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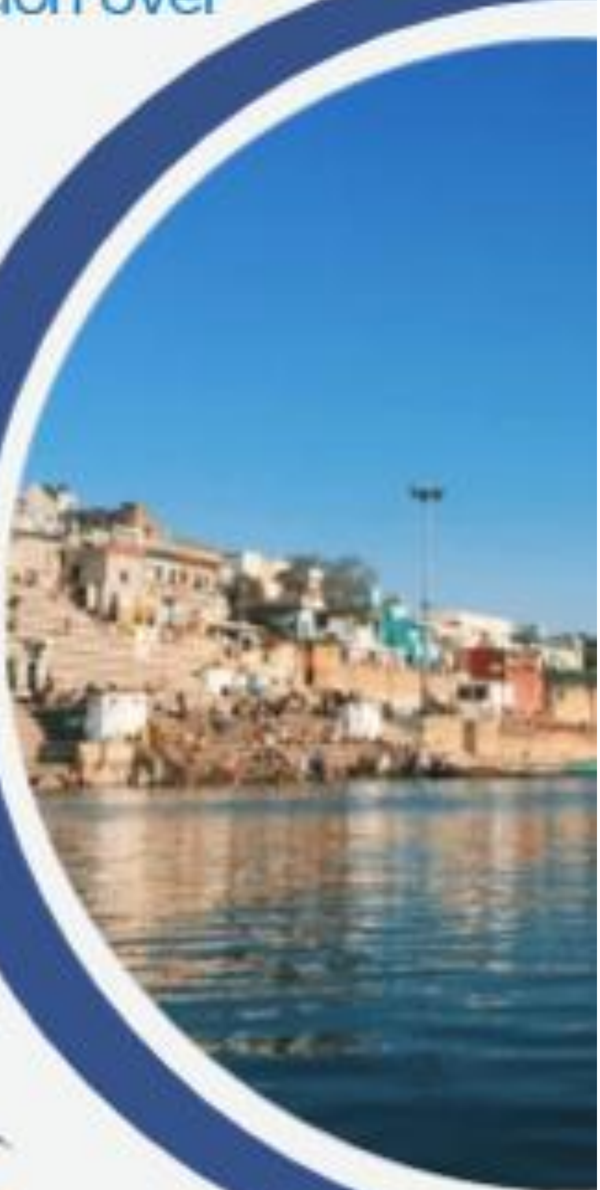
# REIMAGING WASTEWATER REUSE IN INDIA

## Prioritizing Ecosystem Rejuvenation over Direct Agricultural Reuse



Centre for Ganga River Basin Management and Studies
Indian Institute of Technology Kanpur

**REPORT PREPARED BY:**
**Vinod Tare**
Advisor & Mentor
cGanga, IIT Kanpur

# Preface

Water has always been at the centre of India's civilization, culture, economy and ecological security. Yet, the challenges confronting our water resources today extend far beyond the conventional perception of water scarcity. They encompass degradation of rivers and wetlands, declining groundwater reserves, deteriorating water quality, shrinking ecological functions, increasing energy demands, and growing concerns regarding public health and climate resilience. These interconnected challenges call for a fundamental rethinking of how we manage and reuse our water resources.

Across the world, wastewater reuse has rightly emerged as an essential component of integrated water resource management. Successful examples from countries such as Israel and Singapore have demonstrated the immense value of reclaiming treated wastewater under conditions of severe water scarcity. However, every nation's water policy must evolve from its own hydrological, ecological and socio-economic realities. India's unique monsoonal climate, extensive river systems, diverse landscapes and complex institutional framework require solutions that are fundamentally different from those developed for arid regions.

This report seeks to re-examine wastewater reuse from a broader systems perspective. It argues that the objective of wastewater management should not merely be maximizing water recovery, but maximizing societal, ecological and environmental benefits. Rather than viewing treated wastewater as a substitute for freshwater in agriculture alone, the report explores the opportunities of utilizing appropriately treated wastewater to rejuvenate rivers, ponds, lakes, wetlands and other degraded aquatic ecosystems. Such an approach strengthens groundwater recharge, restores environmental flows, enhances biodiversity, supports natural nutrient cycling, improves climate resilience and creates long-term public value while reducing many of the risks associated with large-scale direct agricultural reuse.

