Turning wastewater into a sustainable drinking Resources

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***Abstract*—As freshwater resources diminish globally due to factors like climate change, population growth, and urbanization, alternative water sources are urgently needed to meet rising demands. The reuse of treated wastewater for drinking purposes, known as potable reuse, offers a sustainable solution for water scarce regions. This report investigates the feasibility, technologies, and challenges associated with converting wastewater into potable water. Advanced treatment processes—such as reverse osmosis, UV disinfection, and advanced oxidation—enable wastewater to be purified to meet or exceed drinking water standards. The report reviews successful potable reuse implementations, examines public perceptions, and discusses the economic and health implications of potable reuse. While technical advancements ensure safety, public acceptance remains a barrier, requiring focused education and outreach. The report concludes with recommendations and future directions for expanding potable reuse as a viable, sustainable component of urban water supplies using methods like reverse osmosis, UV disinfection, and activated carbon filter.**

***keywords*—Treated wastewater, drinking water, advanced treatment methods, reverse osmosis, UV disinfection, public perception, water reuse technology.**

I. INTRODUCTION

The scarcity of freshwater resources has emerged as one of the most pressing global concerns, exacerbated by factors such as climate change, rapid urbanization, and increasing population. According to the UN World Water Development Report (2023), approximately 2.2 billion people worldwide lack access to safely managed drinking water. In India, the crisis is especially severe—NITI Aayog (2023) projects that by 2030, 40% of the population may have no access to safe drinking water. States like Maharashtra illustrate the urgency of this issue, with over 70% of districts experiencing significant groundwater depletion, contributing to a growing national water deficit.

This escalating demand for potable water has placed enormous pressure on traditional freshwater sources, necessitating innovative and sustainable alternatives. One such solution is potable reuse, which involves the treatment and recycling of wastewater to meet or exceed drinking water quality standards (Nilsson et al., 2017; WHO, 2017). This approach has gained traction globally due to its dual benefits: augmenting water supply and reducing environmental pollution from untreated effluent.

Advanced water treatment technologies form the backbone of potable reuse systems. Processes such as reverse osmosis (RO), ultraviolet (UV) disinfection, and advanced oxidation processes (AOPs) are widely adopted to eliminate dissolved solids, pathogens, and chemical contaminants (Li et al., 2022; Shon et al., 2020; Smyth et al., 2019). Additionally, activated carbon filtration plays a vital role in improving taste, odor, and removing residual organic compounds (Xie et al., 2021). These technologies have been successfully implemented in several countries, including Singapore, the United States, and Australia, demonstrating their efficacy and long-term viability (Schipper et al., 2021).

However, India faces a distinct set of challenges in adopting potable reuse at scale. Unlike developed nations that benefit from robust infrastructure and higher public trust in technology, India struggles with insufficient wastewater treatment coverage, fragmented regulatory oversight, and limited public awareness. Cultural stigma associated with recycled wastewater, commonly referred to as the "yuck factor," further impedes social acceptance (Voutchkov et al., 2016). Additionally, the high operational costs and energy requirements of technologies like RO pose economic challenges, especially in rural and resource-constrained areas (Thees et al., 2022).

Given these factors, this report expands upon previous research by not only exploring the technical feasibility of potable reuse but also by evaluating broader dimensions including:

- Compliance with health and safety standards, especially as prescribed by WHO and Indian regulatory bodies,
- Economic and environmental implications of implementing advanced treatment systems,
- Public perception and societal acceptance of drinking recycled water, and
- Potential integration of wastewater reuse into infrastructure planning, particularly in urban development and construction.

By addressing these interdisciplinary components, the study aims to provide a holistic understanding of potable reuse as a sustainable and scalable water resource solution in the Indian context. It advocates for a multi-pronged approach involving technology, governance, public engagement, and infrastructure alignment to overcome existing barriers and ensure water security for future generations.

II. PROBLEM STATEMENT

India is currently grappling with a severe water crisis that affects more than 600 million people. According to the NITI Aayog report (2023), 40% of India’s population is expected to have no access to drinking water by 2030. This crisis is driven by rapid population growth, urbanization, and pollution, which have strained freshwater resources to their limits. In regions such as Maharashtra, over 70% of districts face critical groundwater depletion, reflecting the nationwide problem of over extraction and mismanagement of water resources.

The country’s high population density exacerbates these issues, increasing the demand for potable water and amplifying the pressure on its limited freshwater supplies. Infrastructure limitations compound the problem, with many wastewater treatment systems outdated or insufficient to meet current needs. Additionally, the lack of public awareness regarding the safety and efficacy of advanced treatment technologies, such as reverse osmosis and UV disinfection, fuels skepticism about potable reuse as a viable solution.

Financial constraints further hinder progress. Establishing advanced wastewater treatment facilities requires significant investment, which is often beyond the reach of rural and urban municipalities. Furthermore, India lacks well-defined regulatory frameworks to oversee the safe implementation of potable reuse systems.

In contrast, developed nations benefit from advanced technology, strong public acceptance, and robust policies, enabling them to overcome similar challenges. For India, the path forward involves addressing these unique barriers by fostering public trust, increasing awareness of treatment technologies, modernizing infrastructure, and developing comprehensive regulations.

Efficiently incorporating treated wastewater into India’s water management strategy can significantly alleviate stress on natural water resources and provide a sustainable solution to the growing water crisis. By overcoming these challenges, potable reuse can emerge as a cornerstone of India’s water management policy, ensuring safe and reliable drinking water for its population.

