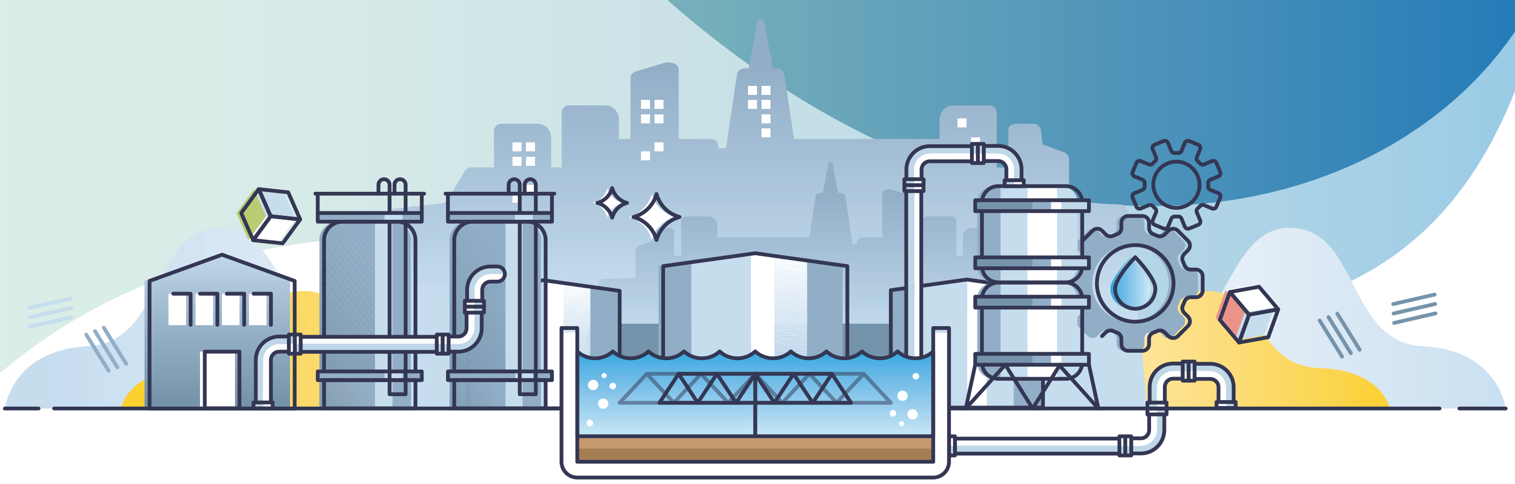
NITI Aayog

ATAL INNOVATION MISSION

URBAN WASTEWATER SCENARIO IN INDIA



ICDK

RuDRA

NAMAMI GANGE

URBAN WASTEWATER SCENARIO IN INDIA

AUGUST 2022

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FOREWORD

Water is the most important natural resource needed to sustain life on this planet. In terms of Sustainable Development Goals (SDGs), water as a resource and access to clean water is a central theme to most SDGs, e.g. out of 17 SDGs at least 7 SDGs is directly linked to clean water and 5 are indirectly linked to water. India, still an agrarian nation with high water demand for agriculture, is also marching towards its goal to become a world leader in sustainable development, for which sustainable water use is key.

With climate change impacts water demands are growing. The hydrological water balance indicates more floods and droughts, with less water recharging groundwater thereby reducing water supply. In addition, growing domestic and industrial demands for water has to be met for India to become a major hub for industries and development. It is therefore necessary to reuse and recycle water as much as possible, in particular urban wastewater. Urban wastewater management needs a holistic approach with all relevant stakeholders and incorporating site-specific conditions and challenges. Involving public participation needs to be increased for better adoption and use of recycled and treated wastewater (e.g. toilet to tap initiatives). It should be noted that, wastewater treatment is not only to augment water resources but should also be viewed from the solid waste perspective.

Waste to wealth initiatives have been increasing across the world, wherein the solid waste is used as fertilizer pellets and other uses, which need to be documented. Such reuse of waste has faced challenges in acceptance, however with improved post-processing methods and Government initiatives, the segregated solid waste from wastewater has found many uses, thereby increasing the support for effective wastewater treatment. Therefore, wastewater treatment needs to be viewed using different lenses to capture all possibilities to increase the efficiency of treatment plans and reuse both the water and solid waste effectively.

On this note, an interdisciplinary team was formed with partners from Government knowledge agencies (Atal Innovation Mission-AIM, NITI Aayog), Government water management agencies (Ministry of Jal Shakti and National Mission for Clean Ganga-NMCG), international agency (Innovation Centre Denmark-ICDK) and academia (Indian Institute of Technology Bombay-IITB) to develop a whitepaper on urban wastewater management. The team had expertise ranging from science, technology, field implementation, to policy, adaptation and application. With such an interdisciplinary team, it was possible to consider all stakeholder's concerns for wastewater management and produce a whitepaper that holistically captures the current status of wastewater treatment in India and potential pathways for future treatment structures, co-creation and collaborations.

This whitepaper curated by experts from IITB, AIM-NITI Aayog, ICDK and NMCG presents the current status of wastewater generation in India, future capacity need for wastewater treatment, scope for improvement and augmentation in existing infrastructure and technologies, methods for public participatory approach, financing and co-financing options, smart technologies for rapid data collection and dissemination and building capacity via training and stakeholder apex bodies for increasing the efficiency of urban wastewater treatment for India.

MESSAGE

परमेश्वरन अय्यर
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2 September 2022

I wish to congratulate the Atal Innovation Mission, NITI Aayog, Innovation Centre Denmark (ICDK), IIT Bombay, Rural Data Research & Analysis (RuDRA) Lab and National Mission for Clean Ganga (NMCG) for bringing out a white paper on Management of Wastewater in India through Innovative Solutions.

I also wish to congratulate all the start-ups and student teams of the five nations - India, Denmark, South Korea, Kenya and Mexico - competing at the IWA World Water Congress 2022 in Copenhagen, Denmark.

Parameswaran Iyer

Parameswaran Iyer

स्वच्छ भारत
एक कदम स्वच्छता की ओर

MESSAGE

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MESSAGE

India and Denmark have a Bilateral Green Strategic Partnership focused on green hydrogen, renewable energy and wastewater management. Addressing the global water woes through innovations is an integral part of the Strategic partnership. The collaboration between Atal Innovation Mission, Niti Aayog and Innovation Centre Denmark, Embassy of Denmark, has effectively exhibited cross-border collaboration between entrepreneurs and innovators aligned with the vision of addressing and mitigating water related issues faced by India and the world today.

Atal Innovation Mission, a flagship initiative of Niti Aayog and Innovation Center Denmark (ICDK) under the aegis of Denmark Embassy in India, and the Denmark Technical University (DTU) launched the AIM-ICDK water innovation challenge to scale up innovations in the water sector. Being the nodal agency to launch this challenge, AIM has played a crucial role in the Indo-Danish Bilateral partnership. In this challenge, the selected startups and student teams received mentorship from IIT Bombay and IIT Madras and funds and incubator access by ICDK and AIM, NITI Aayog. It is a matter of great pride for us that altogether five teams from India will represent us in the IWA World Water Congress 2022 in Copenhagen, Denmark, I congratulate them all on their well-deserved success.

