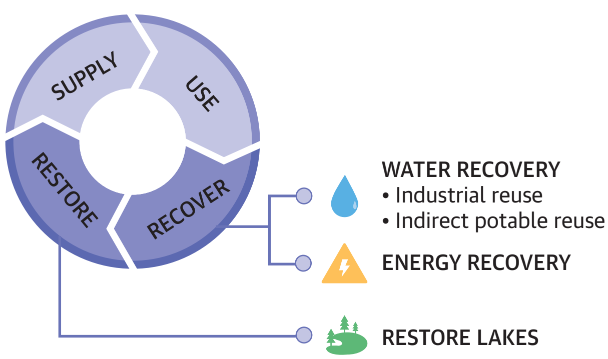
Public Disclosure Authorized

Water in Circular Economy and Resilience (WICER)

The Case of Chennai, India

Recovering Water and Energy from Wastewater



This case study is part of a series prepared by the World Bank's Water Global Practice to highlight existing experiences in the water sector. The purpose of the series is to showcase one or more of the elements that can contribute toward a Water in Circular Economy and Resilience (WICER) system. This case study focuses on the experience of Chennai in India.

Context

Chennai, a city on the southeastern coast of India and the state capital of Tamil Nadu, has one of the world's fastest-growing economies. Chennai is the automotive hub for India and is also home to several other industries ranging from petrochemicals to hardware manufacturing, textiles, and apparel. Besides industries, Chennai's economic activities include medical tourism, software, and financial services. Recent estimates of the economy of the Chennai Metropolitan Area have ranged from US$79 million to US$86 billion (purchasing power parity [PPP] gross domestic product [GDP]), ranking it as India's fourth- to sixth-most-productive metropolitan area. Because of urbanization and economic growth, Chennai's population has increased more than 50 percent over the past two decades. With over 10 million people and covering more than 426 square kilometers (km^2), Chennai is the fourth-largest city in India.

The city's rapid growth has created several water challenges:

- ***Water supply has not kept up with demand.*** Chennai has historically relied on groundwater, which has

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GWSP GLOBAL WATER SECURITY & SANITATION PARTNERSHIP provided between 100 and 120 millions of liters of water per day (MLD) (CMDA n.d.) and four rain-fed lakes nearby with a combined storage capacity of about 11,000 million cubic feet (mcft) and the potential to supply between 632 and 854 MLD of water, depending on the monsoons. Meanwhile, however, Chennai's demand for water has increased more than 50 percent (up to 1,200 MLD) over the past decade. Industrial development, an increasing population, and larger per capita needs triggered by economic growth all play a role in rising demand for water. The per capita availability of water dropped from 1,816 cubic meters (m^3) in 2001 to 1,545 m^3 in 2020. Because of a gap between water demand and the combined water supply from all sources, many households must supplement the city's supply with their own borewells and/or tanker deliveries to meet their water needs.

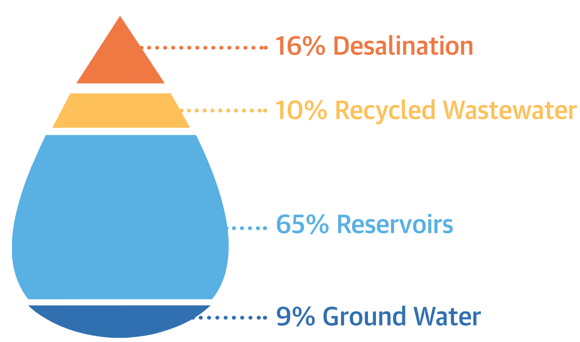
- ***Extreme weather events further aggravate the issue.*** Since the city is entirely dependent on rains for recharging its water resources, monsoon failures lead to acute water scarcity. The city usually gets 1,200 millimeters (mm) of rain between mid-October and mid-December that help replenish surface and groundwater sources. Yet over multiyear cycles, Chennai is regularly afflicted by severe floods and droughts. In the past two decades, the city has seen floods in 2005, 2010, and 2015, bookended by droughts in 2003-04 and 2016-18.
- ***The city's unplanned expansion has caused water bodies in and around the city to contract,*** from 12.6 km^2 in 1893 to 3.2 km^2 in 2017. These water bodies have been important to Chennai, providing water during drought periods and acting as a buffer during heavy rains.
- ***The growing population and failing monsoons*** have required Chennai to transport water from distant sources[1] and to desalinate seawater,[2] increasing the cost of water supply.