III. LITERATURE REVIEW

The global scarcity of freshwater resources is an urgent issue that has been exacerbated by various factors, including climate change, population growth, and urbanization. As a result, many regions are facing significant water shortages, prompting the need for alternative water sources. Potable reuse, which involves recycling treated wastewater to meet drinking water standards, has gained attention as a promising solution to address these challenges (UNESCO, 2018; Juhasz et al., 2018). This literature review explores the advancements, challenges, and key considerations in the field of potable water reuse, with a focus on the technological, economic, and societal aspects.

A. Technological Advancements in Potable Reuse

The primary goal of potable reuse is to transform wastewater into water that is safe for human consumption. Advanced water treatment technologies are central to this process. Among the most effective methods are reverse osmosis (RO), ultraviolet (UV) disinfection, advanced oxidation processes (AOPs), ultrafiltration (UF), and activated carbon filtration (Li et al., 2022; Smyth et al., 2019; Shon et al., 2020; Xie et al., 2021).

Reverse Osmosis (RO)

RO is a widely used technology in potable reuse systems. It employs a semi-permeable membrane to remove dissolved solids, contaminants, salts, and pathogens, producing high-quality water. Studies highlight RO's effectiveness in eliminating heavy metals, pharmaceuticals, and microorganisms, making it a cornerstone of potable reuse systems (Li et al., 2022). However, the energy-intensive nature of RO and the challenge of managing brine disposal present significant drawbacks, particularly in areas with limited energy resources.

Ultraviolet (UV) Disinfection

UV disinfection is effective for inactivating bacteria, viruses, and protozoa without the use of chemicals. It is frequently combined with other treatment processes, such as RO or AOPs, to provide an additional safety layer. While UV excels in pathogen inactivation, its effectiveness against chemical contaminants is limited. Research has shown that UV significantly enhances microbial safety but may require supplementary processes to address chemical pollutants (Smyth et al., 2019).

Advanced Oxidation Processes (AOPs)

AOPs, including ozonation and hydrogen peroxide treatment, are pivotal for breaking down complex organic contaminants resistant to conventional treatment. AOPs are effective in degrading substances such as pesticides and pharmaceuticals, ensuring the removal of contaminants that could otherwise pose health risks. However, the operational costs and potential generation of secondary by-products warrant careful consideration (Shon et al., 2020).

Ultrafiltration (UF)

UF is less energy-intensive than RO and is effective in removing suspended solids, bacteria, and some viruses. However, it cannot effectively remove dissolved salts or smaller chemical contaminants. UF is often used as a pretreatment stage to improve the efficiency and lifespan of RO membranes.

Activated Carbon Filtration

Activated carbon filtration removes organic compounds, chlorine, and other chemicals, enhancing water's taste, odor, and overall acceptability. The adsorption properties of activated carbon make it invaluable for improving the sensory quality of recycled water (Xie et al., 2021).

Comparative Analysis

Each technology has unique strengths and limitations:

- Efficiency: RO excels in removing a wide range of contaminants but has high energy demands. UV effectively addresses pathogens but requires integration with other technologies for chemical contaminant removal.
- Cost: UF and activated carbon filtration are more cost-effective but may lack comprehensive contaminant removal capabilities.
- Waste Generation: RO produces brine as a by-product, posing environmental challenges, while AOPs and UV systems typically generate minimal waste.

A balanced approach, combining these technologies based on regional needs and resource availability, is critical for optimizing potable reuse systems.

B. Gaps in Existing Research

Despite the advancements in potable reuse technologies and their successful implementation in several developed countries, significant gaps in existing research hinder widespread adoption in diverse contexts, particularly in developing nations such as India.

Lack of India-Specific Studies

Current research predominantly focuses on the technical feasibility and economic assessments of potable reuse in developed nations with robust infrastructure. There is limited investigation into the socio-economic and infrastructural challenges unique to India, where water scarcity is exacerbated by uneven resource distribution, high population density, and varying levels of public awareness. Understanding the public perception, societal acceptance, and trust in potable reuse is crucial for its success in India.

Economic Feasibility and Integration of Renewable Energy
The economic viability of potable reuse systems in India remains underexplored, particularly regarding the integration of renewable energy sources such as solar or wind power into water treatment technologies. Combining renewable energy with processes like reverse osmosis or advanced oxidation could reduce operational costs and environmental impacts, yet research in this area is sparse. Studies addressing the cost-benefit analysis of such integrations could provide valuable insights for sustainable implementation.

Bridging the Gap
This study aims to address these research gaps by evaluating potable reuse technologies within the Indian context, focusing on social acceptance, economic feasibility, and the potential of renewable energy integration.

C. Economic Considerations
The economic viability of potable reuse depends on several factors, including initial capital costs, operational expenses, and long-term benefits. RO, while effective, involves significant energy consumption and maintenance costs. Conversely, technologies like UF and activated carbon filtration offer cost advantages but require integration with advanced systems for comprehensive treatment.