AIM strongly believes in the power of innovation and on the fact that Entrepreneurship driven technology is an important driving force in green transition. It is crucial for India to seize bilateral opportunities to learn and collaborate with developed countries, which have successfully tested these technologies, and to implement sustainable solutions for wastewater treatment and reuse.

Many developing countries including India have been experiencing water crisis, both in terms of availability and quality of water. India's urban centers are witnessing unprecedented growth, driven by new economic reforms and migration. This increase in urban population is putting enormous pressure on planners, particularly for the provision of public services, especially clean and affordable water. Sectoral water demands have also increased as irrigation, domestic utilities, energy and industry absorb ever-increasing amounts to meet growing demands. These ever-increasing demands can in some parts be met by Wastewater recycling and reuse. It is imperative that we focus on wastewater and aim to reduce the amount of untreated wastewater and dramatically increase recycling and safe reuse.

This white paper on 'Urban Wastewater Scenario in India' reviews the current scenario of the country and discusses in detail wastewater management and reuse solutions practiced worldwide that India can learn from. It lays emphasis on the need to understand wastewater generation and the associated reuse measures.

I wish to offer my warmest congratulations to Innovation Centre Denmark (ICDK), IIT Bombay, Rural Data Research and Analysis (RuDRA) Lab, National Mission for Clean Ganga (NMCG) and our team at Atal Innovation Mission, NITI Aayog on doing a commendable job on the white paper.

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स्वच्छ भारत
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MESSAGE

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MESSAGE

Management of used water in Indian urban sector has always been a challenge, and thereby one of the prime points of discussion as well. Urban water sector is stressed by tremendously growing demand due to increase in population, rise in domestic use, consumption by industrial and commercial entities, requirements for sanitation, compounded by depletion and contamination of water sources and climate change impacts. Contrary to the general perception, a significant fraction of the urban dwellers is under-privileged, marginalized or poor and live in urban-slums. As resource becomes scarce, competition builds up and the weaker sections get side-lined leading to a widened gap in socio-economic disparity.

Estimates suggest that the present domestic water demand of Indian urban areas is about 90,000 million litres per day (MLD), which works out to be nearly 33 billion cubic meter (BCM) annually. Out of this, 26 BCM is discharged as wastewater, and only less than 10 BCM is treated. While the untreated water pollutes freshwater storage on one side, even the treated water finds no much significant uses owing to social stigmas. During the pluvial urban floods, the sewage gets mixed with the flood water and poses serious health concerns. Further to this, many urban water bodies have been turned to landfills and fresh water rivers became sewerage channels. Curbing this detrimental trend is essential to ensure unhindered and sustainable growth and to achieve the Sustainable Development Goal targets.

Government of India have been collaborating with other countries and multilateral agencies to tackle the urban wastewater problems. We must look for the solutions that can resolve the critical pollution problems efficiently and rejuvenate extinct urban water bodies. Nature based or nature friendly solutions should be promoted. It is heartening to observe that young scientists, start-ups and brilliant students are aware of and concerned about these issues and are striving to innovate in addressing these problems in unorthodox ways. I do always place a high reliance on the power of research & development by scientific community, and am certain that they have solution for every other problem. However, the challenge lies in translating the results into practice and in making the solutions affordable and accessible to everyone.

This whitepaper is an outcome of a novel thought to present in 'black & white', where India is standing, to where it is heading and what it looks for in terms of sustainable urban wastewater management. I am confident that this exercise will help to bring like-minded ones together, cutting across sectors, in resolving many issues which are common across geographies.

AVINASH MISHRA

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MESSAGE

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IIT Bombay

MESSAGE

India is growing at a tremendous pace and has been recognised to be the fastest growing economy in the Asia this year. This elevates India's image and the citizens pride across the globe. To sustain such growth and pride, it is necessary to keep the growth sustainable and long-term. With socio-economic growth, cities have become larger and cater to a large population, higher than the urban carrying capacity of the city. Such growth also puts tremendous pressure on Government agencies that manage natural resources that are used for development, especially water. Scientific and technological solutions can aid to keep the current trend of growth and development in a sustainable manner.

Advances in science and technology are being researched in many educational institutions in India, of which the Indian Institute of Technology-Bombay (IITB) is leading with many recognitions, e.g. IITB has been recognised by the Government of India as an Institution of Eminence (IoE). In IITB, there are many departments, centres and interdisciplinary programs that address issues and create solutions that are scientifically validated. Many initiatives, with collaborations, are started in IITB focussing on specific issues and providing training and up-skilling of people to address these issues. The Rural Data Research and Analysis (RuDRA) lab, at the Centre for Technology Alternatives for Rural Areas, was created to specifically work on rural issues by collecting holistic and interdisciplinary data from different stakeholders and by creating correlations and causality relationships to improve the understanding of the issues and to provide better solutions.

Considerable amount of research is ongoing, however most of them are not readily up-taken for societal or industrial solutions. Thus, there is a need for more action-based research that focuses on ground solutions and there is a need for extension work to upscale the solutions from lab to real world scenarios. Extension agencies, as found in many countries, are key in extending the research activities to the ground. Such solutions should be co-created through collaborations between multiple institutions and government agencies so that expertise can be shared with improved sustainability of projects. Identifying venues for such collaborations is key, which is reviewed in this Whitepaper.

Through this Whitepaper, co-created by multiple partners from academia, government agencies and public networks, it is clear that wastewater should be treated more sustainably and stakeholders need to be sensitised to newer technologies in India. Low cost technological solutions, data monitoring instruments and simulation models are needed for providing better understanding of wastewater treatment issues, which can be researched in premier institutions of India (e.g. IITs) and then promoted and used by Government agencies (e.g. Niti Aayog, ICDK, NCMG). Feedback from data, stakeholders and modes can be routed to the academics for fine-tuning the management plans and efficiency of treatment methods can be improved. With such participation from a multidisciplinary team, wastewater treatment in India can be improved which will lead the path to sustainable development in India.

