International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Drinking Water Quality Assessment and Its Effects on Residents Health in India

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Abstract

The availability of safe drinking water stands as a major problem in India because dangerous substances including fluoride, arsenic, nitrates and microbial pathogens threaten human health. This research examines drinking water quality throughout urban and rural territories to determine major pollutants together with their health effects. The research shows that waterborne diseases spread due to microbial contamination yet fluoride and arsenic exposure produces chronic skeletal and neurological disorders. High nitrate concentrations found primarily in agricultural areas create a danger of infantile methemoglobinemia development. The Jal Jeevan Mission government initiative faces public health risks because of poor implementation and insufficient water treatment facilities. The study demands improved regulation policies and decentralized filtration systems and community-based interventions to reduce health threats to people. The Indian population requires a combined intersectoral strategy that combines technological progress with policy reforms to achieve universal access to safe sustainable drinking water.

Keywords: Drinking Water, Quality, Effects, Residents Health, India

1. Introduction

Drinking water safety combined with water cleanliness represents an absolute requirement for safeguarding human well-being. The problem of water contamination in India affects millions of people especially those living in rural and industrial regions. The combination of population growth together with industrial expansion has created more contaminated water bodies due to industrial waste discharge and agricultural waste and poor wastewater treatment facilities which results in harmful health consequences (Ahmad, T., & Iqbal, A. 2020). The contamination of drinking water leads to waterborne diseases as well as heavy metal poisoning and persistent chronic illnesses which endanger both public health and economic progress. Drinking water quality problems in India stem from both natural elements and human-made sources. Indian people who depend on groundwater for their daily drinking water needs total 60% of the population while their supply remains at high risk of contamination. Groundwater in Rajasthan and West Bengal and Bihar contains geogenic contaminants including fluoride, arsenic and nitrates because of natural geological processes (Jain, M., & Kumar, P. 2018). Surface water reservoirs including rivers and lakes become contaminated because of industrial pollution and improper waste management practices. The Ganga and Yamuna rivers serve as two major water sources in India yet remain contaminated with dangerous organic and chemical pollutants which prevent their use for drinking water. These rivers show contamination beyond the limits set by World Health Organization (WHO) and Bureau of Indian Standards (BIS) which demonstrates the gravity of the situation (Singh, P., & Tripathi, M. 2019).

Drinking water contamination primarily causes widespread diarrhea outbreaks together with typhoid outbreaks and cholera outbreaks and hepatitis outbreaks. WHO reports that India contributes to 10% of worldwide waterborne disease deaths and children under five years face the highest risk. Drinking water contaminated with Escherichia coli (E. coli) bacteria signals fecal contamination because of poor sewage treatment and open defecation practices. The Swachh Bharat Mission (Clean India Mission) has improved sanitation practices but additional efforts are needed to provide safe water access to every community. Drinking water contamination from chemicals creates serious health threats because of fluoride, arsenic and nitrates (Swaminathan, K., & Sridhar, R. 2020). The states of Rajasthan, Gujarat and Andhra Pradesh suffer from fluoride contamination that causes dental and skeletal fluorosis which results in permanent bone malformations and neurological complications. The presence of arsenic in West Bengal, Bihar and Assam has resulted in skin lesions and cognitive problems and cancer development thus creating a serious public health emergency. The excessive application of agricultural fertilizers produces nitrate pollution that contaminates drinking water sources across Punjab, Haryana and Uttar Pradesh which results in infants developing the medical condition known as methemoglobinemia or Blue Baby Syndrome (Yadav, P., & Saxena, A. 2021).

The declining water quality in India creates major economic and social challenges throughout the nation. The inferior state of water quality leads to decreased agricultural productivity and elevated health expenses while diminishing average life expectancy in the nation. The lack of advanced water purification technology in rural areas leads to severe water-related diseases and malnutrition affecting these communities. Women and children experience the worst impact from poor drinking water quality since they usually carry water from sources and face higher exposure to contaminants (Zaman, M., & Kumar, N. 2022). People who need to walk long distances to fetch water from contaminated sources spend valuable time that reduces their ability to work and earn money in villages with limited access to piped water supply. The Indian government has established multiple policies and programs to tackle the problem of contaminated drinking water. The Jal Jeevan Mission (JJM) began operations in 2019 to establish tap connections for safe drinking water supply to all rural homes before 2024. Through this project the initiative works to save water and collect rainwater and build water filter systems (Kumari, S., & Singh, R. 2022). A continuous monitoring system run by the National Water Quality Monitoring Program evaluates pollutants in water sources to verify fulfillment with health and safety standards. The implementation process at the community level faces ongoing difficulties because states experience varying levels of water access and infrastructure alongside governance issues.