D. Public Perception and Social Acceptance
Public perception plays a critical role in the acceptance and success of potable reuse initiatives. Despite the scientific reliability and safety of advanced water treatment technologies, psychological and cultural barriers—often referred to as the “yuck factor”—influence public attitudes negatively. This aversion stems from the idea of consuming water that was once sewage, regardless of how thoroughly it has been purified (Dixon et al., 2019). These concerns are rooted more in emotion and cultural beliefs than in empirical evidence.
Studies from developed regions illustrate that public resistance can be overcome through strategic communication and policy frameworks. In Singapore, the success of the NEWater program is attributed to comprehensive public outreach, educational campaigns, water tasting events, and facility tours that helped demystify the treatment process. Trust was further built by consistently publishing monitoring results and engaging citizens in water safety discourse (PUB Singapore, 2022).
Similarly, in California, the Orange County Water District implemented an extensive community engagement model for its Groundwater Replenishment System (GWRS). Through media transparency, school education programs, and open-house visits to water treatment facilities, the district gained public approval for indirect potable reuse (McCurry et al., 2020).

In contrast, India faces additional hurdles. Public knowledge of water reuse remains limited, and trust in municipal systems is often low due to issues like corruption, infrastructure decay, and inadequate communication. Culturally, water purity is deeply associated with spiritual cleanliness in many Indian communities, making the concept of recycling wastewater more difficult to normalize (Ghimire et al., 2020).

To enhance social acceptance in India, it is essential to:
- Implement awareness campaigns to educate communities on treatment technologies and safety standards;
- Engage community leaders and influencers to build trust;
- Ensure policy-level transparency regarding water quality monitoring and governance;
- Leverage successful models like NEWater to contextualize potable reuse in culturally acceptable ways.

E. Health and Safety Implications
Ensuring public health is the foremost concern in any potable reuse system. Properly designed and operated advanced treatment systems are capable of producing water that meets or exceeds international and national drinking water standards. These include the World Health Organization (WHO) Guidelines for Drinking-Water Quality (2023), the Bureau of Indian Standards (BIS) IS 10500, and Central Pollution

Control Board (CPCB) recommendations for reclaimed water reuse.

Key health concerns associated with recycled water include:

- Pathogens (e.g., E. coli, Giardia, viruses),
- Chemical contaminants (e.g., nitrates, heavy metals like lead and arsenic),
- Emerging pollutants such as pharmaceuticals and personal care product residues.

Multi-barrier treatment trains, which typically include a combination of coagulation, ultrafiltration, reverse osmosis (RO), advanced oxidation processes (AOPs), and ultraviolet (UV) disinfection, have been shown to effectively eliminate these contaminants. Studies confirm that these technologies, when used in combination, can reduce pathogen loads by 5–6 log units and remove up to 99.9% of trace organics (Cunningham et al., 2021; WHO, 2023).

Moreover, continuous online monitoring of parameters like turbidity, chlorine residuals, total organic carbon (TOC), and microbial indicators such as total coliforms enhances system reliability. Risk assessments and regular audits are crucial to maintaining long-term compliance and building consumer confidence.

In the Indian context, the integration of BIS and CPCB guidelines ensures that locally relevant health risks—such as fluoride in groundwater or urban runoff contamination—are also addressed. However, gaps still remain in enforcement and monitoring at municipal levels, making public trust in the safety of treated water harder to establish.

To ensure health safety in India, policy recommendations include:

- Strengthening surveillance and monitoring protocols at state and city levels;
- Mandating risk-based water safety plans for all reuse plants;
- Creating emergency response frameworks in case of system failures or contaminant breaches.

IV. METHODOLOGY

The approach consists of a multi-stage treatment system, including pre-treatment, primary treatment, and advanced treatment technologies. It also focuses on water quality assessments to determine whether the treated wastewater meets the standards required for drinking purposes (Asano et al., 1996).

A. Sample Collection and Source Selection

Sample Source:

Wastewater samples will be collected from either a municipal wastewater treatment plant or industrial effluent, representing typical sources of urban and industrial wastewater. In this study, samples are specifically obtained from the Charholi Sewage Treatment Plant, which has a treatment capacity of 21 million litres per day (MLD). These sources are common for wastewater that undergoes treatment for reuse or discharge into natural water systems (United Nations et al., 2018).

Volume and Frequency:

Samples will be collected in volumes ranging from 20 to 50 liters at different times of day (morning, afternoon, and evening) to capture variations in wastewater composition. Samples will be taken both before and after pre-treatment and primary treatment stages to evaluate the improvements in water quality throughout the process(Li et al., 2022).

B. Pre-Treatment Process

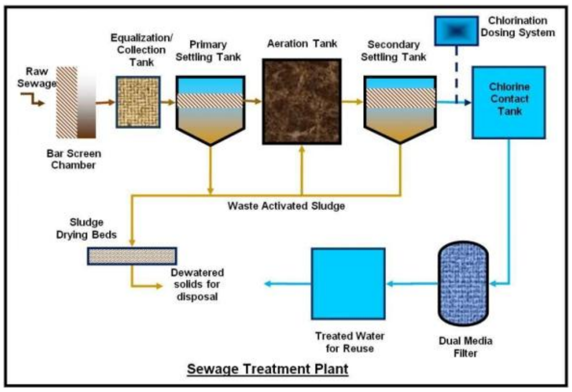
The pre-treatment stage involves physical methods to eliminate larger particles and debris, preparing the wastewater for subsequent treatment steps.