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ABBREVIATIONS

ABR	:	Anaerobic Baffled Reactor
AHP	:	Analytic Hierarchy Process
ASP	:	Activated Sludge Process
BOD	:	Biochemical Oxygen Demand
BORDA	:	Bremen Overseas Research and Development Association
CAG	:	Comptroller and Auditor General
CBO	:	Community-Based Organizations
COD	:	Chemical Oxygen Demand
CPCB	:	Central Pollution Control Board
CPHEEO	:	Central Public Health and Environmental Engineering Organisation
CW	:	Constructed Wetlands
CWWT	:	Centralized Wastewater Treatment
DEWATS	:	Decentralized Wastewater Treatment Systems
DPS	:	Duckweed Pond Systems
DWWT	:	Decentralized Wastewater Treatment
EA	:	Extended Aeration
FAB	:	Fluidized Aerobic Bed Reactor
FC	:	Faecal Coliform
FICCI	:	Federation of Indian Chambers of Commerce and Industry
FSSM	:	Faecal Sludge and Septage Management
FTW	:	Floating Treatment Wetland
FWS	:	Free Water Surface
GAP	:	Ganga Action Plan
GIS	:	Geographic Information System
HRAP	:	High-Rate Algal Ponds
INR	:	Indian Rupee
IoT	:	Internet of Things
JnNURM	:	Jawaharlal Nehru National Urban Renewal Mission
MBBR	:	Moving Bed Biofilm Reactor
MBR	:	Membrane Bioreactor
MLD	:	Million Litres per Day
MoEFCC	:	Ministry of Environment, Forest and Climate Change
MoHUA	:	Ministry of Housing and Urban Affairs
MoJS	:	Ministry of Jal Shakti

MoUD	:	Ministry of Urban Development
MoWR,RD&GR	:	Ministry of Water Resources, River Development and Ganga Rejuvenation
NBS	:	Nature-Based Solutions
NGO	:	Non-Governmental Organizations
NGT	:	National Green Tribunal
NPCA	:	National Plan for Conservation of Aquatic Ecosystems'
NRCD	:	National River Conservation Directorate
NRCP	:	National River Conservation Plan
O&M	:	Operation and Maintenance
OP	:	Oxidation Pond
PCB	:	Pollution Control Boards
PHED	:	Public Health Engineering Department
PPP	:	Public Private Partnership
PPPP	:	Public Private People Partnership
RBC	:	Rotating Biological Contactor
RS	:	Remote Sensing
RWA	:	Residential Welfare Associations
SAFF	:	Submerged Aerobic Fixed Film
SBR	:	Sequencing Batch Reactors
SPCB	:	State Pollution Control Boards
SRTW	:	Safe Reuse of Treated Wastewater
SSF	:	Sub-Surface Flow
STP	:	Sewage Treatment Plants
SWM	:	Solid Waste Management
SWQMS	:	Smart Water Quality Monitoring Systems
SWSDB	:	State Water Supply and Drainage Board
TDS	:	Total Dissolved Solids
TSS	:	Total Suspended Solids
UASB	:	Upflow Anaerobic Sludge Blanket
ULB	:	Urban Local Body
UNDP	:	United Nations Development Programme
UNESCO	:	United Nations Educational, Scientific and Cultural Organization
UWM	:	Urban Waste Management
WQM	:	Water Quality Monitoring

WRG	:	Water Resources Group
WSN	:	Wireless Sensor Network
WSP	:	Waste Stabilization Pond
WSSB	:	Water Supply and Sanitation Boards
WWP	:	Wastewater Treatment Plants

1. Executive Summary

Every nation aims for socio-economic development, however, sustainable development is key. Population growth and urbanisation along with socio-economic development have intensified the water supply and demand imbalance, leading to water shortage conditions, especially in developing countries like India. As cities continue to grow and consume more water, there is added pressure on agricultural productivity factors such as water, land, energy, and changing diets, bringing major challenges to urban and rural food security. Parallelly, climate change impacts are affecting the availability and distribution of water resources due to extreme floods and droughts. There is an urgent need for wisely using the water resources we have. This whitepaper provides a detailed holistic review of the urban wastewater situation with respect to the state of wastewater generation, collection, treatment and reuse; the existing legal, institutional and policy regime for wastewater management; the types of treatment systems and their performance; and pathways for collaborations and engagements between institutions and stakeholders to develop sustainable and affordable solutions for wastewater treatment and reuse purposes.

From the review it is clear that the concept of waste to wealth fits well for water management in India. Wastewater is and should be considered a valuable resource from which water can be recycled and energy/nutrients can be extracted. Globally, innovative wastewater treatment and reuse technologies have played a crucial role in improving urban sanitation and enhancing water security, as stipulated under Goal 6 of the Sustainable Development Goals. Despite the known benefits, wastewater treatment and reuse practices and technologies need to upgraded in India, as currently, India generates 72,368 Million Litres per Day (MLD) of urban wastewater and only 28% (20,236 MLD) is treated. This implies that 72% of the wastewater remains untreated and maybe disposed of in rivers/ lakes/groundwater. This gap, between generated and treated, has to be addressed to utilise the wastewater as a valuable resource. The gap is due to the challenges in wastewater treatment such as: limited land available for setting up new treatment plants, mapping the connectivity of sewage drainage systems, identifying leakages and illegal dumping of sewage water, limited data on load generated and collection points, one size fits all approach, absence of new technologies that can bring down the costs and improve the efficiency of treatment, aversion of public in re-using treated wastewater and absence of collective action between stakeholders from wastewater generation to treated wastewater reuse.

Efforts are needed to develop guiding frameworks for the use of suitable technologies and practices following the fit-for-purpose principle as per the need of each urban centre (city/town/community/building/individual). Strengthening the institutional and monitoring capacity is crucial to increase the assurance and trust of the users in the quality of the treated wastewater, generate demand, and ultimately safeguard human health and the environment. Recent developments show a transition towards advanced technologies and adaptation of nature-based cost-effective solutions for treatment driven by both government and private sectors. New low-cost technologies should be involved in wastewater monitoring and treatment plans. Data should be freely shared to improve confidence in re-using wastewater for purposes that suit the quality. Added public participation and involvement can improve fine-tuning of the infrastructure requirements and also help in the long-term sustainability of the treatment system through effective monitoring and creating ownership among users. This will lead to efficient recycling and reuse of wastewater leading to sustainable development in India.

2. Introduction

India, with 1.38 billion people, is the second largest populous country in the world. Of the total population, 65% (900 million) live in rural areas, and 35% (483 million) are concentrated in urban centres. The estimated wastewater generation is approximately 39,604 Million Litres per Day (MLD) in the rural regions, while in the urban centres, the wastewater generation has been estimated as 72,368 MLD for the year 2020-21. The estimated volume of urban wastewater is almost double (due to the associated water needs for flushing and sewage drainage) that of rural and such availability of more water for sanitation has increased the living standards in urban cities. There is thus more population growth and migration of people to cities for a better source of living immediate attention due to rapid urbanization, and therefore there is an immediate attention to manage wastewater due to rapid urbanization.

Urban areas currently accommodate more than 50% of the global population and by 2050, it is expected that 70% of the population will be residing in urban cities. Rapid urbanization creates opportunities for economic development but may also add pressure on freshwater resources to meet the food and water demands in water-scarce areas and areas in which expansions occur at unprecedented pace. With increase in the population of such cities, it is important to identify water resources to sustain such expansion.