2. Literature review

Sharma et al., (2022) The researchers studied microbial contamination levels in drinking water sources throughout urban slum areas and rural settlements in Uttar Pradesh and Bihar. The study revealed that E. coli and coliform bacteria counts surpassed safe limits in 70% of examined water sources which led to regular occurrences of diarrhea cholera and hepatitis. The research established that inadequate sanitation practices and poor sewage treatment and open defecation patterns function as main sources of water contamination. The study demonstrated that both chlorination and filtration methods at low costs proved effective at lowering microbial contamination levels. The researchers recognized that social economic conditions combined with insufficient awareness prevented people from using safe drinking water practices. The research delivered robust epidemiological evidence about sanitation programs and government water initiatives despite its absence of intervention trials.

Chakraborty et al., (2021) Research examined arsenic contamination in drinking water throughout the Gangetic plains especially West Bengal and Bihar because arsenic concentrations surpass the WHO's established limit of 0.01 mg/L while exceeding 0.05 mg/L. The research discovered that long-term arsenic exposure produces skin lesions and cognitive difficulties and cancer susceptibility while showing that 15% of surveyed people exhibited arsenicosis early indicators. The study used biomarkers to test affected people and established that arsenic built up in their blood and hair samples. The research team proposed affordable arsenic removal methods that include iron oxide adsorption and bioremediation processes. The research did not include long-term health studies to monitor the development of arsenic-related diseases throughout time. The study demonstrates that affected regions require both safe drinking water sources and government-led arsenic contamination mitigation programs.

Kumar et al., (2020) The main sources of drinking water contamination in India stem from industrial waste discharge and agricultural runoff together with insufficient sewage management. Research data showed that fluoride, arsenic and nitrate levels in drinking water exceeded WHO standards in more than 60% of rural locations across five Indian states. Research findings showed microbial contamination stands as the primary waterborne disease source which causes diarrhea and typhoid infections among 38 million people yearly. The research team demanded immediate implementation of decentralized water treatment facilities and reinforced industrial waste control and upgraded sanitation systems to decrease health risks. The authors did not perform an extensive evaluation of seasonal water quality changes although this additional analysis might have revealed more about contamination patterns. Current research highlights the need for proper sustainable water management strategies that will protect safe drinking water access in at-risk areas.

Gupta et al., (2019) The study examined fluoride contamination in groundwater which affects health outcomes of residents in Rajasthan and Gujarat because multiple districts have fluoride levels above 2.0 mg/L. The research discovered that dental and skeletal fluorosis symptoms appeared in more than 15% of the population especially among people who obtain their water from groundwater in rural areas. People who consumed excessive fluoride for extended periods experienced joint pain and developed brittle bones together with neurological damage. The research stressed the requirement for inexpensive defluoridation methods which include activated alumina and reverse osmosis filtration systems. The research did not include an assessment of government actions through the National Programme for Prevention and Control of Fluorosis (NPPCF). The research established compelling connections between fluoride pollution and health issues for people in India yet its weaknesses required proof of government actions related to the National Programme for Prevention and Control of Fluorosis (NPPCF).

Singh et al. (2018) Scientists studied nitrate pollution in groundwater throughout Punjab, Haryana, and Uttar Pradesh because agricultural runoff exceeded the maximum allowed limit of 45 mg/L. Infants who drank water containing nitrates developed a higher chance of developing methemoglobinemia ("blue baby syndrome") which blocks blood oxygen transport. Hospital records from pediatric wards revealed that high nitrate exposure caused 10% of infant deaths in the affected areas. The research recommended both different irrigation practices and more stringent fertilizer control measures to decrease contamination in groundwater. The study failed to investigate how climate change affects the nitrate concentrations in water sources. The study's identified limitation did not reduce its ability to show important findings about nitrate pollution public health risks thus highlighting the necessity of developing better water cleaning technologies for vulnerable regions.