Solution: Chennai's efforts to become circular and resilient

To protect against the vagaries of nature, build resilience, and increase water availability, the Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) embarked on several projects and investments to diversify water supply. Chennai was the first city in India to mandate rainwater harvesting and the first to achieve 10 percent wastewater reuse. It is also the only utility in India with two large-scale desalination plants. Its current water supply is already diverse when compared with other cities in India and around the world, as shown in figure 1, below. CMWSSB is also recovering energy from wastewater in more than half of its wastewater treatment plants (WWTPs) and exploring to sell most of the biosolids generated as manure for application to agricultural land. To boost the city's resilience and push Chennai toward circular economy principles, CMWSSB plans to increase the percentage of wastewater being reused, restore aquifers and lakes, improve rainwater drainage and flood management, and decrease nonrevenue water.

This case study focuses on CMWSSB's experience in reusing, and recovering energy from, wastewater. The wastewater reuse initiative started in 2005 when industries expressed interest in purchasing secondary-treated wastewater from CMWSSB and

FIGURE 1. Chennai Water Supply Sources



Source: CMWSSB, 2020.

further processing it for use in their facilities. Three petrochemical industries led this effort, purchasing and processing 30 MLD of secondary-treated wastewater to meet their industrial-water needs. In 2015, learning from this effort, CMWSSB established two tertiary treatment and reverse osmosis plants, with 45 MLD capacity each, and began to supply high-quality, treated wastewater to industries in and around Chennai. Together these plants supply 120 MLD of treated wastewater for nonpotable industrial uses. Meanwhile, the fresh water previously going to industries has been freed to meet the city's domestic potable water needs. CMWSSB is now piloting indirect potable reuse with the construction of two plants of 10 MLD capacity. If the pilot succeeds, the plan is to scale up to 240 MLD. Moreover, CMWSSB has installed, and is operating, energy-recovery systems in seven of its twelve WWTPs to reduce the energy dependence on grid power and to improve the financial sustainability of its wastewater treatment operations.

Policy, Institutional, and Regulatory Environments

At the national level, the National Urban Sanitation Policy (NUSP) of 2008 promotes the use of reclaimed water, recommending the reuse of a minimum of 20 percent of wastewater produced in every city. The National Water Policy (2012) also recognizes the importance of wastewater reuse to meet national environmental objectives and mentions the possible use of a preferential tariff to incentivize the use of reclaimed water over fresh water.

At the state level, the government of Tamil Nadu promotes wastewater reuse and has created a mandate that industries be supplied only with treated wastewater for their processes. Notable features of the policy are, first, identifying current and future industrial water demand in the state; second, establishing a 10-year horizon for supplying all industries with treated wastewater; third, directing the state industries department to take the lead in developing and operating the needed infrastructure with industries and with utilities/cities; and, finally, a stipulation that capital be financed through national/state government programs or, preferably, through public private partnerships (PPPs).

At the city level, Chennai promotes circular economy principles. CMWSSB has taken a number of steps to close the water loop and make the most of all available water resources in Chennai, including nontraditional water sources such as wastewater. Chennai is the first Indian metropolitan area to achieve almost 100 percent wastewater collection. With a sewer network extending over 3,000 km and twelve wastewater treatment plants with a combined capacity of 727 MLD, Chennai collects, transports, and treats between 520 and 660 million liters of wastewater produced daily by 4.8 million residents in the city core (95 percent coverage). CMWSSB has also launched several bylaws to increase incentives for wastewater recycling and reuse. All stakeholders—including government authorities, the private sector, and citizens—are mandated by those regulations and bylaws to ensure the maximum reuse of water. For example, CMWSSB has increased the freshwater tariff for industries and implemented a zero-discharge policy making it mandatory for industries and manufacturers to achieve zero-liquid discharge in their operations. The purpose of these initiatives is to encourage the industrial sector to reuse its process water and reduce its overall water use.