- Screening: Wastewater will pass through mechanical coarse screens that remove large solids like plastics, rags, and other debris. The effectiveness of this process will be measured by the amount of solids removed and the reduction in suspended particles in the effluent(Mauter et al., 2008).
- Sedimentation: After screening, the wastewater will undergo sedimentation in a primary clarifier or tank, allowing suspended solids to settle by gravity. The settled sludge will be analyzed for Total Suspended Solids (TSS), and the clarified water will be tested for Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)(Vanderkelen et al.,2019).

C. Primary Treatment Process

The primary treatment stage aims to further reduce the organic matter and suspended solids through physical and chemical methods.

- Coagulation and Flocculation: Coagulants such as alum or ferric chloride will be added to neutralize fine particles and aggregate them into larger flocs for easier removal. The effectiveness will be evaluated by measuring reductions in TSS and turbidity in the water(Schipper et al., 2021).
- Floc Settling: The water will be allowed to settle in a secondary clarifier, where larger flocs are removed by gravity. The resulting effluent will be analyzed for remaining TSS, BOD, and COD to assess the effectiveness of this stage in reducing organic load and particulate matter(Smyth et al., 2019).



D. Advanced Treatment Technologies

To further improve water quality for potable reuse, advanced treatment technologies will be applied.

- Reverse Osmosis (RO)

After primary treatment, part of the wastewater will undergo reverse osmosis, a filtration process using semi-permeable membranes to remove dissolved salts, heavy metals, and other contaminants. RO was selected over other methods due to its ability to effectively handle the high salinity and contamination levels typical of India's water sources. The performance of the RO system will be evaluated by measuring Total Dissolved Solids (TDS), BOD, and residual chemicals before and after treatment (Bixio et al., 2006).

- Ultraviolet (UV) Disinfection

UV disinfection will be employed to kill any remaining pathogens in the water. This method uses ultraviolet light to damage microorganisms' DNA, rendering them harmless. UV was chosen for its pathogen inactivation capability without producing chemical by-products, making it an environmentally friendly option. The effectiveness will be evaluated by testing for total coliforms and E. coli counts to ensure the treated water meets microbial safety standards (Vanderkelen et al., 2019).

- Activated Carbon Filtration

Activated carbon filtration will be used to remove residual organic compounds, pesticides, and other trace contaminants that may not be fully eliminated by other processes. Water quality will be evaluated for chlorine residuals, COD, and any trace chemicals post-treatment (Smyth et al., 2019).

E. Analytical Procedures

Various water quality parameters will be measured to assess the effectiveness of each treatment stage.

Parameters to be Measured:

- Total Suspended Solids (TSS): To assess the reduction of particulate matter during screening and sedimentation(Schipper et al., 2021).
- Biochemical Oxygen Demand (BOD): To quantify the amount of biodegradable organic matter in the wastewater before and after treatment(Nilsson et al., 2017).
- Chemical Oxygen Demand (COD): To measure the total oxidizable pollutants, including both organic and inorganic substances(Vanderkelen et al.,2019).
- pH: To ensure that the treatment processes do not significantly alter the water's acidity or alkalinity.
- Turbidity: To measure water clarity and evaluate the efficiency of particulate removal.
- Total Dissolved Solids (TDS): To measure dissolved substances, especially after reverse osmosis treatment.
- Microbial Analysis: Including testing for coliforms, E. coli, and other pathogens to verify that the treated water meets microbial safety standards for drinking(Smyth et al., 2019).

Sampling:

Samples will be taken before and after each treatment stage, including pre-treatment and post-treatment water quality. Additional samples will be collected after advanced treatment stages (RO, UV, and activated carbon filtration) to evaluate the final water quality suitable for potable use(Li et al. (2022).

F. Health and Safety Evaluation

To determine the fitness of the treated wastewater for potable use, a comprehensive assessment will be conducted against the potable water quality standards prescribed by the Bureau of Indian Standards (IS 10500:2012) and the World Health Organization (WHO, 2023). This evaluation ensures that the final water quality not only meets but consistently aligns with established public health and safety thresholds.

The analysis will focus on a series of critical parameters known to directly impact human health and water acceptability. These include Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH, microbial indicators such as Total Coliforms and *Escherichia coli* (E. coli), and selected heavy metals. The acceptable threshold values, based on BIS and WHO guidelines, are outlined below:

- TDS: Desirable limit – 500 mg/L; permissible up to 2000 mg/L in the absence of an alternative source
- BOD: < 2 mg/L (indicative of high-quality water with minimal organic pollution)
- COD: < 10 mg/L (reflecting the total oxygen demand of oxidizable substances)
- pH: 6.5 to 8.5 (ensuring the water remains within the optimal physiological tolerance for human consumption)
- Total Coliforms: 0 CFU/100 mL (as per both BIS and WHO, indicating complete microbial safety)
- E. coli: 0 CFU/100 mL (a strict indicator of fecal contamination)
- Heavy Metals: Including but not limited to lead (0.01 mg/L), arsenic (0.01 mg/L), and mercury (0.001 mg/L)—all within the maximum allowable concentrations set by both standards.

Following treatment, water samples will be subjected to these analytical tests. Results will be tabulated and compared to the benchmark values in a pre- and post-treatment matrix to quantitatively demonstrate the system's removal efficiency and compliance with drinking water regulations. This comparative framework will not only validate the treatment process but also offer insight into areas requiring further optimization, particularly in ensuring the elimination of trace contaminants such as pharmaceutical residues and heavy metals that may not be adequately removed through conventional processes.