A growing set of viable but unconventional water resources, such as wastewater, offer enormous potential for narrowing the water demand-supply gap towards a water-secure future (Jones et al., 2020). Wastewater is increasingly recognized as a reliable and cost-effective source of freshwater, particularly for agricultural applications; however, wastewater remains an "*untapped*" and "*undervalued*" resource (WWAP, 2017), especially in India. Wastewater treatment aims to improve the quality of "used" water sources to reduce contaminant levels below sectoral quality thresholds for re-use or to minimize the environmental impacts of wastewater return flows. Treated wastewater flows can also provide a substantial source of (clean) freshwater flows for maintaining river flows, especially during drought (Luthy et al., 2015). However, much of the wastewater currently re-used is inadequately treated or even untreated due to multiple issues. Demands for clean water are increasing at a faster pace than wastewater treatment solutions and faster than technological developments in institutions that ensure the safe distribution and management of wastewater (Sato et al., 2013). The primary challenge in promoting re-use is ensuring safety – both for human and ecosystem health – and thus ensuring that wastewater is adequately treated prior to use or environmental discharge. If that is not achieved, wastewater is considered as waste and not treated, recycle or reused. There is an urgent need to achieve the required paradigm shift in water resources management, whereby wastewater is viewed as a resource (for energy, nutrients and water) rather than as "waste" (WWAP, 2017; Qadir et al., 2020). However, challenges exist globally.

2.1. Urban wastewater as a growing global challenge

The information on current volumes of wastewater generated, collected, treated and reused at different scales is scattered, infrequently monitored and reported, or unavailable in many countries (Mateo-Sagasta et al., 2015). Such important information is essential for water and energy-related sustainable development in an era when the World is embarking on achieving the Sustainable Development Goals (SDGs) set by the United Nations. In particular, SDG 6.3 target is focused on wastewater and aims to half the proportion of untreated wastewater and substantially increase recycling and safe reuse globally. The SDG 6.3 target is interlinked with many other SDGs and targets, which can help in achieving their goals and targets and vice versa (Fig. 2.1.1), and these are; to expand international cooperation and capacity-building support to developing countries in water-and sanitation-related activities and programmes (SDG 6.a), to enhance international cooperation to facilitate access to clean energy research and technology and promote investment in energy infrastructure and clean energy technology (SDG 7.a), enhancing inclusive and sustainable urbanization (SDG 11.3), reduction in the waste generation through prevention, reduction, recycling and reuse (SDG 12.5) and to increase our adaptive capacity to climate change (SDG 13.2). Therefore, it is important to understand wastewater generation and associated measures to reuse.

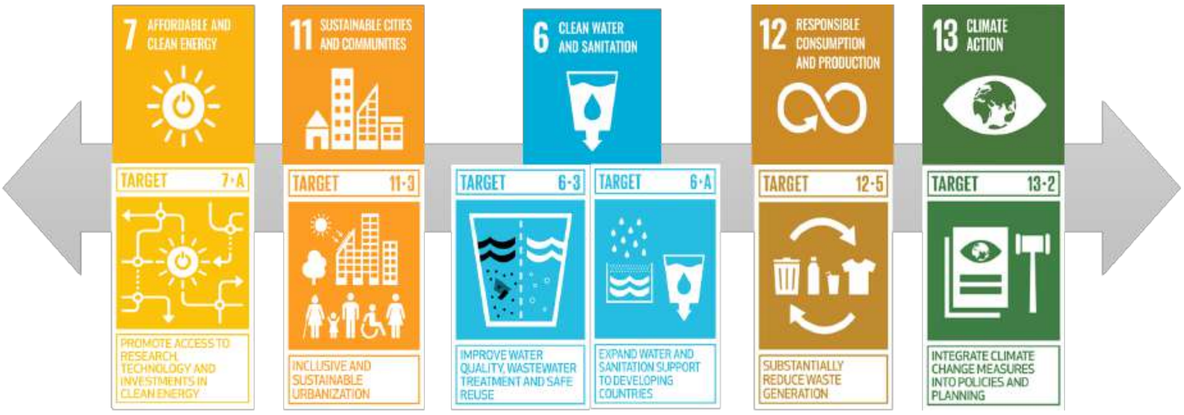


Figure 2.1.1: SDG interlinkages with respect to wastewater treatment and management (Adapted from UN SDGs)

Recently, few global studies have been carried out to estimate the wastewater volumes and make predictions for the future. For example, Qadir et al. (2020) estimated that 380 billion m^3 of wastewater is generated annually across the world. Based on the rate of population growth and urbanization, the daily wastewater generated is expected to increase by 24% (470 billion m^3) by the end of the SDG era in 2030 and 51% (574 billion m^3) by 2050 over the current estimates (Fig.2.1.2). It is to be noted that, among the global regions, Asia generated the largest volumes of wastewater representing 42% (159 billion m^3) of the wastewater globally. It is expected that by 2030 there will be an increase in the wastewater generation to 44%, and hence needs attention.

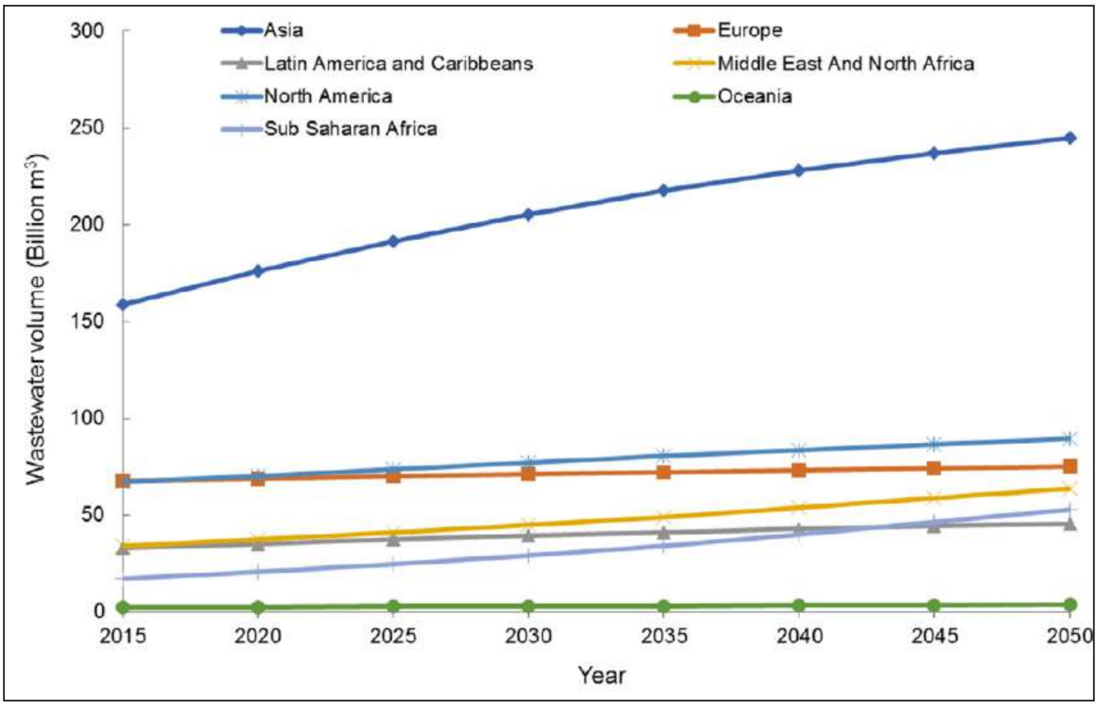


Figure 2.1.2: Wastewater production across the different regions of the world for 2015-2050 (Source: Qadir et al., 2020)

A similar study was done by Jones et al. (2020), wherein the global annual wastewater generation was estimated at 359.4 billion m^3, of which 63% (225.6 billion m^3) is collected and 52% (188.1 billion m^3) is treated. Annual wastewater reuse is estimated at 40.7 billion m^3, representing 11% of the total wastewater generated and 22% of the treated wastewater for direct reuse. This indicates that approximately 40% (171.3 billion m^3) of the wastewater is, unfortunately, discharged directly to the environment without being treated (Fig. 2.1.3).