Wastewater Reuse

First Attempt at Reuse by Industries

Severe water shortages in 2001 caused the Chennai Petroleum Corporation Ltd. (CPCL)—a 10 million metric tons per annum refinery—to shutter operations for 35 days, with consequent financial impacts. Between 2001 and 2004, the company relied on about 500 water tankers per day for its operations. Faced with frequent monsoon failures, CPCL, in 2005, decided to purchase secondary-treated wastewater from CMWSSB and further treat it (tertiary treatment followed by reverse osmosis) to the desired quality levels for its operations. It purchases and processes 24 MLD of wastewater, sufficient to meet its total process water needs. Taking a cue from CPCL, Madras Fertilizer Ltd. (MFL) and Manali Petrochemicals Ltd. (MPL) each built a tertiary treatment plant for reuse, purchasing 10.50 MLD and 1.50 MLD of treated wastewater from CMWSSB, respectively.

Financial and Contractual Arrangements

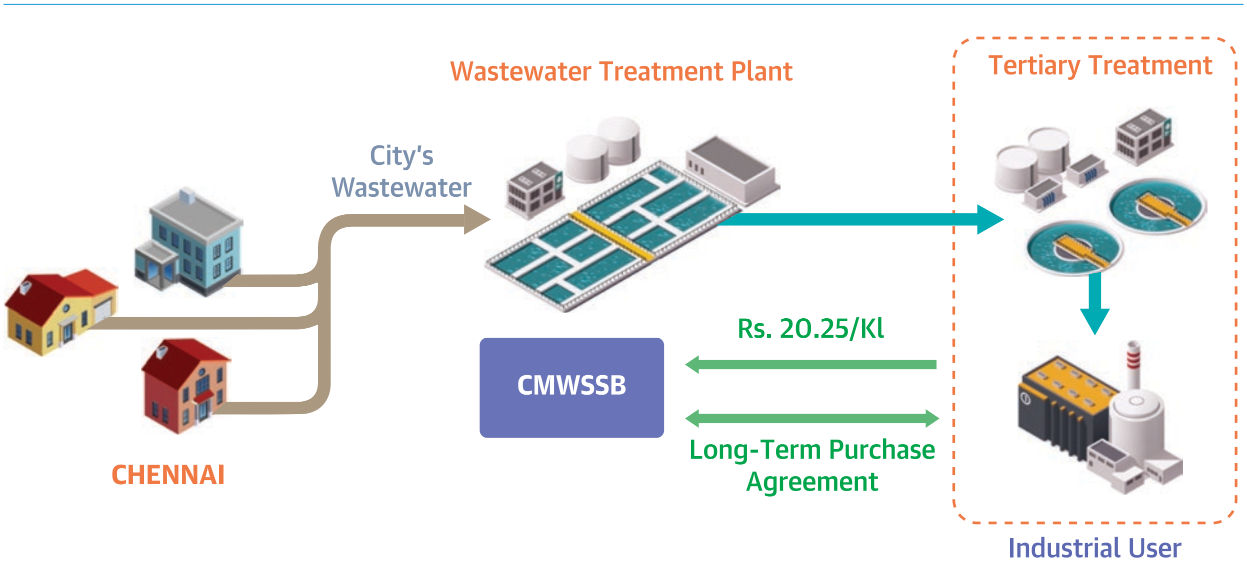
In this case, the end user of the treated wastewater has financed and operates the tertiary treatment plant. CPCL incurred a capital expenditure of Rs 760 million to establish the tertiary treatment plant in its facility. The annual operation and maintenance (O&M) costs are Rs 378 million, including the purchase cost for wastewater from CMWSSB at Rs 20.25/kiloliter (kl) (CMWSSB 2020).[3] As a result of this effort, CPCL saves Rs 126 million annually—the cost differential between the industrial water tariff paid previously at Rs 60/kl (tariff in 2005) and the treated wastewater at Rs 45/kl (Rs 20.25/kl plus the O&M costs of the tertiary treatment plant). The project payback period is 6.4 years, and the internal rate of return is 9 percent. In the agreement, CMWSSB covered the costs of the pipes to convey the wastewater to CPCL, and later to MFL and MPL.