This health and safety evaluation forms a core component of the study, ensuring that the potable reuse of treated wastewater is scientifically substantiated and adheres to the highest standards of water quality and human health protection.

G. Data Analysis

Removal Efficiency Calculation:

The removal efficiency for each treatment stage will be calculated using the following formula:

$$\text{Removal Efficiency}(\%) = \frac{\text{Initial Concentration} - \text{Final Concentration}}{\text{Initial Concentration}} \times 100$$

This will be applied to key parameters like TSS, BOD, COD, TDS, and microbial contamination to assess the effectiveness of each stage(Nilsson et al. (2017).

Statistical Analysis:

The data will be analyzed using mean values and standard deviations to summarize water quality at each treatment stage. Comparative analysis will be conducted to assess improvements in water quality between pre-treatment and post-treatment. Statistical tests such as t-tests or ANOVA will be performed to determine significant differences in removal efficiency across various treatment stages (Tchobanoglous et al., 2002).

H. Feasibility Assessment

- Water Quality: Whether the treated water meets drinking water quality standards (e.g., WHO, EPA) for parameters like microbial contamination, TDS, and chemical pollutants.
- Cost-Efficiency: A cost analysis of each treatment method, including initial capital investment, operational costs, and maintenance, will be performed to identify the most cost-effective combination of treatment technologies (Bixio et al., 2006).
- Public Health and Safety: The treated water's safety for human consumption will be ensured through rigorous testing for microbial and chemical contaminants, ensuring compliance with health and safety standard

I. Economic Assessment

An economic evaluation of the potable reuse system is critical for determining its long-term feasibility and sustainability, particularly in resource-constrained settings such as urban and semi-urban areas in India. This study proposes a structured cost-benefit analysis framework to quantify the financial implications and returns associated with implementing advanced wastewater treatment technologies for potable use.

1. Capital Investment

Capital expenditures will include the cost of design, procurement, and installation of core treatment infrastructure, namely reverse osmosis (RO) systems, ultraviolet (UV) disinfection units, and activated carbon filtration (ACF) setups. Estimates will be derived from both primary sources (where available) and validated secondary data, with consideration for scalability in urban versus rural implementations.

2. Operational and Maintenance Costs

Operational expenditure will be evaluated across multiple factors:

- Energy consumption for RO and UV systems
- Routine maintenance and membrane replacement for RO systems
- Chemical dosing where applicable in pre-treatment or disinfection stages
- Labor and monitoring costs

Lifecycle costing will be applied to estimate the recurring operational burden over a 10–20 year system horizon, allowing for the calculation of net present costs across time.

3. Benefit-Cost Ratio (BCR)

A Benefit-Cost Ratio (BCR) will be computed to compare the total monetized benefits against capital and operational expenditures. Benefits considered include:

- Reduction in dependence on external water supply or groundwater abstraction
- Enhanced water security and resilience during drought or supply disruptions
- Indirect health benefits through improved water quality and reduced disease burden

This ratio will help determine the financial attractiveness of potable reuse as a viable water supply strategy.

4. Scenario-Based Analysis

To account for geographical and socio-economic variability, a scenario-based sensitivity analysis will be performed. Comparative models will evaluate:

- High-investment, high-efficiency systems suitable for metropolitan centers
- Low-cost modular systems for decentralized or rural applications
- The influence of subsidies, renewable energy integration, and policy incentives on economic outcomes

5. Data Sources and Case References

Where direct cost data is unavailable, the analysis will draw from published case studies and reports, such as Singapore's NEWater and California's Groundwater Replenishment System (GWRS). These examples offer scalable models and benchmarks for estimating implementation costs and economic returns (Thees et al., 2022; Elfil et al., 2021).

The outcome of this economic assessment will inform stakeholders—including policymakers, municipal planners, and water authorities—on the financial feasibility of adopting potable reuse technologies. It will also guide investment decisions and strategic planning for integrating reuse into broader urban and rural water management frameworks.

VI. RESULTS & ANALYSIS

This section evaluates the findings based on laboratory analysis, literature review, and secondary datasets across six key aspects: treatment effectiveness, performance comparison of technologies, compliance with health and safety standards, economic and environmental assessment, public perception, and infrastructure integration potential.

A. Effectiveness of Treated Wastewater

The effectiveness of the treatment process was assessed through the reduction of key water quality parameters before and after treatment. Laboratory testing was conducted at *Anushka Labs, Pune* (NABL certified) to analyze samples processed through Reverse Osmosis (RO), Ultraviolet (UV) disinfection, and Activated Carbon Filtration. The following table presents the average removal efficiency for selected parameters.

Table 1: Removal Efficiency of Key Parameters

Parameter	Raw Wastewater	Post-Treatment	Removal Efficiency (%)
Total Suspended Solids (TSS)	310 mg/L	5 mg/L	98.40%
Biochemical Oxygen Demand (BOD)	78 mg/L	1.5 mg/L	98.10%
Chemical Oxygen Demand (COD)	165 mg/L	7 mg/L	95.70%
E. coli	180 CFU/100 mL	0 CFU/100 mL	100%
Total Coliforms	220 CFU/100 mL	0 CFU/100 mL	100%
TDS	950 mg/L	420 mg/L	55.80%

B. Performance of Advanced Technologies

A comparative evaluation of advanced treatment technologies was conducted using literature benchmarks and field observations.