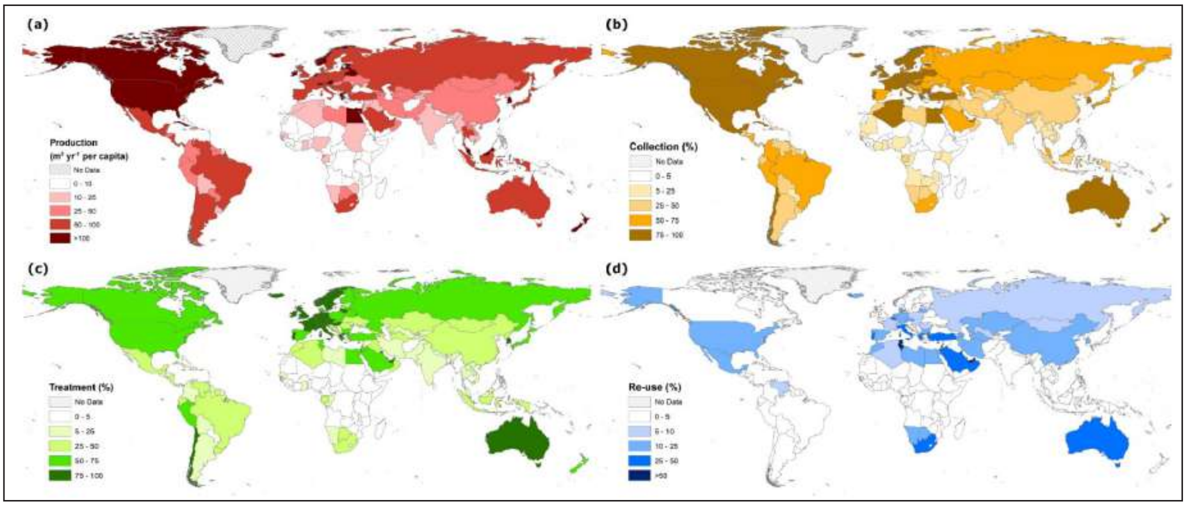


Figure 2.1.3: Global wastewater estimates at country scale: a) Wastewater production (m3/year per capita), b) wastewater collection (%), c) wastewater treatment (%), and d) wastewater reuse (%) (Source: Jones et al., 2020)

The study also found that high-income countries generate 42% of global wastewater, which is almost twice that of low- and lower-middle-income countries (Fig. 2.1.4). Wastewater treatment and collection percentages follow similar patterns, with high-income countries collecting and treating the majority of their wastewater (82% and 74%, respectively), while the low-income groups collect 9% and treat 4% of their total wastewater generated. The wastewater treatment is less than 50% for the upper and lower middle income and low-income groups. In the case of wastewater reuse, the proportion of treated wastewater reuse is higher in the upper middle (25%) and lower middle income (25%) than in the high-income group (19%); while the low-income groups are only able to reuse 8% of the treated wastewater. Regionally, East Asia and the Pacific generate the largest volume of wastewater, coinciding with the largest population share (31%) (Fig 2.15). Wastewater collection and treatment rates were found to be highest in Western Europe and lowest in Southern Asia. With the lowest treatment rates, the reuse of treated wastewater was also low in Southern Asia. These results suggest that even though developed countries generate more wastewater, they also have the infrastructure to reuse wastewater.

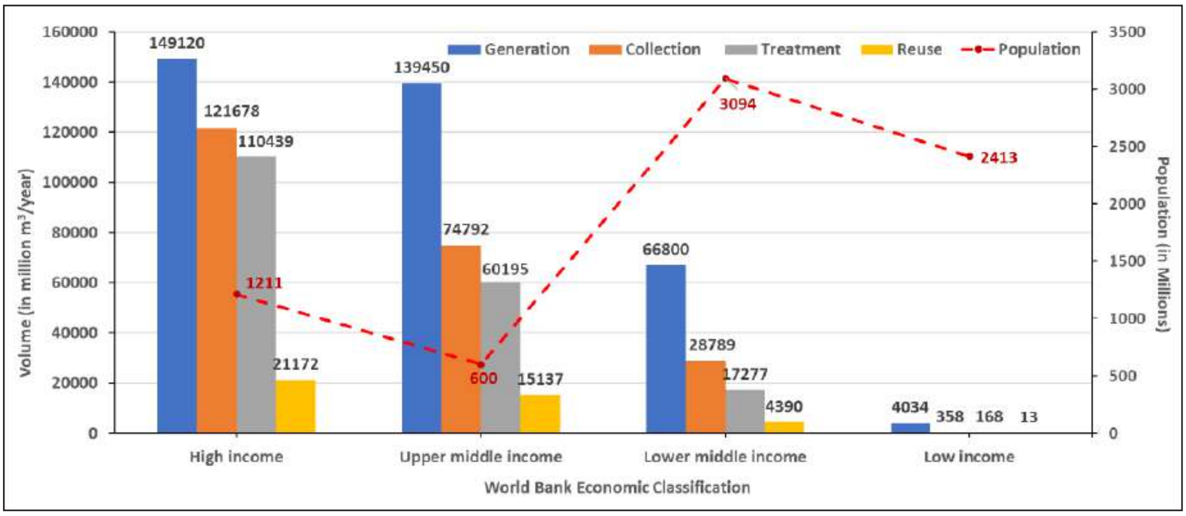


Figure 2.1.4: Wastewater statistics as per World Bank economic classification for the year 2015- 2050 (Data Source: Jones et al., 2020)

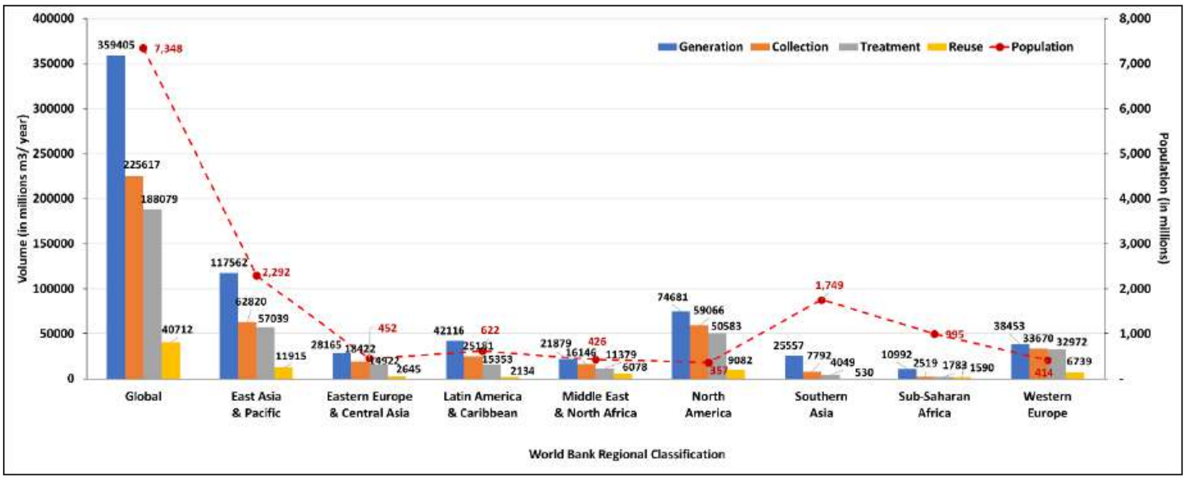


Figure 2.1.5: Wastewater statistics as per World Bank's regional classification for the year 2015 (Data Source: Jones et al., 2020)