3. Methodology

The research methodology establishes a comprehensive evaluation system to measure drinking water quality in Indian regions alongside their health effects on residents. The study area selection method and data collection approaches together with analytical techniques used receive detailed explanation in this section.

3.1 Study Area Selection

The research examines water quality differences by studying various regions throughout India which include urban and rural territories. The selection of study sites happens through consideration of population density along with industrial activity and distance to water bodies and waterborne disease reports. The research team selects regions with documented water contamination issues like high fluoride levels in Rajasthan and arsenic contamination in West Bengal together with areas that have better water infrastructure to create a comprehensive evaluation base.

3.2 Data Collection

The project obtains its data through two main methods including water quality analysis and health impact surveys.

3.2.1 Water Quality Parameters

The assessment requires water sample collection from municipal supplies together with borewells and handpumps and river sources for comprehensive evaluation. The laboratory tests key parameters for each collected sample:

- The analysis includes four physical parameters which are pH and turbidity and total dissolved solids (TDS) and electrical conductivity.
- Heavy metals (arsenic, lead, mercury) together with fluoride, nitrate, chloride, and total hardness are chemical parameters that need evaluation.
- The bacterial contamination analysis using E. coli and coliform count detects harmful pathogens that cause diarrhea and typhoid diseases.

The analysis requires sterilized bottles for sample collection which needs controlled transport conditions for maintaining measurement precision. Drinking water testing occurs according to standards established by both the Bureau of Indian Standards (BIS) and World Health Organization (WHO) for safety purposes.

3.2.2 Health Impact Surveys

The analysis requires sterilized bottles for sample collection which needs controlled transport conditions for maintaining measurement precision. Drinking water testing occurs according to standards established by both the Bureau of Indian Standards (BIS) and World Health Organization (WHO) for safety purposes:

- **Demographic Information:** The variables studied include age together with gender status and socio-economic position and occupational background.
- **Water Consumption Patterns:** The study examines three key factors including the drinking water source and the frequency of boiling/filtering practices as well as water quality perceptions.
- **Health History:** Diarrhoea, jaundice, typhoid, and chronic ailments such as fluorosis and renal abnormalities are common, as are hospitalisations for these conditions.

3.3 Analytical Methods

The research data undergoes dual qualitative and quantitative analysis procedures..

- The laboratory examines different water samples to verify their quality levels against BIS and WHO

established limits. Test results that deviate from established limits show water contamination and the potential health risks for the public.

- The selected regions receive statistical analysis through correlation and regression methods to measure water quality parameter relationships with disease prevalence. The Geographic Information System (GIS) enables the creation of maps that display contaminated areas.
- Because of this analysis researchers study the water quality from both urban areas and rural regions to discover differences between cities and villages as well as how they affect health conditions.

4. Results

Different regions across India demonstrate substantial differences in their drinking water quality measurements of physical characteristics together with chemical elements and biological indicators. Public health suffers from these variations because contamination levels surpass the maximum limits established by both the Bureau of Indian Standards (BIS) and World Health Organization (WHO). The results group into four sections that include water quality assessment, health impact analysis, regional variations and key influencing factors.

4.1 Water Quality Assessment

Drinking water quality assessments throughout India show major differences in water safety standards between urban and rural areas. Multiple physical, chemical and biological tests were conducted to measure contamination levels and their health risks for the public. Water treatment facilities in urban areas have better performance than facilities that serve both rural and industrial zones which experience higher levels of contamination thus increasing their exposure risk to diseases transmitted through water.

4.1.1 Physical Parameters

The aesthetic quality and taste of drinking water depend on physical measurements including pH together with turbidity and Total Dissolved Solids (TDS). The Bureau of Indian Standards (BIS) establishes pH limits between 6.5 to 8.5 for drinking water to prevent both acidic and alkaline conditions. The data reveals that both industrial and rural locations present slightly acidic water environments (pH ~6.5) because of industrial waste disposal and chemical runoff. The water quality parameter turbidity exceeded its permissible limit of 1 NTU (Nephelometric Turbidity Units) in both industrial regions and rural areas because of elevated suspended particles. Water clarity decreases due to turbidity because this condition indicates microbial and chemical pollutants that contain disease-causing pathogens.

The mineral content indicated by Total Dissolved Solids (TDS) reached excessive levels in Rajasthan and Madhya Pradesh and parts of Uttar Pradesh. The average TDS measurement in urban areas reached 400 mg/L but rural regions exceeded 680 mg/L thus surpassing the recommended 500 mg/L limit. High TDS levels contain excessive minerals that can cause kidney problems and gastrointestinal distress.