CMWSSB entered into an agreement with the three industries for the supply of secondary-treated wastewater. The price of secondary-treated wastewater is Rs 20.25/kl with an annual increase in price of 1.5 percent. CMWSSB is responsible for the operation and delivery of secondary-treated wastewater to the industries, and the industries are responsible for establishing and operating the tertiary treatment plants. This agreement has held for the past fifteen years, a testament to the efficacy of the project. See a schematic of the process, below, in figure 2.

CMWSSB's Recycle and Reuse Efforts

With the increasing number of industries in and around Chennai, CMWSSB had to find ways and means to balance the demand for water from industries alongside the growing needs for potable water for household needs. Learning from its experience with recycling and reusing wastewater for industrial users, CMWSSB decided in 2015 to establish two tertiary treatment and reverse

FIGURE 2. Industry use of Secondary-Treated Wastewater



Note: CMWSSB = Chennai Metropolitan Water Supply and Sewerage Board.

osmosis plants of 45 MLD capacity each at two of the existing wastewater treatment plants (photo 1). The goal was to use these to further process secondary-treated wastewater, then supply the treated wastewater to industries instead of fresh water. The implementation of this initiative is also in line with and supported by the treated wastewater policy of the government of Tamil Nadu, as described above. Besides following the policy mandate, the reuse of treated wastewater for the industrial sector is an opportunity for CMWSSB to increase the supply of potable water available for domestic uses. Further, the use of treated wastewater ensures a continued and uninterrupted water supply to industries, which are crucial to the city's economy.

Financial and Contractual Arrangements

The Tamil Nadu Sustainable Urban Development Project of the World Bank supported the CMWSSB in designing and financing one of the tertiary and reverse osmosis treatment plants and also in developing the contract documents adopted in the subsequent project. A design, build, and operate (DBO) contract was signed between the CMWSSB and Wabag-IDE consortium and BGR Energy systems for a period of 15 years and included the construction of the tertiary treatment and reverse osmosis plants and the pipelines to convey and distribute the treated wastewater to industries.

The capital costs of the two tertiary treatment and reverse osmosis plants, in addition to the transmission and distribution system, was Rs 6.32 billion; the operating costs are Rs 972 million/year (at Rs 36/kl, considering 300 days' operation). The O&M cost includes the cost of operating the tertiary treatment and reverse osmosis plants, transmission and distribution of the treated wastewater, and the operator's cost. Regarding the capital costs, one plant was financed under the World Bank's Tamil Nadu Sustainable Urban Development Project, as mentioned above, and the other under the Atal Mission for Rejuvenation and Urban Transformation (AMRUT), a centrally sponsored scheme of the government of India. The treated water is sold to industries at Rs 130/kl and, accounting for O&M costs, the yearly revenues amount to Rs 2.7 billion. Revenue from the sale of treated wastewater pays for the O&M costs of the treatment systems and the operators.

The project was structured as a PPP with 30 percent equity, 70 percent debt (at an interest rate of 14 percent, the commercial finance lending rate), O&M costs of Rs 36/kl (increasing by 3 percent per year), and the sale price of treated wastewater at Rs 130/kl (increasing by 1.5 percent per year). The calculated payback period is 4.9 years and the internal rate of return is 17 percent.