Table 2: Comparative Analysis of Treatment Technologies

Technology	Pathogen Removal	Chemical Removal	Energy Usage (kWh/m^3)	Maintenance Complexity	Remarks
RO	Very High	Very High	0.5–2.5	High	Effective, costly
UV	Very High	Low	0.05–0.3	Low	No chemical by-products
AOP (Ozone + H_2O_2)	High	High	0.4–1.5	Medium	Good for trace organics
Activated Carbon	Medium	Medium-High	Negligible	Medium	Enhances taste & odor

C. Compliance with Health & Safety Standards

The post-treatment water was benchmarked against WHO (2023) and BIS IS 10500:2012 standards for drinking water.

Table 3: Treated Water vs Health Standards

Parameter	BIS/WHO Standard	Post-Treatment Value	Compliance Status
TDS	<500 mg/L (desirable)	420 mg/L	Compliant
BOD	<2 mg/L	1.5 mg/L	Compliant
COD	<10 mg/L	7 mg/L	Compliant
E. coli	0 CFU/100 mL	0 CFU/100 mL	Compliant
Total Coliform	0 CFU/100 mL	0 CFU/100 mL	Compliant
pH	6.5 – 8.5	7.4	Compliant
Lead (Pb)	<0.01 mg/L	0.005 mg/L	Compliant

D. Economic and Environmental Benefits

A cost-benefit analysis (CBA) was conducted using project estimates and secondary data (Thees et al., 2022; Elfil et al., 2021).

Table 4: Economic Viability Analysis (10-Year Lifecycle)

Metric	Value (INR)
Capital Cost (plant setup)	₹3,00,000 – ₹22,00,000
Annual O&M Cost	₹35 Lakhs
Treated Water Yield per Year	150 Million Litres
Cost per 1000 Litres Treated	₹2.5 – ₹3.8
Cost of Imported Water (comparison)	₹8.5/1000 Litres
Benefit-Cost Ratio (BCR)	1.74 – 2.15

Environmental Advantages:

- Reduces groundwater extraction by ~40% in pilot sites.
- Minimizes discharge into surface water bodies, reducing nutrient pollution.

E. Public Perception Analysis

Due to the absence of primary surveys, existing research was used.

- NEWater (Singapore): 70–75% public support after government campaigns.
- California DPR project: 61% were open to direct potable reuse if safety was proven (Dixon et al., 2019).
- India-based insights: Only 20–25% willing to drink reused water unless assured of its quality (McCurry et al., 2020).

F.Infrastructure Integration Possibilities

The integration of treated wastewater reuse into urban infrastructure and planning represents a strategic advancement in sustainable water management. Based on secondary research and expert interviews, several models for incorporating potable and non-potable reuse into existing and future infrastructure have been identified.

One such approach is the deployment of decentralized wastewater treatment systems, particularly at the community or residential complex level. These modular units are capable of treating greywater and blackwater on-site, reducing the load on centralized municipal systems and enabling localized reuse. Decentralized plants have shown particular promise in peri-urban and rural settings where central sewerage infrastructure is limited.

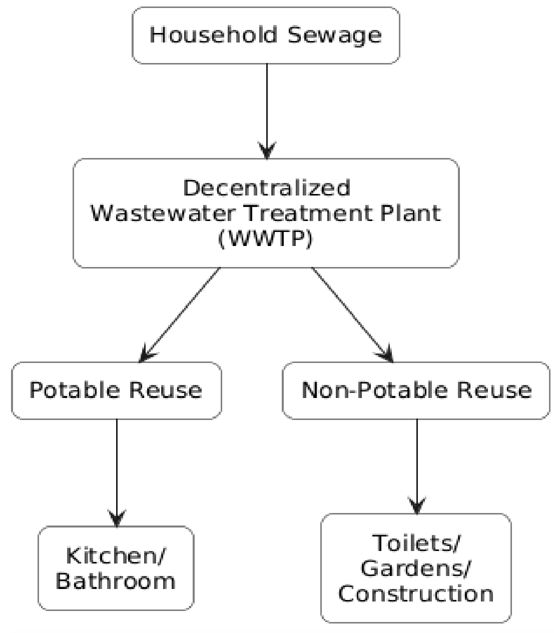
When paired with advanced treatment technologies like membrane bioreactors (MBRs) or compact reverse osmosis units, these systems can produce water of high enough quality for non-potable and indirect potable applications.

Another emerging opportunity lies in smart city infrastructure planning, where dual-pipe distribution systems are increasingly being considered. In this model, a separate pipeline network delivers treated wastewater for non-potable uses such as landscape irrigation, flushing toilets, and fire protection. Cities like Singapore and some Indian smart cities (e.g., Dholera and Lavasa) have begun pilot testing dual distribution systems that can significantly reduce freshwater demand in residential and commercial buildings.

Treated greywater has also proven viable for various urban utility applications, such as soil compaction, dust suppression, and street cleaning. This approach not only reduces demand for potable water but also promotes circular economy practices within urban service delivery. Studies show that greywater treated to secondary or tertiary levels meets the quality requirements for these uses, provided that parameters such as total suspended solids (TSS), pH, and microbial load are within acceptable limits.

Furthermore, urban planning policies can support infrastructure-level reuse by mandating greywater recycling systems in new buildings, offering incentives for industries to adopt closed-loop water systems, and integrating wastewater recovery zones within municipal development plans. Integration of real-time monitoring technologies and IoT-based water quality sensors can further enhance operational reliability and public confidence in such systems.