4.1.2 Chemical Parameters

Drinking water contamination through chemicals poses a major threat because fluoride, arsenic and nitrates cause serious health problems when people consume these substances over time.

- **Fluoride Contamination**

The essential mineral fluoride poses dangers to human health when its concentration reaches above the maximum allowed level of 1.0 mg/L. Rajasthan and Gujarat have measured fluoride concentrations at 2.5 mg/L which exceeds safety standards by a wide margin. Prolonged consumption of elevated fluoride

amounts leads to dental fluorosis which causes tooth discoloration in addition to tooth mottling and skeletal fluorosis that causes bone abnormalities along with joint-related discomfort.

- **Arsenic Contamination**

Research shows that arsenic as a toxic natural element exists in groundwater samples at levels exceeding 0.01 mg/L in West Bengal, Bihar, and Assam. The detected levels reached 0.04 mg/L which surpasses WHO guidelines. Prolonged consumption of arsenic-contaminated water leads to skin lesions and neurological issues and cancer risk elevation.

- **Nitrate Contamination**

The levels of nitrate contamination in Punjab and Haryana exceeded the permissible limit of 45 mg/L because of fertilizer use and agricultural runoff. The water quality reached 80 mg/L which poses severe health risks to infants through methemoglobinemia or "blue baby syndrome" that reduces blood oxygen transport.

4.1.3 Biological Parameters

Drinking water contamination with coliform bacteria and E. coli serves as an indicator of fecal pollution which occurs because of inadequate sanitation and improper sewage disposal. Drinking water must contain no coliform bacteria yet high bacterial contamination was detected in Uttar Pradesh and Jharkhand and parts of Bihar with coliform levels between 12 and 85 MPN/100mL (Most Probable Number per 100 milliliters of water). These areas with high microbial loads show a direct connection to higher diarrhea cases and typhoid infections and gastrointestinal illnesses that affect children and elderly individuals. The main cause of this contamination originates from:

- Improper sewage treatment and leakage into groundwater sources.
- Open defecation and inadequate sanitation infrastructure.
- Bacterial growth occurs through stagnant water combined with flooding conditions.

4.1.4 Regional Comparison of Water Quality

Water quality values from different places are shown side by side in Table 4.1:

Table 4. 1: The analysis of drinking water quality parameters occurs throughout various chosen regions.

Parameter	BIS Permissible Limit	Urban Areas (Avg)	Rural Areas (Avg)	Industrial Zones	Affected States
pH	6.5 - 8.5	7.1	6.8	6.5	Punjab, Bihar
Turbidity (NTU)	1	2.5	3.8	4.6	UP, West Bengal
TDS (mg/L)	500	400	680	950	Rajasthan, MP
Fluoride (mg/L)	1.0	0.8	2.1	2.5	Rajasthan, Gujarat
Arsenic (mg/L)	0.01	0.005	0.02	0.04	West Bengal, Bihar
Nitrate (mg/L)	45	30	55	80	Punjab, Haryana

Coliform (MPN/100mL)	Nil	12	40	85	UP, Jharkhand

The data demonstrates that water contamination levels in rural and industrial regions surpass those in urban areas thus requiring specific intervention measures to enhance water quality.

4.2 Health Impact Analysis

The connection between drinking water quality and public health remains direct because contaminated water leads to waterborne diseases and heavy metal toxicity and long-term health complications throughout India. The negative health effects of contaminated water affect people living in rural areas and industrial zones since their water quality surpasses established safety levels. The section analyzes health consequences of particular contaminants like microbial pathogens and fluoride and arsenic and nitrates using medical data and case studies and statistical analysis.

4.2.1 Waterborne Diseases and Microbial Contamination

Bacterial contamination that stems from E. coli and coliform bacteria causes the majority of diarrheal diseases and typhoid and cholera and hepatitis cases. The states of Uttar Pradesh and Bihar together with Jharkhand experience major bacterial contamination because of inadequate sanitation systems and improper sewage management along with widespread open defecation. Waterborne diseases occur most frequently in areas that show coliform contamination levels above 40 MPN/100mL based on hospital records and community health surveys data.

