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ORIGINAL PAPER

Towards circularity in used water management in India: mainstreaming reuse for its economic and market potential

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Abstract

Per capita renewable freshwater resources have been diminishing steadily over the years across the globe. India is no exception to the issue of water scarcity, with the problem being more severe in rapidly developing urban areas, where there is increasing pressure on existing freshwater resources to meet the growing water demand. In such typologies, the reuse of treated used water (TUW) is one intervention that has the potential to address the demand–supply gap and improve the water environment if managed properly. Using the nexus lens, this paper makes a case for mainstreaming domestic used water treatment and its reuse for non-potable purposes in India by estimating the market potential and direct (irrigation) and indirect (reduction in fertiliser consumption and greenhouse gas emissions) economic value of the reuse at the national scale. The overall daily market value of TUW was estimated at INR 630 million in 2021, which will substantially increase to over INR 1.9 billion by 2050 at the current market rate. Further, about INR 966 billion worth of revenue would have been generated by using TUW for irrigating crops in suburban areas in 2021. Further, reusing TUW for irrigation would lead to nexus gains in terms of reduced dependence on synthetic nutrients, groundwater and energy. The reductions in fertiliser use, on account of the nutrient content of TUW, and carbon emissions, due to less withdrawal of groundwater, would have been 6000 tonnes and 1.3 million tonnes, respectively. To realise these potentials, it is important to strengthen the existing governance on reuse, which would also enable a circular economy approach to used water management in India.

Keywords Water scarcity · Treated used water · Reusing water · Circular economy · Market potential · Governance

1 Introduction

Many regions in the world are facing water stress that occurs when different types of water demand compete for the same water resources (Wada et al. 2011). The main reasons for the increase in water demand are the growing population and economic activities (Mekonnen and Hoekstra 2016; Schlosser et al. 2014). Climate change will further accentuate the water stress, especially in the global south (Gosling and Arnell 2016; Klare 2020). The ability of the global water systems to meet water requirements in the future under socioeconomic growth and climate change will be challenged. By 2050, economic growth and population change alone can lead to an additional 1.8 billion people living under at least moderate water stress, mostly in developing countries (Schlosser et al. 2014).

India which is the most populous country in the world and a major developing economy in the global south will be affected alike. As per the analysis based on the basin-wise water availability in India (Central Water Commission 2021), 11 out of the 15 major river basins in India will experience water stress by 2025, with the annual per capita renewable water availability below 1700 cubic metres (Bassi, Gupta, and Chaturvedi 2023). Already, about a billion people in India live under severe water scarcity (i.e., the ratio of water consumption to water availability through surface water and groundwater sources is more than 2) at least 1 month of the year (Mekonnen and Hoekstra 2016). Thus, managing the freshwater demand should be an area of top priority for India. This means taking support of adaptative measures

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such as water use efficiency improvement, encouraging reduced consumption (Schlosser et al. 2014), and reuse of treated used water, i.e. the treated sewage generated from the domestic sector (Bassi, Gupta, Chaturvedi 2023; Breitenmoser et al. 2022).

In India, a substantial amount of domestic used water is generated, about 72,368 million litres per day (MLD) from urban areas alone but the capacity exists to treat only 44% of this (Central Pollution Control Board 2021). In class I (population above 100,000) and class II (population between 50,000 and 100,000) towns, representing 72 percent of the total urban population, the actual treatment capacity is even lower at only 30 percent (Ministry of Housing and Urban Affairs 2019; Chakraborti, Kaur, and Kaur 2019). Of the total used water generated, only 28 percent, or less than one-third, is actually treated. The remaining untreated used water is discharged into surface water bodies, such as rivers (Kumar and Bassi 2017). This is one of the main reasons for the high levels of pollution in many of the major Indian rivers, especially concentrated in the river stretches passing through urban areas. In 2022, 46 percent of the monitored rivers in India, i.e., 279 out of 603, had a Biological Oxygen Demand (BOD) above the desired criterion for outdoor bathing, which is 3 mg/l (Central Pollution Control Board 2022). Thus, the inadequate and limited treatment facilities, combined with the exponential rise in water demand, are putting a substantial additional burden on already scarce freshwater resources.

The used water management in India requires a holistic shift from a 'use and throw—linear' to a 'use, treat, and reuse—circular' approach (Breitenmoser et al. 2022). There are two aspects to used water treatment: first, treating used water up to a standard to make it safe for discharge into water bodies, and second, further treating the used water to use-specific standards so that it can be reused across different sectors for non-potable purposes. Hence, treated used water (treated to the desired standard) offers tremendous potential to not only improve the water environment but also to address the water supply and demand gap and reduce pressure on existing freshwater resources when reused.

Yet, the reuse of treated used water (TUW) has still not become mainstream in India as in other countries facing water stress or scarcity such as the Middle East, Spain, Israel, and Singapore. United Arab Emirates, Kuwait, and Qatar reuse more than 80 percent of their produced used water (Jones et al. 2021).Spain treats 84 percent of used water in compliance with quality standards under the EU legislation (European Union 2021). In the south-east region of Spain, almost 50 per cent of treated used is reused for irrigation (Jodar-Abellan et al. 2019). In Israel and Singapore, up to 40 percent of the country's water demand is met by reused water (Kehrein et al. 2020). Whereas, treated used water reuse is very low, even in the major urban agglomerations in India. For instance, it is 19 percent in Delhi, and 6 percent in Hyderabad (International Water Association 2018). This can be attributed to several sewage treatment plants (STPs) not functioning at maximum capacity, and many others not meeting the prescribed effluent water quality standards (Central Pollution Control Board 2021). In some cases, STPs are underutilised, as the sewerage network does not cover unauthorised colonies or suburban areas (Centre for Science and Environment 2014). Further, many urban utilities are unable to scale up their used water treatment capacities, as the capital and operating costs of infrastructure are high. Thus, there is a gap in both used water treatment and its reuse. In terms of used water governance, only a few Indian states have framed policies and guidelines for promoting treated used water reuse. Further, the national-level guidelines on safe reuse of treated water (SRTW) were only launched in January 2023 (Ministry of Jal Shakti 2022), hence states are yet to imbibe them fully.

