/sedimentation and filtration.

No health-based guideline value for turbidity has been proposed; ideally, however, median turbidity should be below 0.1 NTU for effective disinfection, and changes in turbidity are an important process control parameter[12].

DISCUSSION

Impact of industrialization and agricultural expansion on water quality through various mechanisms

- **Pollutant runoff**: Industrial activities and agricultural practices contribute to water pollution through runoff[2]. Factories often discharge pollutants like heavy metals, chemicals, and sediments into water bodies. Similarly, agricultural expansion increases the use of fertilizers and pesticides, which can leach into waterways, causing nutrient pollution and algal blooms. These blooms can deplete oxygen in water, harming aquatic life[8].
- **Wastewater discharge:** Industrial processes generate wastewater that may contain harmful substances[2]. If not properly treated, this wastewater can enter rivers, lakes, and oceans, leading to contamination with toxic compounds and heavy metals[6]. This can affect aquatic ecosystems and potentially enter the human food chain[8].
- **Erosion and sedimentation:** Agricultural expansion often involves land clearing and tillage, which increases soil erosion. Eroded soil can be carried into water bodies, leading to sedimentation. High sediment levels can cloud water, reducing light penetration and affecting aquatic plants and animals[8].
- **Temperature changes:** Industrial activities can alter water temperatures through the discharge of heated water or the alteration of natural waterways. Elevated temperatures can disrupt aquatic ecosystems, affecting species that are sensitive to temperature changes[8,9].
- **Alteration of water flow:** Both industrialization and agriculture can alter natural water flows. Industrial activities may involve damming or redirecting rivers, while agricultural practices can change land use patterns. These changes can affect the natural flow of water, impacting sediment transport and the health of aquatic habitats[9].

Effectiveness of existing water quality monitoring and management practices in India[25]

Water quality monitoring and management practices in India have seen significant progress, but challenges remain[25].

- **Government initiatives:** Programs like the National Rural Drinking Water Programme (NRDWP) and the Jal Jeevan Mission focus on improving water access and quality. These initiatives have led to improvements in infrastructure and monitoring systems[25].
- **Rainwater harvesting:** Rainwater harvesting promoted through policies and incentives involves capturing and storing rainwater to supplement traditional water sources and enhance groundwater recharge.[25]
- **Legislation and standards:** India has established water quality standards under the Bureau of Indian Standards (BIS) and various regulations, such as the Water Prevention and Control of Pollution Act, 1974. However, enforcement and adherence to these standards can be inconsistent[25].
- **Monitoring systems:** Organizations like the Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCBs) are responsible for monitoring water quality. They conduct regular assessments, but issues like limited coverage, inadequate data sharing, and delays in reporting can impact effectiveness[26,27]
- **Technological advances:** There has been increased use of remote sensing and data analytics for water quality monitoring. These technologies have improved the precision and efficiency of monitoring but require further scaling and integration[25].

Water contamination

The Safe Drinking Water Act defines the term ”contaminant” as meaning any physical, chemical, biological or radiological substance or matter in water. Therefore, the law defines ”contaminant” very broadly as being anything other than water molecules. Drinking water may reasonably be expected to contain at least small amounts of some contaminants. Some drinking water contaminants may be harmful if consumed at certain levels in drinking water while others may be harmless. The presence of contaminants does not necessarily indicate that the water poses a health risk. Only a small number of the universe of contaminants as defined above are listed on the Contaminant Candidate List (CCL). The CCL serves as the first level of evaluation for unregulated drinking water contaminants that may need further investigation of potential health effects and the levels at which they are found in drinking water.

The following are general categories of drinking water contaminants and examples of each:

Physical contaminants primarily impact the physical appearance or other physical properties of water. Examples of physical contaminants are sediment or organic material suspended in the water of lakes, rivers and streams from soil erosion[8]. Chemical contaminants are elements or compounds. These contaminants may be naturally occurring or man-made. Examples of chemical contaminants include nitrogen, bleach, salts, pesticides, metals, toxins produced by bacteria, and human or animal drugs[9]. Biological contaminants are organisms in water. They are also referred to as microbes or microbiological contaminants. Examples of biological or microbial contaminants include bacteria, viruses, protozoan, and parasites[10]. Radiological contaminants are chemical elements with an unbalanced number of protons and neutrons resulting in unstable atoms that can emit ionizing radiation. Examples of radiological contaminants include cesium, plutonium and uranium. Thus, to ensure a good quality of water, physicochemical analysis of drinking water needs to be assessed periodically for water quality parameters such as pH, Conductivity, Alkalinity, TDS, TSS, BOD, COD, DO[11].

Comparative analysis

Geographical variations:

- **Northern India:** States like Uttar Pradesh and Bihar face significant challenges with arsenic and fluoride contamination due to natural geological sources. Studies such as those by the Geological Survey of India have highlighted high levels of these contaminants in groundwater (BGS, 2014).
- **Southern India:** States like Tamil Nadu and Karnataka have issues related to industrial pollution and high nitrate levels from agricultural runoff. Research published in 'Environmental Monitoring and Assessment' has documented these concerns Mohan et al., 2021[28].
- **Urban vs. rural disparities:** Urban areas, such as Delhi and Mumbai, often struggle with sanitation-related issues affecting water quality, while rural areas may suffer from inadequate water treatment infrastructure Kumar et al., 2018[23].

Technological interventions[29]

- **Remote Sensing and GIS:** These technologies help in monitoring water bodies, assessing pollution sources, and managing water resources.
- **Water quality sensors and IoT devices:** Deployed in various locations for real-time monitoring of parameters such as pH, turbidity, and contaminants.
- **Advanced treatment technologies:** Includes methods like membrane filtration, UV treatment, and advanced oxidation processes to improve water quality.