The report does not advocate replacing one approach with another in every circumstance. Instead, it emphasizes that wastewater reuse strategies must be evaluated through the lenses of public health, ecosystem sustainability, energy efficiency, economic viability and long-term environmental security. India's abundant monsoonal runoff provides a unique opportunity to integrate engineered wastewater treatment with natural ecological processes, thereby allowing our rivers and water bodies to resume their role as dynamic processors of water, sediments, nutrients and ecological functions.

It is hoped that the ideas presented herein will stimulate constructive scientific dialogue among policymakers, researchers, urban planners, engineers, environmental professionals and practitioners. The intention is not to prescribe a universal solution, but to encourage evidence-based policy thinking that aligns wastewater management with India's ecological realities and developmental aspirations.

As India advances towards a circular water economy, the success of our policies should ultimately be measured not only by the quantity of water reused, but by the extent to which they restore ecosystems, safeguard public health, strengthen water security and contribute to a sustainable future for generations to come.

**Dr. Vinod Tare**
Advisor & Mentor
Centre for Ganga River Basin Management & Studies (cGanga), IIT Kanpur

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# Reimagining Wastewater Reuse in India

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## A Public Health, Environmental, Economic, Energy and Sustainability Perspective

## 1. Introduction

The growing emphasis on circular water economy has led to increasing advocacy for wastewater treatment and reuse. International examples, particularly Israel and Singapore, are frequently cited as successful models where treated wastewater has become an integral component of water resource management.

However, direct comparison of India with Israel, Singapore, or other developed countries is neither scientifically appropriate nor practically realistic because of fundamental differences in:

- Scale of water use,
- Rainfall availability,
- Hydrological characteristics,
- Agricultural dependence,
- Socio-economic conditions,
- Institutional capacities,
- Energy availability,
- Public health realities,
- Governance structures,
- Environmental priorities.

India receives approximately **4,000 BCM of annual precipitation**, compared to about **10 BCM in Israel** and **1.7 BCM in Singapore**. India's annual water use is approximately **750 BCM**, compared to **2.5 BCM in Israel** and **0.8 BCM in Singapore**.

The fundamental challenge in India is therefore not absolute water scarcity at the national scale but rather:

- Seasonal variability,
- Spatial mismatch,
- Groundwater depletion,
- Pollution,
- Degradation of rivers and water bodies,
- Inadequate wastewater treatment,
- Declining ecosystem functionality.

Consequently, the question is not whether wastewater should be reused, but rather:

**"What form of wastewater reuse delivers the greatest long-term societal, ecological, economic, and environmental benefit under Indian conditions?"**

## 2. Why International Comparisons Must Be Interpreted Carefully

**Comparative Perspective**

| Parameter | India | Israel | Singapore |
|---|---|---|---|
| Area ($km^2$) | 3.287 million | 22,000 | 735 |
| Annual Rainfall (BCM) | ~4,000 | ~10 | ~1.7 |
| Annual Water Use (BCM) | ~750 | ~2.5 | ~0.8 |
| Wastewater Reuse (%) | ~3–8% | ~90% | ~40–50% |
| Irrigation Water from Reuse | <2% | ~50% | Limited agriculture |
| Energy Use per $m^3$ ($kWh/m^3$) | ~0.2 | ~1.2 | ~1.0 – 1.5 |

Israel and Singapore developed their wastewater reuse systems under conditions of extreme water scarcity and limited freshwater availability.

India, by contrast, receives nearly **400 times more rainfall than Israel** and more than **2,000 times the rainfall volume of Singapore**.

Therefore, wastewater reuse strategies in India should be developed in the context of restoring and enhancing the functionality of natural hydrological systems rather than merely maximizing water recovery.