Studies in the recent past have highlighted several reasons that challenged scaling up treated used water reuse in India. Some important ones include little demand for such water due to subsidised or free freshwater supply in urban areas (Never and Stepping 2018), a dearth of assessment on the indirect social and environmental benefits of reuse (Bassi et al. 2022), and the lack of an umbrella directive for integrated water resources management (Breitenmoser et al. 2022).

In this context, the main objectives of this study were to assess the market potential and direct and indirect economic value of reusing treated used water with a focus on the agriculture sector which is a major consumer of freshwater, and identify the gaps in the existing state policies on treated used water reuse preventing its scaling up in India. Further, the global best practices on used water management were analysed to suggest pointers for improving the existing governance on used water management in India which are relevant for other countries in the Global South as well.

2 Methodology

The methodological approach comprised of five steps: 1] preparing estimates of the used water generation and treatment capacity in urban areas, and sector-wise allocation of available TUW in India for 2025 and 2050; 2] assessing the market potential of TUW in India for 2025 and 2050; 3] assessing the economic value of TUW in India for 2021; 4] analyzing the existing policies in different Indian states on TUW reuse; and 5] analysing global best practices on TUW reuse. The steps are discussed below.

2.1 Estimates on used water generation and treatment capacity in urban areas of India

First, the estimates on the amount of domestic used water generation in urban India for 2025 and 2050 were estimated from the 2021 per capita used water generation estimates of the Central Pollution Control Board (2021) using the Eq. (1)

$$Sewage\ Generation = P_{Urban} \times PC_{WaterSupply} \times RF_{Coefficient} \quad (1)$$

where P_{Urban} is the projected urban populations in 2025 and 2050 based on data available from the Ministry of Housing and Urban Affairs estimates (2019), $PC_{WaterSupply}$ is the average per capita water supply in urban areas, which is about 185 L per person per day including conveyance losses (Central Pollution Control Board 2021), and $RF_{Coefficient}$ is the domestic used water return flow coefficient considered for the urban areas with a sewerage connection. The norm is that 80 percent of water supplied to domestic users in urban areas returns as used water (Central Pollution Control Board 2021). Only off-site used water disposal systems have been considered for preparing the estimates, therefore rural areas that have on-site systems were not made part of the analysis.

Second, treatment capacities as a percentage of sewage generation were estimated for 2025 and 2050 based on the compound annual growth rate in installed capacity from 2014 to 2021 which is computed to be 6 percent per annum. The years 2025 and 2050 were considered to reflect the used water generation and treatment capacities in the near future and long term, respectively.

Third, the estimates for the amount of treated used water that can be made available for reuse across different sectors over the years were arrived at by apportioning the total available treated used water as per the ratio of the current water demand for irrigation, industrial, and other non-potable purposes. While the data on the nation-wide installed sewage treatment capacity were accessed from the Central Pollution Control Board (2021), the sectoral water demand ratio was computed using the water demand growth estimates for 2025 and 2050 by the National Commission for Integrated Water Resources Development, Government of India (Ministry of Water Resources 1999).

2.2 Market value of treated used water

The market value of TUW comprises the revenue that can be generated from the sale of the total available TUW to different sectors for reuse.

The estimate of the current market value of TUW that will be available for sale in 2025 and 2050 was based on the average daily market rate for treated used water which was accessed from the Ministry of Housing and Urban Affairs, Government of India (2021). The average standard price is INR 20 per cu m/day (As of February 2024, 1US$ equals INR 80). It is considered that this would be realised if the mechanism exists to sell treated used water to different sectors for reuse, and they would pay as per the market price.

2.3 Economic value of treated used water

The economic value of reusing TUW was estimated, mainly focusing on the agriculture sector. The irrigation sector accounted for 72 percent of the national freshwater demand in 2021, and it is estimated that it will account for 68 percent in 2050 (Bassi et al. 2020), thus retaining its relative dominance. It was undertaken for the year 2021 considering the availability of data sets and limited reliability of future projections concerning changes in actual cropping patterns and irrigated areas. Further, the analysis focused on direct and indirect economic value, and not on cost-benefit assessment of treating used water. This is the first such attempt at the national scale to estimate the nexus gains associated with the treated used water reuse. This includes changes in the use of synthetic fertilisers, and groundwater and energy use, leading to the reduction in carbon emissions.

2.3.1 Irrigation-related economic value of treated used water reuse

The direct economic value of TUW comprises the revenue that can be generated from reusing for irrigation purposes. The indirect economic value comprises of additional economic benefits from its reuse. For this study, savings from the reduction in fertiliser use, reduced groundwater pumping and electricity consumption for irrigation, and reduced greenhouse gas (GHG) emissions were considered as additional benefits.

First, the potential area that can be irrigated using the available TUW for the agriculture sector in 2021 was assessed. For this, the weighted irrigation delta (i.e., the total depth of the water required by a crop during its entire growing period) for a cropping pattern consisting of wheat, winter maize, other fodder crops, and vegetables was computed. The cropping pattern is reflective of the situation in the peri-urban and sub-urban areas in India. The total water requirement for such a cropping system is 541 BCM for a gross irrigated area of 87 million hectare (Mha) (NITI Aayog 2019). Based on this, the weighted irrigation delta was computed to be 621 mm which is the ratio of water requirement to the total area irrigated.