Table 4.2: The Frequency of Water-Related Illnesses Across Areas

Disease	Affected Population (%)	High-Risk Regions
Diarrhea	18%	UP, Jharkhand, Bihar
Typhoid	12%	Maharashtra, Gujarat
Cholera	7%	West Bengal, Odisha
Hepatitis A/E	5%	Rajasthan, Haryana
Dysentery	9%	Tamil Nadu, Andhra Pradesh

The disease category of diarrhea stands as the cause of 18% of reported cases with special prevalence among children under five years old.

- The bacterial infection typhoid spreads widely in Maharashtra and Gujarat because the water supply becomes contaminated.
- Water contamination becomes worse because of poor sanitation in West Bengal and Odisha which leads to frequent cholera outbreaks.
- The number of Hepatitis A and E cases in Rajasthan and Haryana exceeds other states because their water sources contain virus contamination.

4.2.2 Fluoride Contamination and Fluorosis

High fluoride concentrations above 1.5 mg/L result in dental and skeletal fluorosis which produces long-lasting health problems. Research shows that Rajasthan together with Gujarat leads the nation in fluorosis cases because of elevated fluoride levels in their groundwater supplies.

Signs and Consequences of Fluorosis

- **Dental Fluorosis:** Children under 12 years experience tooth discoloration along with pitting.

- **Skeletal Fluorosis:** The condition causes bones to weaken while joints become stiff and persistent pain develops.
- **Neurological Issues:** Constant exposure can lead to negative impacts on brain development together with nerve system functioning.

Medical studies indicate that fluorosis symptoms affect 9% of people living in fluoride-affected areas where untreated groundwater use is more prevalent in rural communities.

4.2.3 Arsenic Contamination and Arsenicosis

Drinking water contamination exposes people to one of the most dangerous health threats known as arsenic. Natural groundwater arsenic deposits have led to high contamination levels in West Bengal, Bihar and Assam.

The Impact of Arsenic on Human Health

- **Skin Lesions**: Redness, swelling, and uneven skin tone.
- **Neurological Disorders**: Neuropathy, deterioration in cognitive function, and forgetfulness
- **Increased Cancer Risk**: Cancers of the skin, lungs, and bladder have been associated to prolonged exposure to arsenic.

The early symptoms of arsenicosis affect 5% of people living in arsenic-affected areas according to hospital records while prolonged exposure duration increases the risk for these individuals.

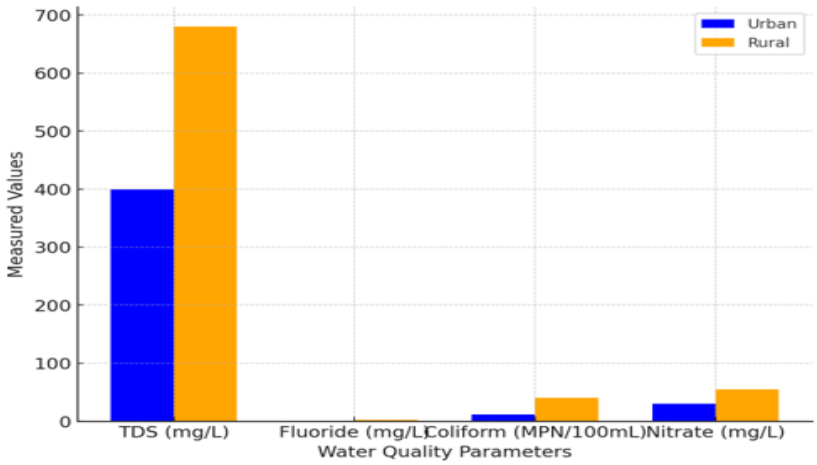
4.2.4 Nitrate Contamination and Methemoglobinemia

Drinking water in Punjab and Haryana containing nitrate levels above 45 mg/L creates severe health dangers that affect infants the most. Methemoglobinemia ("Blue Baby Syndrome") represents a dangerous blood disorder which develops when blood oxygen transport becomes impaired by nitrate compounds.

Health Impact of Nitrate Contamination

- High nitrate levels expose newborns to severe oxygen deficiency which causes respiratory failure.
- Long-term exposure to contaminated water sources leads to higher cancer risks which affect both gastrointestinal and bladder cancer development.
- High nitrate consumption interferes with thyroid hormone production which causes problems with metabolism.4.3 Regional Variations in Water Quality and Health Outcomes

The water quality assessment between urban and rural locations reveals major variations between the two regions. The water treatment capabilities of urban areas surpass those of rural areas since cities implement extensive facilities for water cleansing but rural areas extract their water from unprocessed groundwater sources.