Thus, both of these recent studies highlighted the under-performance of the Asian region, particularly the Southern Asia region, in the treatment and reuse of wastewater. It is to be noted that, among the South Asian countries, India, the second largest populous country, has the highest wastewater generation.

2.2. India's wastewater scenario

India's urban centres are witnessing unprecedented growth, propelled by new economic reforms and migration. Its population, 1.38 billion (as on 2020), is now fast converging on cities in search of a better source of income generation and quality of life. According to recent estimates, 35% of the total population (483 million) is concentrated in urban centres (United Nations, 2019). According to Census 2011, as many as 53 cities in India had a population above a million. At this current growth rate, the urban population is estimated to reach 607 million by 2030; and it is estimated that by 2050, 50% of the country's population (877 million) will be urban cities. This unsustainable increase in urban population exerts enormous pressure on city planners, especially for provisioning utility services, particularly for clean and affordable water. Allocation of water for such urban cities will eventually take water from the common pool where multiple sectoral demands exist.

Sectoral water demands are reaching new heights where irrigation, household supply, energy and industry constantly seek increased volumes to meet growing needs. The 2050 projections for India report that it will require 1,447 km^3 of water, of which 74% is identified for irrigation, while the rest is for drinking water (7%), industry (4%), energy (9%) and others (6%) (Amerasinghe et al., 2013). However, with the aforementioned rapid urban growth in Indian cities and towns, the demand for drinking water is also rising and has a higher priority than competing rural water needs, including irrigation. Water transfers from rural and peri-urban regions to urban cities are increasing. A large number of these growing cities are located in major river basin catchments, taking freshwater away and discharging wastewater back into the catchments and thus polluting irrigation water as well as posing major challenges for urban and rural planners, especially concerning urban wastewater management.

2.2.1. Urban waste generation and treatment

In India, the sewage generation in the urban centres, as per the recent assessment by Central Pollution Control Board (CPCB), was 72,368 Million Litres per Day (MLD) for the year 2020-21. Currently, the installed sewage treatment capacity is 31,841 MLD, but the operational capacity is 26,869 MLD, which are much lower than the load generated. Of the total urban sewage generated, only 28% (20,236 MLD) was the actual quantity of wastewater treated. This implies that 72% of the wastewater remains untreated and is disposed of in rivers/lakes/groundwater. There are some increases in infrastructure e.g., another 4,827 MLD sewage treatment capacity, has been proposed. If this is added to the existing installed capacity, even then, there is a gap of 35,700 MLD (i.e., 49%) between the wastewater generated and the capacity available for treatment (CPCB, 2021b).

Looking more closely at the city-scale wastewater generation, the estimated wastewater generation from Class I cities and Class II towns (as per the 2001 census) is 29,129 MLD, which is expected to be 33,212 MLD at present, assuming a 30% decadal growth in urban population (Fig. 2.2.1). Against this, the installed sewage treatment capacity is only 6,190 MLD. There remains a gap of 79% (22,939 MLD) between sewage generation and installed sewage treatment capacity. Another 1742.6 MLD wastewater treatment capacity is under the planning or construction stage. If this is added to the existing capacity, there still is a gap of 21,196 MLD (equal to 73%) in sewage treatment capacity (CPCB, 2021c).

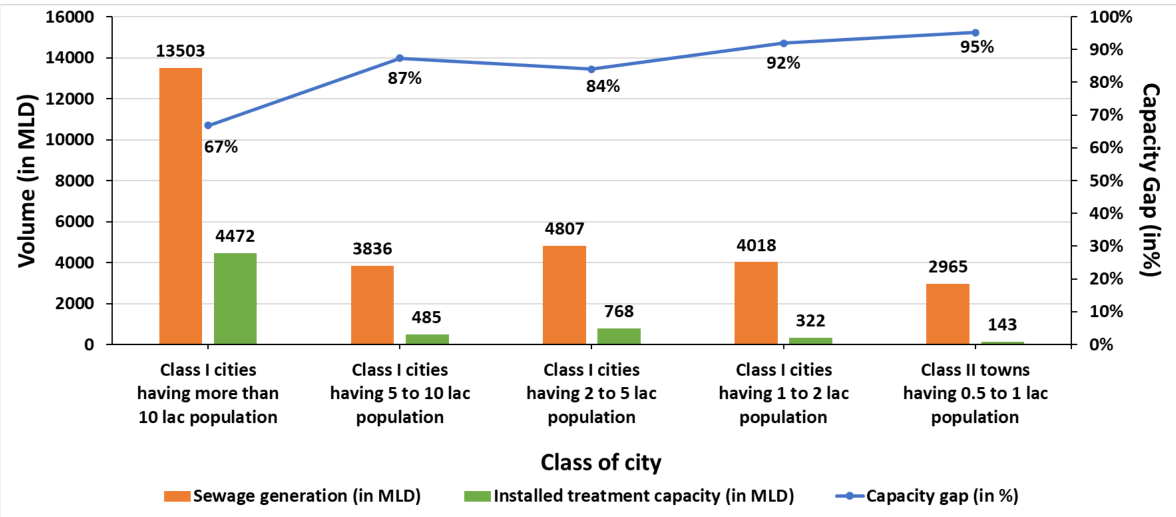


Figure 2.2.1: Wastewater generation and treatment capacity gap at city level in India (CPCB, 2022)

The untreated wastewater largely finds its way out through the nearby rivers, lakes, and groundwater aquifers, thus causing contamination and deterioration of water quality. The CPCB has identified 351 stretches on 323 rivers to monitor the river water quality using Biochemical Oxygen Demand (BOD) as an indicator of pollution. The monitoring results (Table 2.2.1) show that 13% of Indian river stretches are in Priority 1, which indicate that they are severely polluted, and 17 % of the stretches in Priority 2 and 3 are moderately polluted. Apart from high BOD and Chemical Oxygen Demand (COD) levels, high levels of heavy metals, arsenic, fluorides, and hazardous chemicals are also found in many places, especially in groundwater (CPCB, 2018).