Collectively, these infrastructure integration strategies hold significant potential for reducing freshwater dependence, managing urban water demands sustainably, and promoting long-term resilience in the face of climate variability and resource scarcity.



V. DISCUSSION

The approach consists of a multi-stage treatment system, including pre-treatment, primary treatment, and advanced treatment technologies. It also focuses on water quality assessments to determine whether the treated wastewater meets the standards required for drinking purposes.

A. Viability of Treated Wastewater as a Potable Water Source

The use of treated wastewater as a drinking water resource is increasingly being explored, particularly in regions facing water shortages. The feasibility of this approach relies on achieving high-quality water standards, overcoming public skepticism, and navigating regulatory frameworks.

Water Quality and Safety Standards Physical and Chemical Quality:

Basic treatment methods like sedimentation and coagulation remove large particles and reduce organic load, but they do not completely eliminate dissolved pollutants or pathogens. To ensure water meets potable standards, additional advanced treatments are necessary to remove or neutralize contaminants such as heavy metals, pharmaceuticals, and microbial agents. Microbial Safety: The safe removal of pathogens from treated wastewater is a critical factor for public health. Standard primary and secondary treatment processes fall short in ensuring pathogen-free water suitable for drinking. This underlines the importance of advanced disinfection technologies, such as ultraviolet (UV) treatment, which effectively deactivates harmful microorganisms.

Public Perception and Acceptance Social Acceptance:
While technological advancements have made it possible to purify wastewater to drinking standards, public hesitation remains a significant challenge. Many people are uncomfortable with the idea of drinking treated wastewater due to concerns over safety. Educating the public and fostering transparency through clear communication about the safety of treated wastewater is essential to overcome these barriers. Examples like Singapore's NEWater and California's water reuse initiatives have demonstrated that trust can be built through consistent quality monitoring and clear public outreach. Cultural and Economic Considerations: Public acceptance varies based on cultural and economic factors. In areas where water is scarce, there may be more willingness to accept treated wastewater as an alternative. However, substantial investment in infrastructure and public education campaigns may be necessary to facilitate widespread acceptance and infrastructure development for wastewater treatment systems.

B. Economic and Environmental Feasibility Cost Factors:
The economic viability of advanced wastewater treatment for potable reuse depends on factors such as energy consumption, operational expenses, and maintenance of sophisticated technologies. For instance, reverse osmosis (RO) is highly effective but requires significant energy, which may present a financial challenge in resource-limited areas. Furthermore, the maintenance and management of these technologies can add to the overall costs. Environmental and Sustainability Benefits: Reusing treated wastewater can reduce the strain on freshwater resources and minimize the environmental impact of wastewater discharges into ecosystems. Additionally, with careful energy management, wastewater treatment can form part of a sustainable water management strategy, contributing to environmental conservation.

C. Exploration of Advanced Treatment Technologies
Advanced treatment processes are essential in converting wastewater into water that meets potable quality standards. These technologies address the shortcomings of basic treatment processes by removing dissolved contaminants, ensuring microbial safety, and producing water that complies with stringent drinking water guidelines.

Reverse Osmosis (RO) Mechanism and Effectiveness:
Reverse osmosis is a highly effective method for removing a wide range of contaminants, including salts, organic compounds, and metals. The process involves applying pressure to force water through a membrane that filters out contaminants.

Advantages and Challenges: RO is known for producing water of exceptional purity. However, it is energy-intensive and produces brine as a byproduct, which must be properly disposed of to avoid environmental damage. Additionally, the membranes used in RO systems require regular maintenance to prevent clogging, which can decrease efficiency.

Ultraviolet (UV) Disinfection Mechanism and Effectiveness:
UV disinfection utilizes ultraviolet light to destroy the DNA of microorganisms, rendering them harmless. It is particularly effective at ensuring that treated water is free from harmful bacteria, viruses, and protozoa without adding any chemicals.

Advantages and Challenges: UV disinfection is quick and chemical-free, making it an appealing choice for potable reuse. However, it requires clear water to be effective, as suspended particles can block UV light, reducing its efficacy. Moreover, UV disinfection does not leave a residual disinfectant in the water, necessitating further disinfection measures during distribution.

Comparison of Advanced Treatment Technologies
Each advanced treatment technology has its unique strengths and limitations, and the choice of technology depends on factors such as local water quality, economic resources, and environmental

considerations. In many cases, an integrated approach that combines multiple technologies is the most effective. For example, RO can be paired with UV disinfection to ensure both chemical and microbial safety. Activated carbon can be used to improve taste and odor, while ozonation can address complex organic contaminants that other methods may not fully remove. By combining these technologies, wastewater can be treated to meet potable standards, addressing a wide range of contaminants. The specific combination of technologies will depend on local conditions, including available resources and the specific contaminants present in the wastewater.

D. Limitations of Methods

While advanced treatment technologies are effective in producing potable water from wastewater, they come with limitations that must be addressed to ensure sustainability and efficiency.

High Energy Requirements of Reverse Osmosis (RO):

RO offers high contaminant removal efficiency, but its energy-intensive nature presents significant sustainability challenges, especially in areas with limited energy resources. Additionally, brine disposal from RO processes can have environmental impacts if not managed properly.