Second, the revenue from the total production of the selected crops (12 vegetable crops) from the area irrigated by TUW was calculated based on their production and retail prices released by the National Horticulture Board (2022) on a per unit basis (quintal in this case) across 21 centres in India. The chosen crops are considered to be more amenable to the use of treated used water (Sane, Nagarkar, and Shinde 2020). These 12 vegetable crops are also commonly grown in suburban areas and include potato, onion, brinjal, tomato, cabbage, garlic, cauliflower, lady finger, green chillies, peas, bitter gourd, and ginger. The amount of available TUW (estimated as explained in 2.1) was divided as per the fraction of total irrigated land area under each of the 12 crops to estimate the TUW irrigated area under each crop. The crop-wise TUW irrigated area was further multiplied with crop-wise productivity, accessed from the Directorate of Economics and Statistics, to estimate the total production of selected crops from the area irrigated by TUW. The revenue was estimated using the Eq. (2).

$$Revenue\ Generated = Pr \times RP \quad (2)$$

where *Pr* refers to the total production of selected vegetable crops from the area irrigated by TUW; and *RP* refers to the retail price of the selected vegetable crops released by the National Horticulture Board (2022) on a per-unit basis across 21 centres in India.

Third, the total fertiliser requirement of the selected vegetable crops cultivated on the land irrigated by TUW was estimated. It was considered that 156 kg of fertiliser per hectare of land is required by vegetable crops, as per the norm provided by the Ministry of Housing and Urban Affairs, Government of India (2021). The total fertiliser requirement was computed by multiplying the per unit fertilizer application rate with the estimated area for crops irrigated using TUW.

Fourth, the quantity of nutrients (in metric tonnes) supplied by TUW was estimated for the total TUW available for reuse in the irrigation sector in 2021. This estimation assumes that treated used water contains 0.63–0.73 tonnes of nutrients (Nitrogen, Phosphorus, and Potassium) per MLD (Kumar, Raman, and Jain 2014). Thereafter, the amount of reduction in the fertiliser requirement on account of using the available TUW in irrigation was estimated for 2021 using the Eq. (3).

$$Nutrients\ provided\ by\ TUW\ available = TUW \times Nu \quad (3)$$

where, TUW refers to the quantity treated used water available for irrigation (in MLD) in 2021, and Nu refers to the nutrient load in per unit (in this case MLD) of TUW. On account of this inherent nutrient value of TUW (Hashem and Qi 2021), the reduction of synthetic fertiliser use was estimated as a percentage of total fertiliser requirement per hectare of land. Fifth, the amount of GHG emissions that could have been reduced if the available TUW was used for irrigation in 2021 was estimated. This reduction in emissions can be attributed to two factors. Firstly, as mentioned above, the inherent nutrient value of TUW has the potential to reduce the dependence on synthetic fertilisers, thereby reducing the energy usage associated with their production. This estimation considers the GHG emission reduction potential of the following three fertilisers—urea (0.75 tonnes CO_2/tonne), di-ammonium phosphate (0.29 tonnes CO_2/tonne), and murate of potash fertilisers (0.095 tonnes CO_2/tonne), which are the key sources of Nitrogen, Phosphorus, and Potassium (N, P, K), respectively (Dolejsi and Bull 2010).

Secondly, the reuse of TUW for irrigation can reduce the pressure on groundwater sources, thereby reducing the pumping requirements for extracting groundwater. India has a net irrigated area of 68.2 million hectares (Mha), of which 60 percent (about 39 Mha) is through groundwater (Jain, Kishore, and Singh 2019). Further, nearly 30 million irrigation pumps (diesel and electric) are used for groundwater extraction (Agrawal and Jain 2018) in the country. Thus, each pump irrigates about 1.3 ha of land (ratio of groundwater-irrigated area to the total number of pumps). Based on this assumption, the number of pump sets that would have been reduced if the available TUW was used for irrigation in 2021and the associated reduction in GHG emissions were estimated. For the latter, it was considered that a 5 HP diesel pump runs for 2.5 h per day for a total of 200 days per year, consumes 0.75 L of fuel per hour of operation, and releases 2.64 kg of CO_2 per litre of diesel consumption (Bassi 2017). Another important consideration was that the used water treatment plants derive their energy from renewable sources, which minimises their carbon footprints from operations. As per India's Nationally Determined Contributions (NDCs), most of the additional power generation capacity in recent times is based on renewable energy (Ministry of Environment, Forest and Climate Change 2022).

2.4 Analysis of policies on used water management of Indian states

Overall, 10 out of 28 Indian states have formulated used water treatment and reuse policies and guidelines which were reviewed. It included the states of Gujarat (Government of Gujarat 2018), Haryana (Government of Haryana 2019), and Rajasthan (Government of Rajasthan 2016), which were among the first to formulate and adopt such policies or guidelines. Other states that were considered include Punjab (Government of Punjab 2017), West Bengal (Government of West Bengal 2020), Jharkhand (Government of Jharkhand 2017), Chhattisgarh (Government of Chhattisgarh 2017), Karnataka (Government of Karnataka 2016), Andhra Pradesh (Government of Andhra Pradesh 2016), and Madhya Pradesh (Government of Madhya Pradesh 2017). The policies and guidelines were reviewed based on a framework comprising nine sequential steps designed by the authors (Fig. 1). It includes the following parameters: overall objectives, targets, the planning and implementation of treated used water reuse systems, the water allocation mechanism,