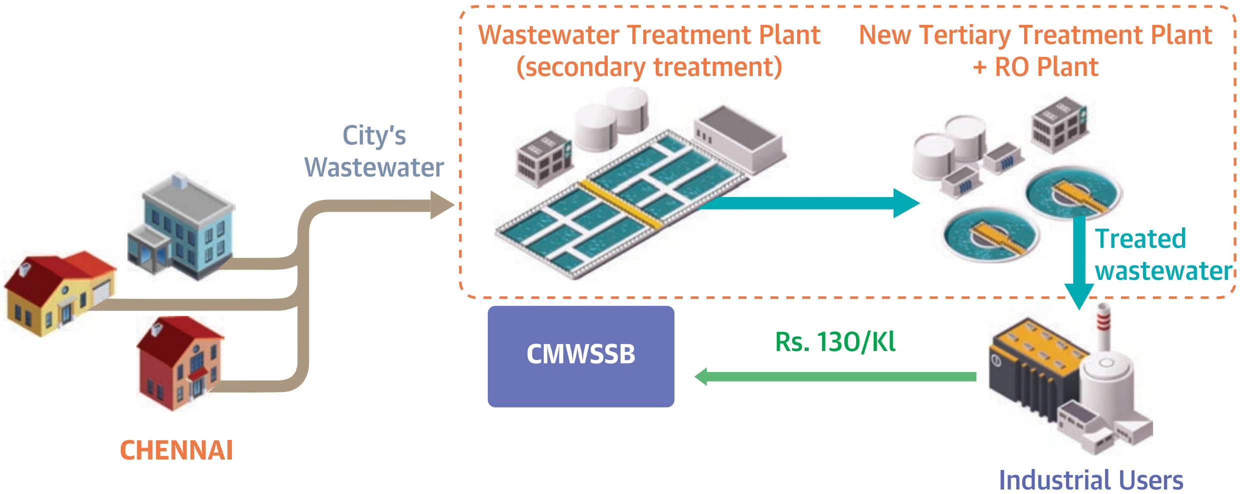
A schematic of the process is detailed in figure 3.

Energy Recovery from Wastewater Sludge

In order to reduce the energy drawn from the grid and to meet the operating needs of WWTPs, CMWSSB embarked on a program in 2005 to anaerobically digest sludge from its WWTPs and use the biogas, a byproduct of anaerobic digestion, in gas engines to generate electricity. Seven of the twelve WWTPs have installed energy recovery plants with a total installed capacity of 7 megawatts (MW).

The cost of retrofitting the seven plants to be able to general electricity was about Rs 174 million. These plants generated 144,529,270 kilowatt-hours (kWh) of electricity since the time of commissioning until April 2020 and resulted in energy savings of Rs 680 million (less energy drawn from grid). Financial analysis indicates an internal rate of return of 35 percent and a payback period of 2.8 years. Further, the energy recovered in the seven plants meets 50 percent of the energy needs of all the WWTPs. CMWSSB is trying to step up its game in sewerage and wastewater treatment by ensuring energy recovery systems in most WWTPs, and is now exploring solar energy to reduce energy dependence on the grid and make operations more financially sustainable.

FIGURE 3. Industry use of Tertiary-Treated Wastewater



Notes: CMWSSB = Chennai Metropolitan Water Supply and Sewerage Board; RO = reverse osmosis.

PHOTO 1. Tertiary Treatment Plant at Kodungaiyur

Source: CMWSSB.

Benefits

Lower operating costs and decreased risks of water scarcity for industrial users. The establishment and operation of the wastewater reuse plants have insulated industries from the uncertainties of water supply and ensured the availability of water now and into the foreseeable future, making industries more resilient to droughts. The reuse of treated wastewater by the three big industries (CPCL, MFL, and MPL) has resulted in annual savings of Rs 164 million.

Increased sustainability of CMWSSB. The sale of treated wastewater is providing additional revenue to CMWSSB, thus improving its financial sustainability as it continues to provide sanitation services to the residents of Chennai. The revenues from the sale of secondary-treated wastewater to CPCL, MFL, and MPL add up to Rs 222 million annually. Additional revenue from the sale of wastewater treated at tertiary treatment plants is enough to cover O&M costs, and the yearly revenues of this amount to Rs 2.7 billion.

More sustainable use of existing water resources. Approximately 30 MLD of reclaimed wastewater are sold to the industrial users, CPCL, MFL, and MPL. Together with the tertiary treatment, a total of 120 MLD of treated wastewater will be used for industrial purposes. This means that the use of an equivalent amount of fresh water is being avoided, indirectly augmenting available fresh water to meet the city's increasing water needs.

Reduction of greenhouse gas emissions. The use of biogas to produce electricity reduces the emissions of greenhouse gases and decreases CMWSSB's dependency on electricity from the city grid.

