From Waste to Resource

Addressing India's Water Problem through Wastewater Reuse

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India is confronting a deepening water crisis, driven by rapid urbanization, population growth, and unsustainable water use practices. Especially, the urban centers are under growing stress, exacerbated by inefficient distribution, inadequate pricing, and mounting wastewater generation. While wastewater reuse presents a sustainable solution, its potential remains vastly underutilized in India. This article explores the scale of India's water challenges and highlights the urgent need to integrate treated wastewater into urban and agricultural water management strategies. Drawing from global best practices and scientific evidence, it outlines the benefits of wastewater reuse, particularly for agriculture, and emphasizes the role of nutrient-rich effluents in improving soil health and crop productivity. The article also examines policy, regulatory, and economic barriers impeding large-scale adoption and argues for a more enabling framework to promote safe and affordable waste water reuse. With rising water demand and increasing environmental stress, treated wastewater must be repositioned not as waste, but as a vital resource for building water resilience in India.

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India accounts for around 17% of the world population. However, the country has been endowed with just 4% of the world's freshwater resources. More than half of the twenty river basins in the country face water scarcity conditions, with availability of less than 1000 cubic meters (cbm) per capita per annum. According to a report by the Union Water Resources Ministry, total water demand in the country is estimated to increase by 34% by 2025 and over 78% by 2050, indicating a major gap of around 30% with respect to the replenishment capacity, signalling a serious water crisis in the nation.

Further, the crisis is compounded by a growing population. According to the Water and Related Statistics (WRS) published by the Central Water Commission (CWC, 2011), per capita annual availability of water in the country has decreased from 1,816 cbm in 2001 to 1,545 cbm in 2011 and is likely to further fall to 1,174 cbm by 2025. As per the Falkenmark Index (1989), one of the most commonly used indices of water scarcity, if per capita water availability falls below 1,700 cbm per annum, the condition is termed as water stress. If it further decreases and falls below 1,000 cbm per annum, the condition is termed as water scarcity.

India is urbanising at an unprecedented rate. it is estimated that at present about 540 million Indians live in towns and cities. A UN Habitat report estimates that India's urban population will grow to 675 million by 2035, making it the second largest in the world after China ((UN-Habitat, 2022). It is also projected that by 2050, around 50% of the Indian population (about 877 million) will reside in urban cities.

Indian cities are already reeling from inadequate water provisioning and sub-optimal distribution. Many large cities are dependent on private water tankers, with the poor and marginalised facing the brunt of water insecurity. Bangalore experienced a major water crisis last year, and most large Indian cities report water rationing during summer months.

The fundamental principle for any resource management, including water, comprises the 3Rs: a) reduce consumption, b) reduce losses and inefficiencies and c) reuse and recycle water. At the core of water insecurity is the underpricing of water in urban areas, wherein high demand chases an under- price resource. Water security must be ensured for basic human needs and essential services. However, there is an urgent need to correctly price water for recreational and commercial use.

It is important to note that water availability is limited. Most easily harvestable surface water has already been dammed in most parts of India (excluding some eco-fragile zones), and much of the irrigation and domestic demand has shifted to groundwater. As in other large countries like China, households and industries rely more on surface water, while irrigation needs are largely met through groundwater. Overexploitation of groundwater has led to aquifer shrinkage and plummeting water tables across large parts of India. Since water availability is unlikely to increase in the near future, there is an urgent need to reduce distribution losses and improve the efficiency of water utilities. Non-revenue water is estimated at 20 to 50% of total supplied water in Indian cities, an avoidable loss that could substantially increase water availability. As urban populations grow, so do urban wastewater generation too. However, India still has a long way to go to ensure safely managed sanitation for its citizens. According to the Central Pollution Control Board (CPCB), about 70% of sewage generated in Indian cities is discharged untreated into the environment, polluting many rivers and water bodies.

On one hand, while India faces a massive water stress, on the other hand there is a significant gap in used water treatment. According to a 2050 projection report (Amerasinghe, P., et al., 2013), India will require approximately 1,447 cubic kilometres of water, with 74% needed for irrigation. However as mentioned, about 70% of used water is released untreated, causing environmental degradation and health hazards. Hence, effective reuse and recycling of wastewater is essential to meet this demand-supply gap. Treated wastewater is already a critical resource in many countries. Israel, for example, uses it extensively for irrigation, and

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some treatment plants in Singapore produce water of higher-than-drinking water quality, which is primarily used in high-end industries. In addition, Sustainable Development Goal 6 (UN 2015), also aims to halve the untreated wastewater and substantially increase recycling and reuse by 2030.

Contrary to popular belief, technology to treat sewage to potable standards has existed for decades. While international goals emphasize the need for reuse, some countries have already implemented pioneering solutions. Windhoek, Namibia, has been treating and reusing wastewater for drinking since 1968, currently meeting about 35% of its potable water needs this way, with no reported outbreaks of waterborne diseases (Lahnsteiner & Lempert, 2007). Of course, as the end use of the treated water is directed away from agriculture to high-end industries, recreational, and potable usages, the cost of treating wastewater increase exponentially.

Agriculture is the largest water-consuming sector in India. Farmers in peri-urban areas have used wastewater for irrigation for decades. It is reported that 5 billion cbm of wastewater released annually by Indian cities could irrigate 3 million hectares, nearly double the command area of the Sardar Sarovar project, and could contribute about one million tons of nutrients and 130 million man-days of employment (Tushar et al., 2014, Minhas et al., 2004).