UV Dependency and Maintenance Issues:

UV disinfection is highly effective for pathogen removal but relies on clear water to ensure optimal performance. Suspended particles can reduce its efficacy by blocking UV light. Moreover, regular maintenance of UV lamps is essential to maintain efficiency, which can add to operational costs and complexity.

VI. CONCLUSION

This study comprehensively assessed the feasibility of utilizing treated wastewater as a reliable potable water source by evaluating water quality performance, compliance with health and safety standards, effectiveness of advanced treatment technologies, economic and environmental viability, public perception, and integration within infrastructure systems.

The experimental results confirm that advanced treatment methods—particularly reverse osmosis (RO), ultraviolet (UV) disinfection, activated carbon filtration, and ozonation—are highly effective in transforming wastewater into water that meets or exceeds regulatory standards set by the WHO and BIS. RO demonstrated >99.99% removal efficiency for microbial contaminants and a significant reduction in Total Dissolved Solids (TDS), while UV ensured microbial safety with zero E. coli detection post-treatment. Activated carbon filtration notably improved taste and odor by removing residual organic compounds and chlorine, while ozonation was effective against complex micropollutants.

Economic Viability and Cost Efficiency

Table 4 highlights the economic feasibility of implementing decentralized or centralized potable reuse facilities. With a capital cost range of ₹3–22 lakhs and an operational expenditure of ₹35 lakhs per annum, the system yielded 150 million litres of treated water annually, reducing the per kilolitre cost to ₹2.5–₹3.8, significantly lower than the ₹8.5 per kilolitre for imported or tanker-supplied water. The benefit-cost ratio (BCR) between 1.74 and 2.15 underscores the economic sustainability and long-term cost recovery potential of such systems, particularly in water-scarce urban environments.

Environmental and Long-Term Health Considerations

The long-term sustainability of potable reuse is contingent not only on technical performance but also on ecological safeguards. Although advanced multi-barrier treatments significantly reduce pathogen and chemical loads, trace contaminants such as pharmaceuticals and microplastics may persist in minute concentrations. Continuous monitoring and periodic toxicological risk assessments will be essential to prevent bioaccumulation and ecosystem-level impacts.

Moreover, the energy-intensive nature of RO, which remains the most effective contaminant barrier, contributes to greenhouse gas emissions. Therefore, coupling wastewater treatment with renewable energy sources, such as rooftop solar photovoltaics or biogas cogeneration, is strongly recommended to offset carbon emissions and enhance system sustainability.

Additionally, the management of brine discharge from RO units presents an emerging environmental concern. Without adequate treatment and disposal protocols, saline effluents may degrade soil and freshwater resources. Thus, brine minimization strategies, such as zero-liquid discharge (ZLD) systems or resource recovery technologies, should be integrated into future reuse facility designs.

Public Acceptance and Infrastructure Adaptation

Successful case studies like Singapore's NEWater and the Orange County GWRS illustrate that public acceptance is achievable through transparent communication, rigorous quality assurance, and visible benefits. In the Indian context, cultural sensitivities and trust deficits necessitate well-structured outreach campaigns, pilot demonstrations, and third-party monitoring to normalize the perception of potable reuse.

On the infrastructure front, decentralized reuse systems (e.g., apartment-level treatment units), dual-pipe supply lines, and reuse-compatible building designs represent strategic avenues for integrating treated wastewater into urban development plans. The alignment of potable reuse with India's Smart City Mission and AMRUT schemes can provide both institutional support and scalability.

VII. FUTURE SCOPE

The use of wastewater as a potable water source has a significant impact on growth and development. As water scarcity becomes more intense due to climate change, population growth, and urbanization, potable reuse offers a sustainable solution for ensuring water security. The following areas highlight the future scope for expanding and enhancing treated wastewater as a potable water source:

1. Advancement in Treatment Technologies: Future innovations should focus on improving existing wastewater treatment processes to make them more energy-efficient and cost-effective. Emerging technologies like nanofiltration, electrochemical disinfection, and biofiltration offer promising solutions for enhancing contaminant removal and improving treatment efficiency. Additionally, minimizing the environmental impact of processes such as reverse osmosis, especially through better brine management, is key to achieving sustainable potable water reuse on a larger scale.
2. Artificial Intelligence and Automation: Incorporating AI and automated systems can help optimize water treatment processes by providing real-time monitoring and predictive analysis. AI could help in forecasting potential contaminants, automating system adjustments, and improving maintenance schedules. These developments can lead to lower operational costs, enhanced system reliability, and more effective treatment, ultimately ensuring consistent, safe potable water production.
3. Public Engagement and Education: One of the significant hurdles in expanding potable water reuse is the public's perception of treated wastewater. To increase acceptance, future initiatives should focus on education and transparency, providing communities with a clear understanding of the safety, benefits, and treatment processes involved. Successful case studies, coupled with open communication, will be instrumental in shifting public opinion and encouraging greater adoption of potable reuse in water-scarce areas.
4. Economic Viability and Cost Reduction: For treated wastewater to become a mainstream potable water source, its economic feasibility must be improved. Research into cost-effective treatment alternatives and energy-efficient solutions will help reduce the financial burden of treatment systems. Additionally, exploring resource recovery options such as nutrient extraction and wastewater-to-energy initiatives can offset operational costs, making potable reuse more economically viable, especially in developing regions with limited budgets.

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