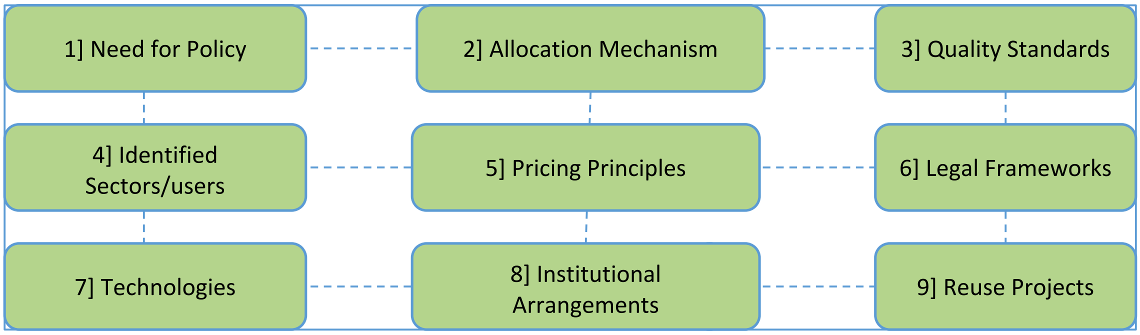

Fig. 1 Framework for policy analysis. Source: authors' analysis

treated used water quality standards, the funding mechanism, and the governance and management of such systems. The review specifically explored the mechanism proposed for allocating treated used water for various uses, including the institutional arrangement and the proposed financial models. The findings of the review of state policies and guidelines were compared with the guidelines provided under the National Framework on Safe Reuse of Treated Water which was launched in 2023.

2.5 Analysis of global best practices

The selected global best practices on used water management and reuse were analyse to understand their governance mechanisms and draw key learnings for India. This included policies and practices in Spain, Israel, and Singapore, which are at the forefront of used water management.

Spain witnesses regional imbalances in the water resource demand compared to annual rainfall, particularly between the northwest and southeast regions (Jodar-Abellan et al. 2019). To address this, Spain established the Water Law in 1985, which focused on pollution control. Spain broadened its approach to comply with the European Economic Community (EEC) by formulating the Spanish Royal Decree in 2007, which provides a legal framework for the reuse of treated used water (Govt. of Spain 2011). The National Investment Plan of 2020 aimed to improve governance and promote the reuse of used water, making the southeast region of Spain one of the world leaders in desalinated and used water reuse rates.

Israel faces chronic water shortages due to droughts, urbanisation, and increased water consumption (Marin, Tal, and Yeres 2017). As one of the responses, it has established a strong institutional framework for used water treatment and reuse. The Israel Water Authority (IWA) was established in 2007 (Marin, Tal, and Yeres 2017) to oversee planning and regulatory responsibilities for all elements of the water cycle. As a result, almost 90 percent of the TUW is being reused in Israel.

Singapore witnesses geographical and topographical challenges in the form of limited land area to build reservoirs and a lack of aquifers. To address these challenges, the roles of non-conventional sources of water supply have been mainstreamed (Tortajada and Bindal 2020). It has developed a long-term water security strategy, including the establishment of a strong institutional and legal framework and the institutionalisation of the Public Utilities Board as the primary agency for water management. It now relies on the reuse of TUW for about 40 percent of the total water demand, with plans to increase to 55 percent by 2060 (Tortajada, Biswas, and Joshi 2013).

A Driver, Enabler, and Barrier (DEB) framework was designed for analysing and comparing the TUW reuse models of Spain, Israel, and Singapore. For this, in addition to the literature review, detailed consultations were undertaken with the identified key experts working on used water management in the three countries for deeper insights. A checklist was prepared to structure the experts' response on the drivers, barriers, and enablers in the three selected countries.

3 Results

As per our assessment, the sewage generation in India is estimated to increase from 55,812 MLD in 2010 to 120,472 MLD in 2050 (Fig. 2). Further, considering the increase in the sewage treatment capacity in the country in recent years, it is estimated that the treatment capacity as a percentage of the total sewage generation will rise from 41 percent in 2010 to 80 percent in 2050. This means that an estimated 96,378 MLD (or 35,178 million cubic meters per annum) of treated used water will be available for reuse by 2050.

This presents major opportunities for the reuse of TUW in various sectors. Based on the estimates presented in Table 1, about 8603 million cubic meters (MCMs) of treated used water was available for reuse in the irrigation sector in 2021. This volume of treated used water has the potential to irrigate about 1.38 Mha of land, which is equal

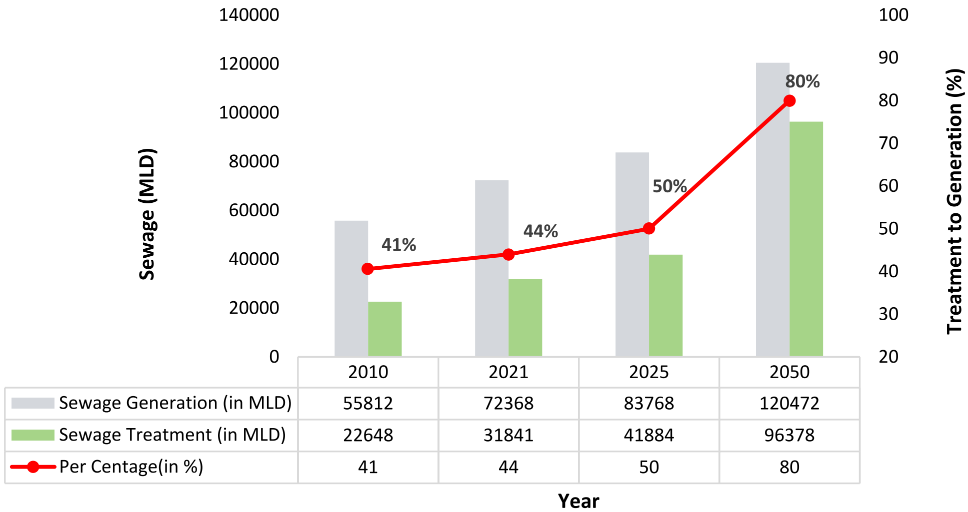

Fig. 2 In 2050, sewage treatment capacity in India is estimated to be 80 percent of sewage generation. Source: authors' analysis using data from Niti Aayog Demographic Scenario 2025 (NITI Aayog 2019) and Central Pollution Control Board (2021)

Table 1 An amount of 28,560 MCMs of treated used water will be available for reuse in 2050. *Source* authors' analysis based on data accessed from EnviStats India 2018 (Central Statistical Office 2018)

Year	Sectoral water demand projection (MCM)			Sewage treatment capacity (MCM)	Estimated TUW available for reuse (MCM)		
	Irrigation	Industry	Energy		Irrigation	Industry	Energy
2021	596,108	57,188	28,482	11,622	8603	922	459
2025	611,000	67,000	33,000	15,288	11,081	1215	598
2050	807,000	81,000	70,000	35,178	24,058	2415	2087

MCM, million cubic metres

to nine times the area of Delhi. Further, this will substantially increase to over 3 Mha by 2050, which is equal to twenty-six times the area of Delhi, given the projected levels of treatment capacity. The irrigation depth assumed here is 621 mm.