Table 2.2.1: Priority wise number of polluted Indian river stretches

Priority Category	Health Status	BOD Value (mg/L)	Number of stretches
1	Severely polluted	BOD >30 mg/L	45
2	Moderately polluted	BOD between 20-30 mg/L	16
3	Moderately polluted	BOD between 10-20 mg/L	43
4	Mildly polluted	BOD between 6-10 mg/L	72
5	Clean	BOD between 3-6 mg/L	175
Total			**351**
Data Source: CPCB. (2018)			

With the rapid increase in population and urbanization of the country, the generated wastewater volume also would increase at the same pace. In addition, the depletion of freshwater resources in terms of quantity and quality would worsen the situation. On the other hand, the time needed to develop understanding of these concerns and testing treatment technologies is limited. Because of these issues, it is crucial for India to use bilateral opportunities to learn and collaborate with the developed countries, who have successfully tested these technologies, and implement sustainable solutions for the treatment and reuse of wastewater. With this objective, this white paper reviews the current scenario of wastewater management in India and documents categories in which collaborations can be made. It offers a detailed discussion on waste treatment, and reuse solutions practiced worldwide that India can learn from and tailor as per the requirements of land, natural resources, energy, cost and in accordance to abiding with the country's specific laws and regulations.

2.3 Structure of the white paper

This white paper is structured in six sections starting from section 2.

Section 2 gives an introduction and a general overview of wastewater generation, treatment and use across the globe. Based on the analysis of global statistics, India's urban wastewater scenario is discussed as per the recent assessments.

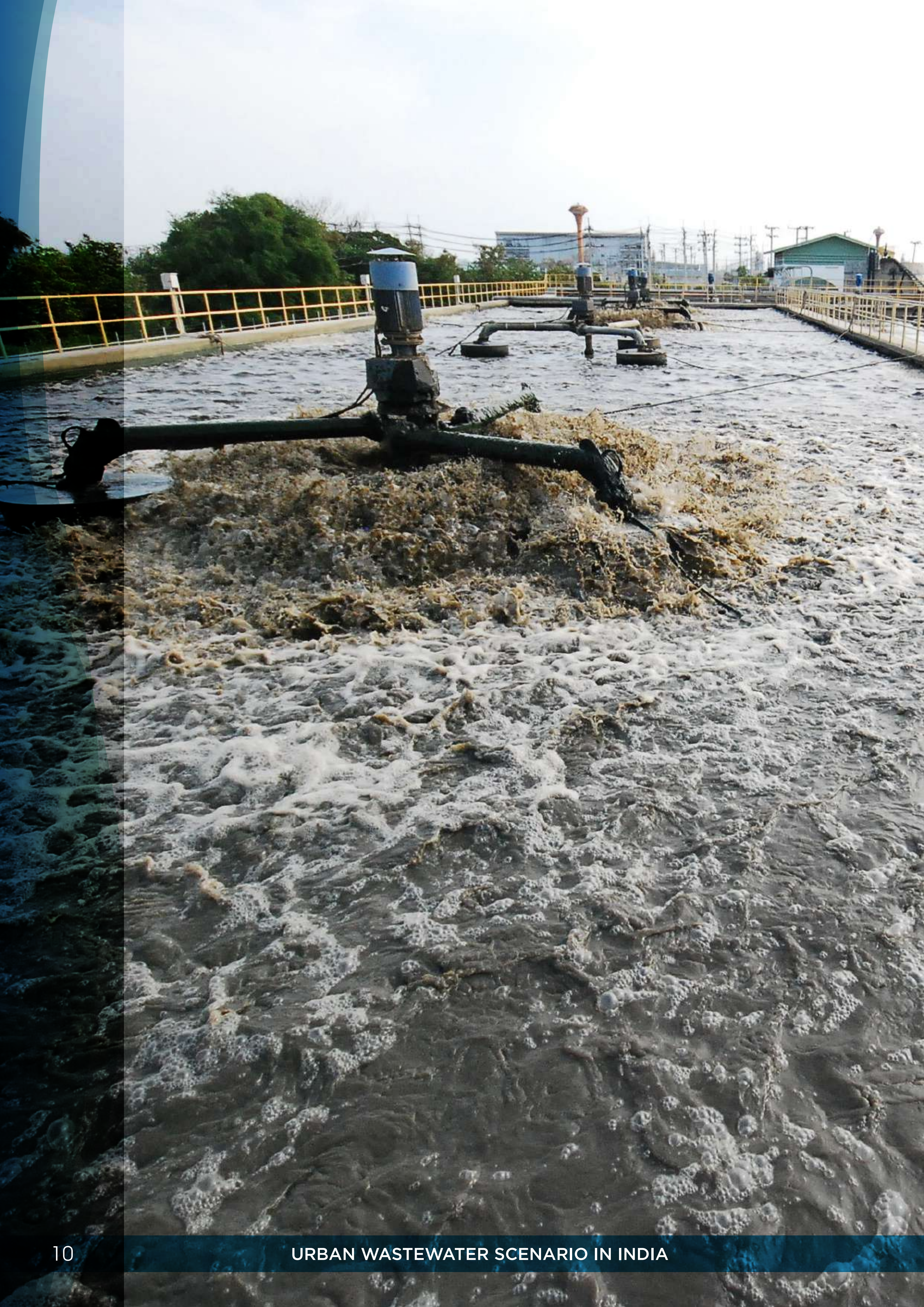
Section 3 explains the different policies and legal frameworks along with the role of different institutions in India responsible for Urban Wastewater Management (UWM). Also, the transfer of power in managing wastewater from national to state and local levels has been mentioned. Various initiatives taken by the government of India for urban wastewater management have been enlisted. Further, the section explains India's storage, transport, and treatment of urban wastewater. Different types of sewage management setups followed in India are discussed, and technologies used for wastewater treatment are explained. This section includes the scenario of reusing treated wastewater and the current practices followed in India. Lastly, various challenges faced by a centralized domestic wastewater treatment system in India are explored.

Section 4 provides a review of innovative, sustainable, cost-effective, and energy-efficient solutions to treat urban wastewater using multiple case studies, globally. The decentralized approach and popular conventional, nature-based and advanced technologies are discussed. Innovative solutions such as the Internet of Things, Remote Sensing and Geographic information systems are explored to achieve near real-time water quality monitoring and management, leading to more efficient and effective problem detection and treatment. Also, the section explores the potential reuses and advantages of treated wastewater in the light of the National Framework on the Safe Reuse of Treated Wastewater-2020. The need and scope of upgradation in traditional septic tanks and possible technological advancements have been explained using case studies. Further, how these solutions can be promoted and adopted at the institutional, community and individual levels are discussed using Public Private Partnership and Public Private People Partnership.

Section 5 focuses on capacity building and raising awareness for Urban Wastewater Management (UWM). The purpose of this section is to present a theoretical framework for capacity building at the national level to address and identify capacity gaps. The focus is on building a human resource base (with training and knowledge transfer), researchers and institutional and international collaboration, and sensitization of the public/community to face the future wastewater management challenges.

Section 6 mentions the key learnings from the case studies under the National Clean Ganga Mission.