Recommendations[29]

- **Enhanced monitoring:** Regular and comprehensive water quality assessments are crucial for timely intervention and management.
- **Infrastructure investment:** Increased investment in water infrastructure is needed to address deficiencies and ensure equitable access.
- **Public awareness:** Education and awareness programs can help communities adopt practices that reduce water contamination and improve conservation.

Public health implications

- **Waterborne diseases**[30]: Contaminated water is a major cause of diseases like cholera, dysentery, and hepatitis A. The World Health Organization and the Indian Council of Medical Research report that these diseases are prevalent in areas with poor water quality (WHO, 2021; ICMR, 2022)
- **Chronic health issues:** Long-term exposure to contaminants such as arsenic has been linked to cancer, cardiovascular diseases, and developmental issues in children. Research by the Indian Institute of Toxicology Research provides extensive data on these health impacts[31].
- **Economic impact:** Waterborne diseases impose a substantial economic burden on healthcare systems and affect productivity. Studies estimate that poor water quality costs India billions annually in healthcare expenses and lost labor World Bank, 2020[30]

Policy development and recommendations ongoing initiatives

- **Government Programs**: Initiatives like the Jal Jeevan Mission aim to provide safe and adequate drinking water through improved infrastructure and management[7].
- **Community Efforts**: Localized efforts, including rainwater harvesting and community-managed water systems, are improving water access and quality in many regions[7].
- **Technological Advances**: New technologies for water purification and monitoring are being introduced to address contamination and ensure safe drinking water.

To enhance water safety and sustainability in India, policymakers and stakeholders could implement the following actionable recommendations:

1. Strengthen Water Quality Monitoring and Regulation: Develop a comprehensive and transparent system for monitoring water quality across all regions. This includes regular testing for contaminants and enforcing stricter regulations on industrial discharges and agricultural runoff[7].

2. Promote Integrated Water Resource Management (IWRM): Encourage a holistic approach to water management that integrates the needs of all stakeholders, including agriculture, industry, and domestic users. This should involve better planning and coordination between different levels of government and sectors[7].

3. Invest in Water Infrastructure: Upgrade existing water infrastructure and invest in new technologies for efficient water distribution, wastewater treatment, and rainwater harvesting. Ensure that investments are made in both urban and rural areas to address disparities[7].

4. Encourage water conservation practices: Launch national and local campaigns to promote water conservation

at the individual and community levels. This can include incentives for water-saving technologies and education on sustainable practices[20].

5. Enhance Public Awareness and Education -Implement educational programs to increase public awareness about water issues, conservation techniques, and the importance of maintaining clean water sources. Engage communities in water management decisions and actions[7].

6. Support Research and Innovation: Fund research into new technologies and methods for water purification, recycling, and conservation. Promote innovation in water management practices that can be adapted to local conditions[7].

7. Strengthen Policy and Governance Frameworks: Develop and enforce comprehensive water policies that address current challenges and future needs. Ensure that governance structures are in place to manage and regulate water resources effectively[7].

8. Encourage local communities, NGOs, and private sectors in water management initiatives. Collaborative approaches can enhance resource management[7].

As of September 2024, a clear view of the review article on drinking water quality assessment in India would likely reflect the following updates:

1. Enhanced data collection: Recent studies have improved data collection techniques, allowing for more accurate and comprehensive assessments of water quality across diverse regions.

2. Focus on contaminant trends: There is increased attention to emerging contaminants like microplastics, pharmaceuticals, and industrial chemicals, with new research emphasizing their detection and impacts.

3. Regional analysis: Updated reviews highlight significant disparities in water quality between urban and rural areas, with ongoing challenges in regions affected by industrial pollution and inadequate infrastructure.

4. Policy developments: Recent policy changes and governmental initiatives aim to strengthen water quality regulations and enforcement, but implementation challenges persist.

5. Technological Advances in water purification and monitoring technologies are being integrated into water quality management practices, offering new solutions for improving safety and accessibility.

This summary indicates that while progress is being made in addressing water quality issues in India, continued efforts are needed to overcome persistent challenges and adapt to new threats.

CONCLUSION

In conclusion, the assessment of drinking water quality across various parts of India reveals significant regional disparities with certain areas exhibiting high level of contamination. This variation is largely influenced by factors such as industrial pollution, agricultural runoff and inadequate infrastructure in urban and rural areas. The health implications are severe, particularly in regions where contaminants like heavy metals and pathogens are prevalent, posing serious risks to public health.

The assessment of drinking water quality across various regions of India reveals significant challenges and disparities. While some areas benefit from relatively good water quality, many regions struggle with contamination due to industrial discharges, agricultural runoff, and inadequate infrastructure. Physical, chemical, biological, and radiological contaminants are prevalent, impacting public health and environmental sustainability. Addressing these issues requires a multifaceted approach, including improved water management practices, enhanced purification technologies, and stringent regulatory measures. By understanding regional variations and contaminant sources, targeted policies and interventions can be developed to ensure safe and reliable drinking water for all communities.

To address these challenges, there is a pressing need for more robust water quality regulations, improved treatment facilities, and widespread public education on safe water practices. Future research should focus on understanding seasonal changes in water quality and the long-term impacts of climate change on water resources. Ensuring access to clean and safe drinking water must be a top priority for policymakers, communities, and all stakeholders, as it is fundamental to the health and well-being of the population.

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Conflict of Interest

The authors have no conflicts of interest to declare.

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