Furthermore, the land being irrigated using treated used water will generate revenue from the agricultural produce obtained from it, along with additional direct and indirect benefits, such as the economic value of nutrients recovered from used water and energy savings from reduced groundwater pumping. Thus, there is immense un (der) tapped potential of reusing TUW that can promote circularity in urban used water management.

3.1 Market value of treated used water

The used water treatment plants can generate earnings for urban local bodies by selling treated used water of a prescribed quality to different categories of users, thereby covering the costs of operation and maintenance. The estimated daily market value of the TUW available in 2021 (11,622 MCMs) was over INR 630 million. By 2050, the present daily market value will be over INR 1.9 billion, at the current market rate.

3.2 Irrigation-related revenue potential and other indirect benefits from treated used water reuse

The estimated amount of TUW available for reuse in 2021 could have irrigated 1.38 Mha of land. It was assumed that this land area would have under 12 horticulture crops commonly grown in sub-urban and peri-urban areas of India. Overall, in absolute terms, the selected 12 crops make up over 90 percent of the area under vegetables at the Pan India level (Horticulture Statistics Division 2018) and the irrigation potential of TUW equals to about 12 percent of the irrigated area under vegetable crops. .

As per the estimations presented in Table 2, the total production of vegetable crops from 1.38 Mha of land irrigated using TUW equals to 28 crore quintals, or 28 million metric tonnes (MTs). The revenue that could have been generated from the sale of this produce was INR 966 billion (average of minimum revenue generated—INR 423 billion; and maximum revenue generated—INR 1510 billion) in 2021, had the available TUW been used for irrigation. The estimated revenue from the reuse of TUW in irrigation (INR 966 billion) accounts for about 2.5 percent of the agriculture sector's share of India's GDP at nominal prices (2021–2022).

Table 2 INR 966 billion would have been generated as revenue from the sale of selected vegetables irrigated using TUW in 2021. *Source* authors' analysis, crop-wise irrigated land area and productivity data from Horticultural Statistics at a Glance (Horticulture Statistics Division 2018), NHB Interactive: Month-wise Annual Price and Arrival Report (National Horticulture Board 2022)

S. No	Vegetables	Area under irrigation (in ha)	TUW-irrigated area (in ha)	Productivity (MTs/ha)	Total produce (in MTs)	Price (INR/Quintal)		Revenue generated (INR Billion)	
						Min	Max	Min	Max
1	Bitter ground	27,505	18,190	12	221,187	27,690	83,100	6	18
2	Cauliflower	56,216	37,177	19	713,797	26,410	72,710	18	51
3	Peas	35,021	23,160	10	231,602	26,400	146,860	6	34
4	Lady Finger	66,434	43,934	12	527,212	29,080	86,120	15	45
5	Brinjal	163,408	108,065	18	1,891,146	14,940	71,720	28	135
6	Green Chillies	42,155	27,878	2	53,805	38,320	103,300	2	5
7	Potato	1,032,175	682,601	24	16,382,427	12,380	41,870	202	685
8	Onion	312,349	206,564	18	3,738,801	14,930	60,000	55	224
9	Tomato	198,771	131,452	25	3,286,296	18,890	63,580	62	208
10	Ginger	21,101	13,955	7	97,403	23,710	102,980	2	10
11	Garlic	59,775	39,531	5	200,815	20,760	122,890	4	24
12	Cabbage	71,816	47,494	22	1,044,859	19,140	63,300	19	66
Total	2,086,726				28,389,349			423	1510

3.2.1 Reduction in fertiliser usage

Used water has inherent nutrient value (Nitrogen, Phosphorus, and Potassium). The, reuse of treated used water for irrigation can aid crop growth and reduce the demand for synthetic fertilisers. This can lead to both environmental and economic benefits.

As per the estimates presented in Table 3, the quantity of nutrients supplied by TUW available for reuse in the irrigation sector in 2021 was approximately 6000 tonnes. On account of this inherent nutrient value of treated used water, fertiliser usage could have been reduced by 9–10 percent. In the case of five vegetables (highlighted in blue), the nutrients supplied by TUW are more than their actual requirements.

Further, the market value of nutrients (mix of NPK) is about INR 8000/tonnes (Ministry of Housing and Urban Affairs 2021), based on which the estimated total savings on account of the reduction in fertiliser use through irrigation using TUW to be over INR 50 million per annum. This could have led to an equivalent amount of reduction in the

Table 3 From 9 to 10 percent of the nutrients required by vegetables can be supplied by using TUW for irrigation. *Source* authors' analysis based on Kumar, Raman, and Jain 2014 and. Ministry of Housing and Urban Affairs 2021

S. No	Vegetables	Area under irrigation through TUW (in ha)	Fertiliser required (kg/ha)	Total fertiliser required (in MTs)	Nutrients supplied from TUW (in MTs)	
					Min	Max
1	Bitter ground	18,190	2	37	71	83
2	Cauliflower	37,177	4	156	146	169
3	Peas	23,160	3	61	91	105
4	Lady finger	43,934	5	218	173	200
5	Brinjal	108,065	12	1320	424	492
6	Green chillies	27,878	3	88	109	127
7	Potato	682,601	77	52,672	2681	3106
8	Onion	206,564	23	4823	811	940
9	Tomato	131,452	15	1953	516	598
10	Ginger	13,955	2	22	55	64
11	Garlic	39,531	4	177	155	180
12	Cabbage	47,494	5	255	187	216
	Total	1,380,000	156	61,783	5420	6280

fertiliser subsidy provided by the government to farmers, and the savings generated could have been further channelised to strengthen sewage treatment infrastructure. Thus, reusing TUW for irrigation has the potential to not only reduce the demand for synthetic fertilisers, but can also generate substantial savings for the state exchequer.