## 3. Public Health Responsibility and Institutional Liability

Any Urban Local Body, State Government, Central Government, or associated agency recommending the use of untreated, partially treated, or inadequately treated sewage for agriculture may potentially assume responsibility for risks associated with:

- Pathogenic microorganisms,
- Antibiotic-resistant bacteria,
- Pharmaceutical residues,
- Endocrine-disrupting compounds,
- Heavy metals,
- Emerging contaminants,
- Microplastics and nanoplastics.

Such contaminants may affect:

- Farmers,
- Agricultural labourers,
- Livestock,
- Food chains,
- Consumers,
- Groundwater users.

Unlike Israel, maintaining uniform treatment standards and monitoring systems across thousands of Indian cities, towns, peri-urban settlements, and rural areas presents significant challenges.

Therefore, public health liability considerations cannot be ignored when advocating direct agricultural reuse.

## 4. Relative Risk: Agricultural Reuse versus Ecosystem Rejuvenation

It is important to recognize that several concerns often associated with agricultural reuse are not unique to agriculture.

These include:

- Pharmaceutical residues,
- Microplastics,
- Emerging contaminants,
- Antibiotic resistance,
- Potential contaminant migration,
- Long-term ecological impacts.

Such risks may also arise when treated wastewater is used for rejuvenating ponds, lakes, wetlands, streams, and other water bodies.

Therefore, the issue should not be framed as:

**Agricultural reuse = risky**
**Ecosystem rejuvenation = risk-free**

Instead, the issue should be viewed in terms of:

- Magnitude of risk,
- Exposure pathways,
- Ease of monitoring,
- Reversibility,
- Public benefit,
- Long-term sustainability.

### Agricultural Reuse

Potential exposure pathways include:

- Crop uptake,
- Fodder contamination,
- Livestock exposure,
- Food chain transfer,
- Farmer exposure,
- Consumer exposure.

### Ecosystem Rejuvenation

Potential risks include:

- Sediment contamination,
- Ecological impacts,
- Groundwater interactions,
- Accumulation of emerging contaminants.

However, exposure pathways can often be more effectively managed through:

- Controlled access,
- Non-contact uses,
- Ecological assimilation,
- Natural attenuation,
- Dilution,
- Sedimentation,
- Biological uptake.

Thus, ecosystem rejuvenation may offer lower direct human exposure while still requiring proper monitoring and management.

## 5. Long-Term Soil Health Concerns

Continuous irrigation using treated wastewater may result in long-term accumulation of:

- Salts,
- Sodium,
- Chlorides,
- Sulphates,
- Trace contaminants,
- Residual pollutants.

Over extended periods this may contribute to:

- Soil salinization,
- Sodicity,
- Reduced infiltration,
- Soil structural deterioration,
- Reduced agricultural productivity.

Many Indian regions are already facing serious soil degradation and declining soil organic carbon levels.

Accordingly, long-term soil health implications must be considered when evaluating wastewater reuse strategies.

## 6. Monsoonal Hydrology, Natural Flushing and Completion of the Salt Cycle

A critical distinction between India and countries such as Israel is the role of the monsoon.

India receives approximately 4,000 BCM of annual precipitation, most of which occurs during a concentrated monsoon period.

This generates enormous runoff volumes through:

- Drains,
- Streams,
- Rivers,
- Lakes,
- Ponds,
- Wetlands,
- Floodplains.

These annual monsoonal flows perform important ecological functions including:

- Sediment transport,
- Nutrient redistribution,
- Pollutant dilution,
- Groundwater recharge,
- Floodplain rejuvenation,
- Salt transport.

### Rivers as Natural Processors

Rivers are not merely conduits for water transport.

They are dynamic ecological systems that naturally:

- Process nutrients,
- Transport sediments,
- Redistribute organic matter,
- Complete biogeochemical cycles,
- Convey salts from terrestrial ecosystems toward terminal sinks such as estuaries and oceans.

This natural movement helps prevent excessive long-term accumulation of salts within terrestrial systems.