Closing the Loop

CMWSSB's Future Plans for Indirect Potable Reuse

Having maximized the supply of treated wastewater to industries and learning from the experience of the Indian Institute of Technology (IIT), a university in the city that has been operating an indirect potable reuse plant for a number of years to meet its own water needs, CMWSSB decided to pilot two plants for indirect potable reuse, each of 10 MLD capacity, scaling up afterwards to 240 MLD to meet growing water demand.

The advantages of the proposed process are as follows:

- Critical infrastructure (network and wastewater treatment plants) are available and operational.
- Required secondary treated wastewater is available.
- Financial (capital and operating costs) are an attractive option to increase water availability when compared to other options (see table 1).
- Lakes have the capacity to take in tertiary-treated water, which is expected to be about 10 percent of the lake capacity.

TABLE 1. Cost Comparison of Different Water Sources

S. No.	Source	Capital cost (Rs millions/MLD)	Operating cost (Rs/kl)
1.	Desalination	153	55
2.	Tertiary treatment + reverse osmosis (supply of treated wastewater to industries)	40	36
3.	Tertiary treatment + ultrafiltration + water treatment plant	35	18
4.	Distance surface-water source (~250 km from the city)	77	23

Source: CMWSSB 2019.

- Land for construction of tertiary treatment plants at existing WWTPs and water treatment plants near the lakes/distribution head works is also available.

The proposed scheme envisages:

- Tertiary treatment and ultrafiltration
- Conveyance of treated wastewater to the lakes
- Water treatment of blended lake and tertiary-treated wastewater
- Aquifer recharge during periods when the lake is full
- Distribution of treated water

CMWSSB consulted with many stakeholders (residents, industries, commercial associations, and educational institutions) to explain the proposed scheme and responded to stakeholder queries on water quality and cost. The stakeholders welcomed the proposed scheme, and several industrial and commercial establishments evinced interest in the purchase and use of the water.

A schematic of indirect potable reuse is shown, below, in figure 4.

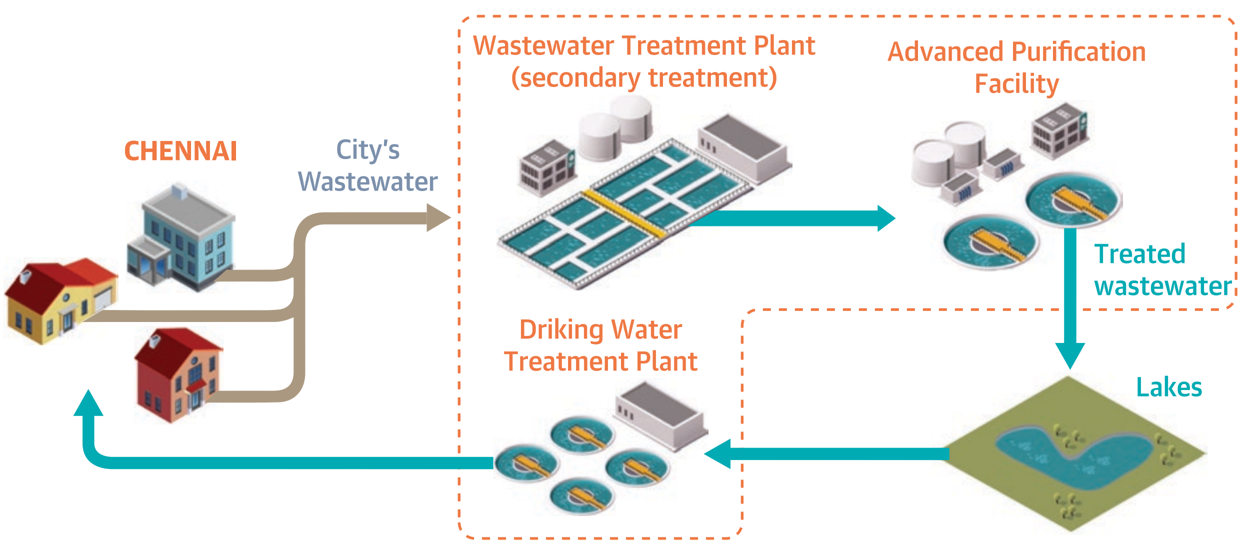
CMWWSB's attempts to recycle and reuse wastewater for industrial purposes will free up to 120 MLD of fresh water. Together with the planned indirect potable reuse plants of 260 MLD capacity, CMWSSB will be able to augment its supply capacity by 380 MLD, diversifying its water sources and contributing toward building the resilience of the city's water supply. The indirect potable reuse project is expected to be completed by 2024.