3.2.2 Reduction in GHG emissions

Reusing treated used water in irrigation has manifold benefits, one of which is the reduction in GHG emissions on account of reduced groundwater pumping, as there would be a reduction in the energy usage to pump out groundwater. The available TUW in 2021 used to irrigate 1.38 Mha of land (3 Mha by 2050) would have led to a reduction of 1 million pump sets, which would have reduced the CO_2 emissions by 1 million tonnes. By 2050, this will be 2.2 million tonnes of CO_2 emissions under the business-as-usual scenario. Additionally, as we discussed in the previous section, TUW has an inherent nutrient value (N, P, K) that would further reduce the demand for synthetic fertilisers. The corresponding reduction in the consumption of fertilisers would have further reduced GHG emissions by 0.3 million tonnes in 2021.

4 Discussions

This section focuses on the review of the existing state policies on TUW in India and the global best practices on managing used water to draw learnings for mainstreaming circularity in used water management in India, thereby realising the market and economic potential presented in the results section.

4.1 Review of treated used water reuse policies in selected Indian states

A strong governance framework in terms of policy and institutional support is a prerequisite for harnessing the economic and market potential of TUW and enabling its reuse in different sectors. At present, only 10 out of 28 states in India have formulated TUW reuse policies. They were analysed using the nine parameters discussed in the methodology section.

4.1.1 Need for the policy

Many state-specific policies recognise the reuse of TUW as a response to addressing the growing water scarcity in urban areas. However, only a few state policies emphasise the positive externalities associated with used water treatment and reuse, such as improving the water quality of natural water bodies and benefiting public health at large. These include policies of Rajasthan and Chhattisgarh states in India.

4.1.2 Identified sectors for reuse of treated used water

Agriculture and industries are the two main sectors identified by most states for the potential reuse of TUW. For industrial purposes, nearly all states have classified the reuse of TUW in thermal power plants for cooling requirements, boiler-feed water, and power generation. Haryana and Gujarat have taken it a step further by incorporating mandatory and non-mandatory provisions in their policies. Some states, such as Andhra Pradesh, Gujarat, and Haryana, have also acknowledged the construction sector as one of the potential users of TUW.

Nevertheless, the identification of sectors for reuse and their prioritisation is very context-specific, as there is huge diversity among states on various fronts. Non-potable usage, particularly in water-intensive sectors, such as thermal power plants, is one of the main focus areas for reuse. Minimising water demand in such sectors could have a considerable impact on the availability of freshwater required for potable purposes.

However, reuse in the sectors that are categorised as non-mandatory depends on certain conditions being fulfilled by local bodies—for instance, laying special supply lines for TUW and filling tankers with TUW for use in construction sites. Nevertheless, opportunities for TUW reuse in high-end technology industries are being explored by some state policies.

4.1.3 Recommended technologies for used water treatment

The selection of appropriate used water treatment technologies is key to achieving Sustainable Development Goals target 6.3, which focuses on improving water quality by reducing pollution, reducing untreated used water, and promoting safe reuse. Currently, in India, 30 percent of STPs use sequencing batch reactors (SBRs); 20 percent use the activated sludge process (ASP); 12 percent use moving-bed biofilm reactors (MBBRs); 5 percent use upflow anaerobic sludge blanket (UASB); 4 percent each use oxidation ponds (OPs) and waste stabilisation ponds (WSPs); 2 percent use extended aeration (EA); and 1 percent use fluidised aerobic bed reactors (FABs).

Used water treatment essentially comprises three stages, primary, secondary, and tertiary. However, depending on the end use, the number of stages and the nature of the treatment process might vary. Some states, such as Madhya Pradesh and Rajasthan, have emphasised the need for the right mix of on-site and off-site treatment methods to generate treated used water of the desired quality. On-site treatment options are mentioned as a means to reduce the burden on centralised systems, with potential benefits, such as affordability, a lower energy footprint, and the localised reuse of treated used water.

In some state policies, notable innovations were also observed. For instance, Andhra Pradesh has introduced the concept of 'demand profiling', where the major demand areas are identified at the urban-local-body level and, accordingly, treatment systems and technologies are designed to meet the required quality requirements.

Further, a majority of the states emphasise the need for appropriate and innovative technologies to enhance used water treatment efficiency. Some states also mention nature-based solutions for used water management.

4.1.4 Mechanism for allocating treated used water

Ideally, the allocation of treated used water should be guided by the principles of equity, sustainability, and fairness to ensure its effective distribution and optimum reuse. However, only a few state policies explicitly mention guiding principles. Nevertheless, different criteria have been adopted by different states for the allocation of treated used water. For instance, Gujarat and Haryana categorised TUW allocation criteria based on its availability in comparison to the demand, whereas Karnataka mandates the industrial estates/zones within 30 km of STPs to prioritise its reuse. It is to be noted that the mechanism established for the allocation of TUW requires strong enforcement mechanisms with well-defined roles and responsibilities for effective implementation.

Thus, although most state policies define the criteria for the allocation of TUW for different purposes, foundational principles, such as equity and sustainability, were found lacking. Further, provision for enforcement mechanisms for effective policy implementation was lacking in most of the state policies reviewed.