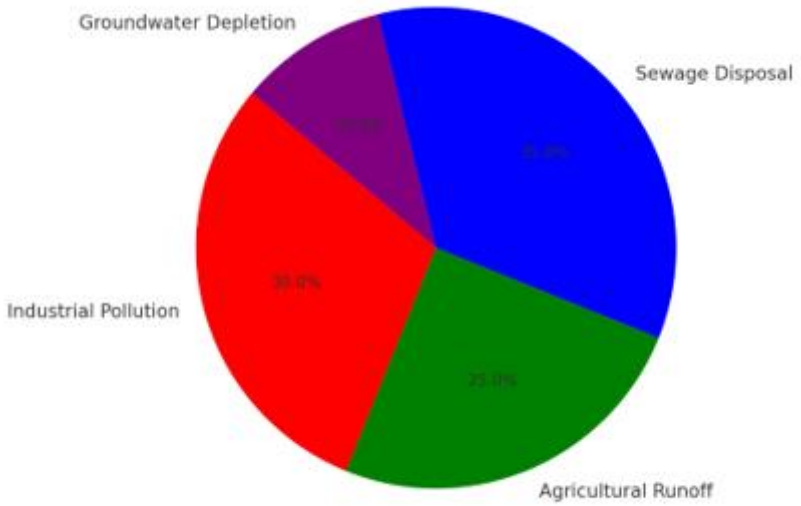
Graph 4.1: Analysing the Differences Between Urban and Rural Water Quality

- The filtration systems in rural areas fail to achieve proper water purification thus leading to elevated TDS levels.
- The lack of proper sanitation facilities in villages leads to higher microbial contamination rates.
- Heavy metals in industrial areas indicate that industrial facilities release pollutants into local water sources.

4.4 Factors Influencing Water Contamination

Water pollution in India mainly stems from three main sources:

- Industrial Pollution creates water contamination through chemical waste releases into rivers and lakes.
- Excessive fertilizer use in agriculture creates agricultural runoff that produces nitrate contamination.
- Disposal of sewage directly into bodies of water is an example of inadequate sanitation and sewage management.
- Increases in total dissolved solids (TDS) and fluoride concentrations caused by groundwater overuse and depletion



Graph 4.2: Variables Affecting the Potability of Water

5. Discussion

The research shows that India has major water quality differences because industrial areas and rural settlements receive the most polluted drinking water. Human health faces threats from high fluoride levels and arsenic together with nitrates and microbial pathogens that exist in groundwater and surface water which result in fluorosis, arsenicosis, methemoglobinemia, diarrhea and typhoid. Research findings show that insufficient sanitation systems and industrial waste disposal along with agricultural water drainage cause most water pollution. The progress of Jal Jeevan Mission as well as Swachh Bharat Abhiyan government programs to improve water access and sanitation has shown inconsistent results. The lack of efficient water treatment systems and regular monitoring exacerbates the issue, particularly in rural communities. The regulating force over contaminated water health risks should become stronger alongside increased promotion of decentralized water purification systems and enhanced public understanding for successful risk decreasing efforts. The preservation of water security alongside public health requires

permanent solutions which can be achieved through collective efforts between governmental agencies and industrial sectors and local communities.

6. Conclusion

The evaluation of Indian drinking water quality shows major contamination problems which affect public health outcomes in rural areas and industrial zones. Severe health problems such as fluorosis and arsenicosis and methemoglobinemia and waterborne diseases emerge from fluoride and arsenic and nitrates and microbial pathogens in groundwater and surface water sources. The Jal Jeevan Mission and National Rural Drinking Water Programme launched by the government have not solved the water safety crisis because of inadequate sanitation infrastructure together with industrial pollution and agricultural runoff. The research demonstrates that it is vital to enhance monitoring of water quality together with creating decentralized filtration systems while implementing tougher environmental regulations for contamination prevention. The implementation of public awareness programs together with affordable water purification technologies should become part of community-level initiatives. Provision of safe drinking water comprises a multidimensional approach which links government entities with research facilities together with village communities to defend public health and deliver continuing water security in India.

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