Moreover, it should be noted that CMWSSB also reuses a small percentage of treated wastewater for other urban purposes. About 0.3 MLD of treated wastewater are provided for free to the city to be used to water plants and lawns at public parks and traffic islands. 0.5 MLD of treated wastewater are supplied to the Chennai Metro Rail Ltd at a rate of Rs 18.40/Kl and another 0.5 MLD of treated wastewater are supplied to the Road Development Corporation for free.

Other Circular Economy Activities

Besides reusing treated wastewater for several purposes and recovering energy in wastewater treatment plants, CMWSSB is also exploring other circular economy activities. CMWSSB produces around 50kg of

FIGURE 4. Indirect Potable Reuse



dried sludge per ML of treated wastewater and is planning to sell the dried sludge to farmers for use as soil conditioner at Rs 71.50 per Ton. The use of biosolids as soil conditioner reduces the amount of sludge to be transported and landfilled, saving the related costs, which can be significant. Further, the agricultural application of biosolids benefits farmers too, since it increases moisture retention and reduces synthetic fertilizer use. CMWSSB is also exploring options to recycle the brine produced in the desalination plants.

Lessons Learned

Government support and regulations that foster wastewater reuse are crucial for success. The fact that there were national, state-level, and local regulations and policies that incentivized or mandated wastewater reuse was a catalyst for this type of project's success in Chennai. The higher water tariffs for industries and the zero-discharge policy also forced industries to explore other options and consider alternative sources such as treated wastewater.

Water scarcity encourages water reuse. Besides adequate government support and regulations, this case study shows that water scarcity also triggers the exploration of more innovative solutions that consider nonconventional water sources. It also shows that wastewater reuse is economically viable in water-scarce areas, especially where the cost of tapping the nearest freshwater source is high.

Proactive planning and innovative thinking are important for building urban water resilience. Rapid urbanization, increasing populations, and rapid economic development exacerbate water scarcity. Cities should adopt proactive planning mechanisms to project economic growth, urbanization patterns, and water demand. Nonconventional water resources will play more and more important roles in building urban water resilience and should be incorporated in planning and in the water balance.

Treated wastewater tariffs are best set at competitive levels. Besides reliable and constant water quality, a competitive tariff is needed to ensure that industrial consumers consider the use of reclaimed wastewater instead of fresh water.

The right contract design can incentivize energy recovery in treatment plants. Including provisions in the O&M contracts that penalize the operator by charging it a higher tariff whenever power is drawn from the grid to operate the WWTPs (where energy recovery systems are available) incentivizes operators to maximize the efficiency of energy recovery systems.

Piloting a small-scale project first, with one or two end users, can serve as a proof of concept. The success of the first pilot led by the industrial user (CPCL) fostered the implementation of more wastewater reuse projects.

Conclusions

This case study shows how CMWSSB's efforts to recycle and reuse between 60 and 75 percent of the city's wastewater for industrial and indirect potable reuse will result in 380 MLD of water becoming available for domestic consumption at very economical costs. Further, the city's efforts to reuse treated wastewater and diversify water supply builds resilience, improves water security, and helps protect city residents from the vagaries of climate change. Besides, revenue from the sale of treated wastewater and reduced grid power to operate WWTPs on account of the energy recovery system helps CMWSSB meet 90 percent of the O&M cost of sewerage systems, proving that circular economy initiatives are not only sustainable, but make economic and financial sense.

Notes

1. The Veeranam Canal brings 180 MLD of water from the Cauvery River.

2. Desalination efforts add up to 800 MLD: two plants in operation, with a capacity of 100 MLD each; a plant of 150 MLD capacity under construction; and a detailed project report for a plant of 450 MLD capacity under preparation.

3. See https://www.cpcl.co.in/Refineries.

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