### Rejuvenated Water Bodies as Connected Ecosystems

When treated wastewater is used to maintain ecological flows in:

- Drains,
- Streams,
- Wetlands,
- Lakes,
- Ponds,

these systems become components of a connected hydrological network.

During non-monsoon periods they can:

- Sustain ecological functioning,
- Recharge groundwater,
- Support biodiversity,
- Maintain environmental flows.

During monsoon periods, accumulated salts and contaminants can be redistributed through natural hydrological processes including:

- Dilution,
- Transport,
- Dispersion,
- Sedimentation,
- Ecological transformation.

Thus, the monsoon acts as a natural flushing mechanism that complements ecosystem-based wastewater reuse.

### Relative Risk of Terrestrial Accumulation

In contrast, repeated application of treated wastewater to agricultural lands represents a relatively closed terrestrial system. Inputs are repeatedly added to the same soil profile year after year.

Consequently:

- Salts may accumulate,
- Trace contaminants may accumulate,
- Groundwater quality may be affected,
- Soil quality may progressively deteriorate.

Although contaminant accumulation may also occur in rejuvenated water bodies, connected aquatic systems generally possess greater opportunities for redistribution, dilution, transformation, and ecological processing than terrestrial irrigation systems.

## 7. Energy Footprint and Climate Implications

To make wastewater consistently suitable for unrestricted agricultural use, advanced treatment may be required for removal of:

- Pathogens,
- Pharmaceuticals,
- Microplastics,
- Endocrine disruptors,
- Nutrients,
- Salinity.

Such treatment often requires:

- Membrane systems,
- UV disinfection,
- Ozonation,
- Advanced oxidation,
- Activated carbon,
- Reverse osmosis.

These technologies significantly increase:

- Energy consumption,
- Carbon footprint,
- Capital expenditure,
- Operating costs.

Israel's water sector consumes approximately six times more energy per cubic metre than India's water sector.

While such investments may be justified under severe water scarcity conditions, their large-scale replication across India would substantially increase energy demand and potentially contribute to climate change.

## 8. Economic Viability and Revenue Recovery

Agriculture in India consumes approximately 620 BCM annually while irrigation charges remain heavily subsidized.

Unlike Israel, irrigation water pricing in India is politically sensitive because:

- A large proportion of farmers are small and marginal,
- Farm incomes remain low,
- Agricultural profitability is uncertain,
- Social acceptance of higher water pricing is limited.

Consequently, recovering advanced wastewater treatment costs from farmers is generally unrealistic.

Public agencies therefore bear most treatment and conveyance costs while generating little revenue.

## 9. Public Good versus Private Benefit

Agricultural reuse primarily benefits specific agricultural users. In contrast, rejuvenated water bodies generate benefits for broader society through:

- Groundwater recharge,
- Biodiversity enhancement,
- Environmental flow restoration,
- Urban cooling,
- Carbon sequestration,
- Improved landscape aesthetics,
- Recreation,
- Flood moderation,
- Supplemental water availability.

Thus, public investment in ecosystem restoration often creates broader and more equitable societal benefits.

## 10. Rejuvenation of Water Bodies as Functional Ecosystems

Appropriately treated wastewater can be utilized for:

- Restoration of ponds,
- Rejuvenation of lakes,
- Wetland creation,
- Stream restoration,
- Drain rehabilitation,
- Environmental flow maintenance.

These systems can function as:

- Ecological assets,
- Groundwater recharge systems,
- Biodiversity habitats,
- Climate resilience infrastructure,
- Water security assets.

Furthermore, rejuvenated water bodies can support:

- Non-contact human uses,
- Landscape enhancement,
- Urban ecology,
- Supplemental raw water sources.

## 11. Nature-Based Systems Can Reduce Treatment Costs

Instead of relying solely on energy-intensive treatment systems, treatment can be supplemented through:

- Constructed wetlands,
- Ecological lagoons,
- Oxidation ponds,
- Riparian systems,
- Nature-based treatment corridors.