4.1.5 Pricing of treated used water

Pricing principles play a crucial role in driving demand, especially for non-conventional products. Almost all states have defined pricing principles to cover the operation and maintenance costs of used water treatment systems. States such as Punjab, Jharkhand, Rajasthan, and Karnataka mention the 'polluter (or generator) pays principle', where a charge is levied on generators for used water services. Additionally, the role of the private sector in the management of used water treatment and reuse infrastructure has also been incorporated into the majority of the state policies. However, the provision for incentivising end users to mainstream the reuse of TUW was lacking in nearly all state policies.

4.1.6 Institutional arrangements

Robust institutional arrangements provide a strong footing for the effective implementation and coordination of the policy instruments. In the context of used water treatment and reuse, the institutional arrangement varies widely across the states depending on the governance architecture. For instance, Gujarat and Haryana have a three-tier institutional structure, whereas Jharkhand has a two-tier institutional structure. Karnataka categorises the departments into primary and secondary based on their extent of involvement and role in used water treatment and reuse.

Overall, most state policies have well-defined institutional structures with the delineation of roles and responsibilities. Further, many state policies have also defined the role and responsibilities of urban local bodies as part of their institutional structures. Moreover, most of the state policies identify different stakeholders in used water management; however, their roles are not well defined.

4.1.7 Quality standards and performance benchmarking

The quality and standardisation of treated used water are essential to safeguarding public health and the protection of the environment. The Central Pollution Control Board (CPCB), Government of India, and the respective State Pollution Control Boards (SPCBs), have laid down safe disposal requirements for TUW that are to be followed by all states. State policies have also made references to manuals by World Health Organization (2017) and Central Public Health and Environmental Engineering Organisation (2013) for the reuse of treated used water for different purposes, such as agriculture and industries.

Although most state policies have limited themselves to CPCB/SPCB discharge norms for water quality standards, reuse-specific treated used water quality standards are not defined properly in the majority of state policies.

4.1.8 Supporting legal and regulatory instruments

Many state policies align with various constitutional provisions in the form of Fundamental Rights (Article 21), Directive Principles of States Policy (Article 48A), Fundamental Duties (Article 51A), and the Role of Local Self Governments (73rd and 74th Constitutional Amendment Act). Some of the key legal and regulatory instruments that form the basis for used water treatment and reuse that most state policies have referred to include the National Urban Sanitation Policy (2008), guidelines for the Swachh Bharat Mission (2014), the Environment Protection Act (1986), the Water (Prevention and Control of Pollution) Act (1974), and Municipal Solid Waste Management (MSW) Rules (2016).

Thus, states have referred to numerous central and state acts, rules, and guidelines in their used water treatment and reuse policies. However, there is very limited mention of binding provisions, which generally leads to a lackadaisical approach towards policy implementation. Further, no single agency was identified that will be responsible for the effective implementation of the used water treatment and reuse policy on the ground.

4.1.9 Business models for developing treated used water reuse projects

The selection of appropriate business models for TUW reuse projects forms the basis for the effective on-ground implementation of reuse policies. The provision for exploring appropriate public–private partnership (PPP) models is mentioned in all state policy documents. Some state policies even mention the project-sanctioning priorities based on certain parameters, such as the quantity of sewage generated, the location of STPs, the status of existing infrastructure, and strategic location.

While most state policies mention PPP models for used water treatment and reuse projects, none address the time-bound creation of treatment facilities, conveyance systems, distribution of treated used water, smart metering for transparent pricing, or sustainable operation and maintenance (O&M). Nevertheless, some state policy documents align TUW reuse projects with existing city master plans, which is a positive step in terms of integrated planning.

4.2 Analysis of global best practices to derive learnings for India

This section presents the analyses of the used water management governance architectures of selected countries that are considered frontrunners in this space. The objective is to draw lessons from countries that are at an advanced stage in the reuse of TUW and derive actionable recommendations for strengthening the relevant policies in India.

4.2.1 Comparative analysis through the DEB framework

Drivers play a critical role in used water management governance, as they provide the impetus for change and innovation. Drivers vary across different countries depending on their contextual factors. In Table 4, a comparative analysis for the selected countries on certain key drivers is presented.

Barriers are factors that impede or hinder the effective implementation of used water governance practices. They are important to understand because without addressing them, policies might not achieve their desired impact. In Table 5, a comparative analysis for the selected countries on certain key barriers is presented.

Enablers play a crucial role in governance, as they facilitate and support the implementation of effective used water management practices. In the following table (Table 6), a comparative analysis for the selected countries on certain key enablers is presented.

4.2.2 Learnings for India

The reuse models of the selected global best practices indicate that the formulation and adoption of a dedicated

Table 4 Drivers providing impetus to used water governance in selected countries. *Source* authors' analysis. Empty cells indicate that the particular driver is not relevant for the respective country

Drivers	Spain	Israel	Singapore
Demographic factors		Water consumption increased manifold owing to rapid urbanisation	Water demand expected to double by 2060 in comparison to 2020
Natural factors	Climatic variability: uneven rainfall distribution across different regions	Naturally water scarce area with limited availability of freshwater	Geographical topography: absence of aquifers and limited land area for constructing reservoirs
Geopolitical factors	Joining the European Economic Community (EEC) in 1986 led to the broadening of the national mandate to include used water management in water resource management and governance		Achieving self-sufficiency in terms of water resources was a key objective after separation from the Federation of Malaysia in 1965
Role of stakeholders	Demand of TUW from Golf-course promoters and hotel resort owners	Farmers' associations were one of the key drivers in mainstreaming reuse of TUW in the agriculture sector	Citizens were well informed and aware of the problems associated with water scarcity
Changing nature of economic activities	Intensive agricultural practices and boost in the tourism industry	Due to diversified economic activities, the water demand–supply gap increased in the agriculture sector	