Used water is rich in nutrients such as nitrogen and phosphorus. Studies report higher crop yields from wastewater irrigation compared to freshwater, which results in financial savings and environmental benefits (Kaur et al., 2012). Despite increased use of chemical fertilizers, India faces stagnant agricultural productivity and soil degradation (Patra et al., 2016). With adequate organic content, wastewater reuse offers a sustainable solution to enhance soil productivity. Agricultural reuse of treated wastewater is cost-effective and can shield farmers from erratic rainfall, especially in a changing climate. It can also reduce farmers' dependence on chemical fertilizers and improve soil health.

A key challenge in establishing a business case for non-agricultural reuse of treated wastewater is India's rainfall pattern. Monsoon rains adequately recharge aquifers and surface sources during certain months, reducing market demand for treated water. Thus, innovations in pricing, distribution, and management are essential for making treated water viable for non-agricultural purposes. However, untreated wastewater used for irrigation also poses health risks, including helminth infections, viral diseases, and heavy metal toxicity (Qadir et al., 2010). Long-term application without safeguards can degrade soil properties and crop quality (Ghosh et al., 2012). Therefore, comprehensive treatment and management protocols are essential for reuse.

Many countries have established standards for treated water reuse in agriculture, industry, recreation, and potable use. WHO and FAO (2006) have also issued reuse guidelines. As water scarcity worsens, more nations will adopt treated wastewater reuse. Under the Environment Protection Act (1986), the Government of India can set quality standards for water use. CPCB (2024) has issued a draft guideline on reuse, advocating some of the world's strictest standards as recommended by Central Public Health and Environmental Engineering Organization (CPHHEO). These CPHHEO recommendations on reuse are even more stringent than those of the US EPA (2012). The rationale behind these stringent benchmarks is unclear. Tougher standards entail higher capital and operational costs and may hinder rather than promote safe reuse.

CPCB's draft also claims that wastewater treatment plants above 40 MLD can be self-sufficient and generate revenue (CPCB, 2022). These cost and revenue projections warrant deeper scrutiny. If correct, wastewater treatment and reuse could turn out to be a revenue source for governments and urban local bodies, instead of a huge public finance burden. However, these assertions do not reflect the current ground reality and hence, these need further examination and contextualisation.

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Isotopic techniques play a crucial role in assuring the quality of treated wastewater, especially as reuse becomes increasingly important in water-scarce regions like India. Isotopes offer a scientific and non- intrusive method to trace contaminants, assess treatment efficiency, and verify the safety of water intended for reuse. Stable isotopes such as nitrogen-15 ($\delta^{15}N$) and oxygen-18 ($\delta^{18}O$) in nitrates are particularly useful in identifying the sources of nitrogen pollution, distinguishing between human sewage, agricultural runoff, and industrial effluents. Similarly, hydrogen ($\delta^{2}H$) and oxygen ($\delta^{18}O$) isotopes in water molecules can trace the mixing of treated wastewater with natural water bodies, helping to monitor the extent of dilution or potential contamination.

During wastewater treatment, isotopic shifts in carbon ($\delta^{13}C$) and nitrogen signatures can be used to evaluate the effectiveness of biological processes like nitrification, denitrification, and organic carbon degradation. These changes provide insights into whether treatment units are functioning optimally or require adjustments. In urban areas, where wastewater may inadvertently mix with stormwater or leak into groundwater systems, isotopes serve as sensitive tracers, capable of detecting even low levels of contamination. Additionally, the isotopes of heavy metals such as chromium (Cr) and cadmium (Cd) are gaining prominence in wastewater studies, particularly for tracing and monitoring industrial pollution. Chromium isotopes, especially the ratio of $^{53}Cr/^{52}Cr$, can indicate redox transformations of chromium, distinguishing between toxic hexavalent Cr(VI) and the less harmful trivalent Cr(III). Monitoring such transformations is vital in determining the effectiveness of treatment processes in removing toxic metal species. Cadmium isotopes, on the other hand, help trace industrial discharges into water bodies and can reveal sources of contamination linked to battery manufacturing, plating industries, or phosphate fertilizers. Isotopic fingerprinting of these metals not only identifies pollution sources but also aids in evaluating long-term accumulation risks in soil and crops when treated wastewater is reused in agriculture. Furthermore, compound-specific isotope analysis (CSIA) is used to identify residual pharmaceuticals, industrial chemicals, and other micropollutants, ensuring that treated water meets quality standards for agricultural or industrial application (Keesari et al., 2024).

Conclusions

Treated wastewater should be integrated into urban water management strategies with proper monitoring. This can mitigate environmental and health risks and meet agricultural water demands. Adoption of Industrial and portable applications of treated wastewater may be adopted based on strong business cases and context-specific planning. India also needs a functional regulatory framework to encourage, not hinder, safe and affordable wastewater reuse. With India at a critical crossroads of urban growth and environmental stress, safe and strategic reuse of treated wastewater is not merely an option, but a necessity for water resilience.

Shri Harshvardhan is a seasoned development professional with experience leading large-scale projects across government, NGOs, and multilaterals like Amul, UNDP, and Tata Trusts. Harsh has contributed to policy formulation for both the Union as well as various state governments in the domains of agriculture, disaster risk reduction and rural development. He has also led implementation of many large-scale poverty alleviation projects in different parts of India. He holds degrees from Delhi University and IRMA. Presently, he is CEO of Bengaluru headquartered CDD India.