These systems provide:

- Nutrient removal,
- Pathogen reduction,
- Carbon sequestration,
- Biodiversity enhancement,
- Reduced energy consumption.

## 12. Eutrophication: Management Rather than Elimination

A common criticism of using treated wastewater for water-body rejuvenation is the possibility of eutrophication. However, under Indian climatic conditions, eutrophication cannot be completely eliminated even if nutrient contributions from sewage are entirely removed.
Water bodies naturally receive nutrients from:

- Agricultural runoff,
- Livestock activities,
- Atmospheric deposition,
- Catchment erosion,
- Organic matter decomposition,
- Groundwater inputs.

Moreover:

- High temperatures,
- Long sunlight duration,
- Favorable growing conditions

naturally promote biological productivity. Therefore, the objective should not be elimination of nutrients but management of nutrient cycling and ecosystem functioning.

## 13. Biomass Harvesting as Nutrient Recovery

Rather than viewing nutrients solely as pollutants, they may be treated as recoverable resources.

Periodic harvesting of:

- Aquatic vegetation,
- Macrophytes,
- Algae,
- Wetland biomass

can remove:

- Nitrogen,
- Phosphorus,
- Organic carbon.

The harvested biomass can be utilized for:

- Compost,
- Biochar,
- Soil carbon enhancement,
- Bioenergy,
- Organic fertilizers.

This creates opportunities for circular nutrient management.

## 14. Secondary Economy and Employment Generation

Ecosystem-based wastewater reuse can support:

- Biomass harvesting enterprises,
- Wetland management,
- Ecological restoration services,
- Fisheries,
- Eco-tourism,
- Green jobs,
- Carbon-credit mechanisms.

Such activities can generate substantial secondary economic benefits while improving environmental quality.

## 15. Limitations of Ecosystem-Based Reuse

A balanced assessment requires recognition of limitations.

Potential concerns include:

- Eutrophication,
- Algal blooms,
- Sediment contamination,
- Pharmaceutical accumulation,
- Microplastics,
- Emerging contaminants,
- Groundwater impacts,
- Long-term monitoring requirements.

Therefore:

- Appropriate treatment standards remain necessary.
- Monitoring systems must be established.
- Carrying capacities must be respected.
- Adaptive management must be practiced.

The objective should be risk minimization and ecosystem optimization rather than risk elimination.

## 16. Conclusion

Wastewater reuse should not be viewed merely as a mechanism for recovering water but as part of a broader framework of resource regeneration, ecosystem restoration, and water security enhancement. While both agricultural reuse and ecosystem-based reuse involve risks, the nature and magnitude of those risks differ significantly.

Under Indian conditions, characterized by:

- Large monsoonal runoff,
- Extensive river networks,
- High rainfall volumes,
- Large-scale agricultural systems,
- Limited cost recovery potential,
- Growing concerns regarding soil degradation,
- Need for ecosystem restoration,

the use of appropriately treated wastewater for rejuvenation of ponds, lakes, wetlands, drains, streams, and degraded river systems may often provide greater long-term societal benefit than large-scale direct agricultural reuse.

Such an approach allows:

- Restoration of ecological functions,
- Groundwater recharge,
- Environmental flow enhancement,
- Biodiversity conservation,
- Nutrient recovery,
- Carbon restoration,
- Employment generation,
- Utilization of natural treatment processes,
- Completion of natural nutrient and salt cycles.

Importantly, India's annual monsoon provides a unique hydrological advantage that can facilitate dilution, redistribution, transport, and ecological processing of contaminants through connected aquatic systems. By allowing rivers and water bodies to perform their natural functions—including sediment transport, nutrient cycling, groundwater interaction, and completion of the salt cycle—ecosystem-based reuse aligns more closely with India's hydrological realities than approaches developed primarily for water-scarce regions.

Accordingly, wastewater reuse strategies in India should be evaluated not solely on the basis of water recovery, but on their ability to maximize public good, restore ecosystem functionality, strengthen water security, minimize long-term environmental risks, and contribute to sustainable development.

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