Table 5 Barriers that have impacted used water governance in selected countries. *Source* authors' analysis. Empty cells indicate that the particular barrier is not relevant for the respective country

Barriers	Spain	Israel	Singapore
Financial viability	Absence of well-developed and competitive markets for TUW reuse		To achieve self-sufficiency post-separation from Malaysia, massive capital investment was needed in reuse projects and desalination plants
Institutional barriers	Inadequate enforcement mechanism	Multiple institutions, overlapping jurisdictions, and ambiguity in roles and responsibilities	
Political barriers	Populist policies inhibited the development of robust pricing mechanisms and led to poor cost recovery for the government		

national legal framework with defined institutional responsibilities is fundamental for implementing the reuse of TUW. Such a framework can act as an umbrella document guiding the revision of existing state policies on reuse and formulation of new policies in the states that don't have it. The revision is necessary as the existing state level reuse policies in India refer to various other central and state environmental acts as their regulatory framework. Further, there is very limited mention of the binding provisions required for policy implementation and they do not identify agencies responsible for the effective implementation of the used water treatment and reuse policy on the ground.

Another key enabler is ensuring demand-driven technological advancements in used water treatment based on comprehensive need-based assessments. The global cases suggest carrying out targeted technological improvements in alignment with international directives that define reuse-specific quality standards and benchmarks for treated used water.

Finally, the role of stakeholders and citizens is key for driving the shift towards circularity in used water management. Most states in India that have reuse policies recognise the role of civil society, private sector, and local municipal authorities in the effective operationalisation and implementation of reuse projects. However, their respective roles are not properly defined. This should be addressed while making revisions to the existing policies.

5 Conclusion and recommendations

Using the nexus lens, this study provides the first estimates on the market potential and economic value of TUW at the national scale, especially considering the agriculture sector, which is the major consumer of freshwater in India. Nevertheless, the technical feasibility and financial viability including cost-benefit assessment of transferring TUW to the point of use need to be explored further.

Further, this study undertook an analysis of existing policies on used water treatment and reuse. Even before the launch of the National Framework on TUW and its reuse, about 10 states in India had reuse policies. However, as per our analysis, these existing policies are not comprehensive in scaling up the reuse, as only a few of them identify the positive environmental and public health benefits associated with reuse, prioritise sectors for reuse, incentivise users, identify the role of external stakeholders, define water quality standards for the specific reuse purpose, and provide criteria for the selection of appropriate reuse business models. The successful implementation of these policies is directly linked with the economic feasibility of reuse projects. Further, there are learnings from global best practices, such as from Spain, Israel, and Singapore, that India can use to strengthen its governance on used water treatment and reuse. Based on this analysis, the following recommendations are made for improving the existing governance on the reuse of treated used water in India.

Make a paradigm shift in ideology: India needs to recognise used water as an integral part of water resources by including it in all water management policies, plans, and regulations. Experiences from Spain, Israel, and Singapore demonstrate that following such an approach can transform a nation with water stress into a leader in water management.

Define water quality standards: India needs to define water quality standards for both safe discharge and reuse with a risk-reducing approach and implement a regular monitoring programme. Such a practice is followed in the European Union (such as Spain), where a working group meeting on water reuse is organised every 6 months to ensure the regular assessment of water quality standards and monitoring requirements for water reuse in different sectors.

Set robust institutional mechanisms: Urban local bodies in India should be empowered to formulate and adopt long-term used water reuse plans with roles and responsibilities clearly defined. Further, end-user groups should be involved in the implementation of reuse projects. In Israel, the farmers' associations played a key role in mainstreaming reuse in the irrigation sector. They contribute to the investment required for the conveyance of treated used water to the point of reuse and are able to meet 50 percent of the irrigation water demand from it.

Improve financial viability: Indian states need to have a performance-based incentive for the operators of used water treatment plants, and an effective pricing mechanism based on the market potential of the treated used water, considering different categories of end users and their paying abilities. Global experiences suggest that mixed funds, such as private sector investment, public equity, and loans from multilateral institutions, are required to ensure the financial viability of such projects.

Leverage technological developments: Indian states need to come out with a clear strategy for research and development, especially focussing on low-cost highly energy-efficient technological innovations that could be in cooperation with other relevant global actors. Israel has a commission that periodically reviews the status of treatment and reuse, setting the agenda for technological advancements and water standards based on its assessment.

Invest in public outreach: Indian states should develop effective public outreach plans to build public confidence and nudge behaviour towards the successful implementation of used water reuse projects. Singapore invested massively in public outreach programmes and designed a comprehensive information, education, and communication strategy to gain public trust and acceptance of the reuse projects.

Many Indian states have yet to frame the reuse policies, and even those that have been framed need revision. The discussed recommendations can make a substantial contribution to mainstreaming and scaling up the reuse of treated used water in India and other countries of the Global South.

Table 6 Enablers facilitating used water governance in selected countries. *Source* authors' analysis. Empty cells indicate that the particular enabler is not relevant for the respective country

Enablers	Spain	Israel	Singapore
Policy framework	Evolving framework from Water Law in 1985 to National Investment Plan 2019 created an enabling environment for reuse	Sewage was recognised as an integral part of national water resources in Water Law 1959 itself	Formulation of a comprehensive water policy that emphasises non-conventional sources of water to meet the rising demand
Institutional arrangements	Adoption of a decentralised approach with regional governments managing water resources	Adoption of a centralised model: Israel Water Authority (IWA) is the national regulator for the entire water sector	Adoption of a centralised model: Public Utilities Board is the national water authority for the entire water sector
Technological advancements	Technological advancement in used water treatment aligned with changing mandate in used water governance from used water regulation to reuse-specific treatment after joining EEC	Used water treatment technologies evolved with changing nature of economic activities, from basic sewerage technology to soil aquifer technology	Technological advancements in used water treatment were demand-driven and backed by comprehensive need-based assessments

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