Section 7 discusses the ways forward



3. Current scenario of Urban Wastewater Management (UWM) in India – An Overview

3.1 Policy and legal regulation framework for UWM

As per Schedule Seven of the Indian constitution, the "*water*" is a State subject. But in case of inter-state waters, Parliament has a power to legislate, whereas State has power to make policy and legal regulations about the use of water within the State. The 74th Constitutional Amendment, enacted in 1993, decentralizes the water supply and sanitation services from state government to the urban local bodies (ULB).

As far as dedicated regulation regarding wastewater is concerned, there is no specific Act dedicated to management of wastewater in India. But there are provisions in the Water (Prevention and Control of Pollution) Act, 1974 which deals with wastewater as a source of pollution. The Central and State Pollution Control Boards are established under this act and thy are responsible for the prevention and control of water pollution. There are penal provisions regarding pollution in water flowing into the streams, wells, sewer, or land. The Central Pollution Control Board (CPCB) prescribes the criteria for different class of Water as "*Water Quality Standards*" and "*Industrial Effluents Standards*", however these need to be constantly updated using international standards and considering emergent pollutants. The municipal laws impose certain obligations regarding wastewater disposal into sources of drinking water supply.

The Water (Prevention and Control of Pollution) Cess Act, 1977, which came into force in 1992, provided the financial resources for the Central and State Boards by levying taxes on industrial water use. In order to incentivize the wastewater treatment, a provision of a rebate of 25% on the payable cess is made in the Act.

The Environment (Protection) Act, 1986 empowered the Central Government to prescribe the standards for sewage and effluent and ensure compliance. This is an umbrella act about environmental protection and it enshrines the "polluter pays principle" into the Indian environmental policy. Under the Environment (Protection) Rules, 1989 the industry specific standards for emission/effluent discharge are prescribed. The Wastes (Management and Handling) Rules, 1989 regulate the business of sewerage and sewage treatment, along with other matters.

The National Environment Policy, 2006 emphasises the direct and indirect causes of pollution of surface (e.g. river, wetlands) water sources, groundwater, and coastal area and recycling of wastewater before discharging into water bodies. The policy prescribes the action plans for urban cities to address water pollution through appropriate regulatory systems and technological development for treatment, reuse, and recycle of urban wastewater before final discharge into water bodies.

National Urban Sanitation Policy, 2008, focuses on sanitary and safe disposal of human waste and recommends recycle and reuse.

The integrated water resources management in planning, development, and management is adopted in **India's National Water Policy, 2012**. This policy incentivises decentralised sewage treatment plants, recycling and reuse of treated water through planned tariff systems, and subsidized treatment of industrial effluents. National Water Policy focuses on reducing water pollution and the draft revised National Water Policy, 2020 that embraces the imperative of recycling and reuse.

National Faecal Sludge and Septage Management Policy, 2017 focuses to achieve 100% access to safe sanitation, achieve integrated urban sanitation, safe disposal of faecal waste and mandates strict environmental discharge standards, and promotes an appropriate, affordable and incremental approach to achieving these standards.

The Model Bill for Regulation of Groundwater Development 2016 deals with regulation of ground water in both urban and rural areas and various State Governments enacted the Ground Water Development Act, based on this model bill. These Acts provides the regulation for control on use of chemical fertilizers or pesticides, to regulate the disposal, burial or injection of waste, industrial effluent and to protect the quality of groundwater.

The Prohibition of Employment as Manual Scavengers and their Rehabilitation Act, 2013 prohibits the manual cleaning of sewers and septic tanks and it aims to eliminate insanitary latrines, and rehabilitate identified manual scavengers in alternative occupations.

The Coastal Regulation Zone Notification aims to protect the livelihood of fishermen families, protect the coastal area ecology and generate economic activities in coastal areas. This also aims to reduce the disposal of waste along the coastal regions.

The National Water Mission promotes the recycling of wastewater for meeting water needs of urban areas. The Tariff Policy, 2016 by Ministry of Power mandates the thermal power plants located within 50 km radius of a sewage treatment plant of an urban local body to mandatorily use treated urban waste. The Service Level Benchmarks of the Ministry of Housing and Urban Affairs (MoHUA) mandate the extent of reuse and recycling of sewage in urban areas as 20%.

The National Water Quality Monitoring Programme of India, through its network of SPCBs, advises central and State governments on prevention, control, abatement of water pollution and sets standards on water quality in streams and wells. The Guidelines of National Building Code 2016, emphasizes the reuse of treated sewage and sullage in commercial or residential multi-storeyed complexes for flushing of toilets, horticulture and fire-fighting purposes. It also suggests separate storage tanks and separate distribution pipes.

The National Guidelines on Zero Liquid Discharge developed by CPCB for industrial sectors highlights the zero effluent discharge. The CGWB Master Plan for Artificial Recharge to Ground Water in India, 2013 emphasizes careful monitoring for regarding the treated urban wastewater in order to avoid any possibility of contamination of ground water. The Prime Minister's Krishi Sinchayi Yojana emphasises exploring the feasibility of reusing treated municipal used water for peri-urban agriculture.

The vision expressed in **the National Framework on the Safe Reuse of Treated Water, 2021** is – "*widespread and safe reuse of treated used water in India that reduces the pressure on scarce freshwater resources, reduces pollution of the environment and risks to public health, and achieves socio-economic benefits by adopting a sustainable circular economy approach*" (MoJS, 2020) and accordingly requisite recommendations are made in the framework.

3.2 Institutional arrangements/organizational set-up–Roles and responsibilities

Under Article 246, Indian Constitution vested the state government's legislative jurisdiction of water resources (water supply and treatment, wastewater treatment, irrigation and canal management, water storage and water power). Thus, the States are vested with the constitutional right to plan, implement, operate and maintain and cost recovery of water supply and sanitation projects. At the local level, the responsibility is entrusted by legislation to the local bodies like municipal corporation, municipality, municipal council, and notified area committee/authority for towns or on a state/regional basis to specialized agencies. The organization flow chart is shown in Fig. 3.2.1.

The Public Health Engineering Department (PHED) is the principal agency at the State level for planning and implementing water supply and sanitation programs. In several states, statutory Water Supply and Sanitation Boards (WSSBs) have taken over the functions of the PHEDs. The primary objectives for creating WSSBs have been to bring in the concept of commercialization of the water supply and sanitation sector management and more accountability.

Ministry of Housing and Urban Affairs (MoHUA) formulates policy guidelines concerning the urban water supply and sanitation Sector. It provides technical assistance to the States and Urban Local Bodies (ULBs). Central Public Health and Environmental Engineering Organization (CPHEEO) supports MoHUA in policy formulation and also handholds States by technical advice, guidelines, scrutiny and appraisal of schemes, and propagation of new water supply and sanitation technologies, including municipal solid waste management. Also, State Water Supply and Drainage Boards (SWSDBs) were formed at the state level to support ULBs in planning, designing, and implementing sewerage and wastewater treatment infrastructure. SWSDBs draw funds from national and state governments. They can build treatment plants and then hand them over to ULBs for operation and maintenance.

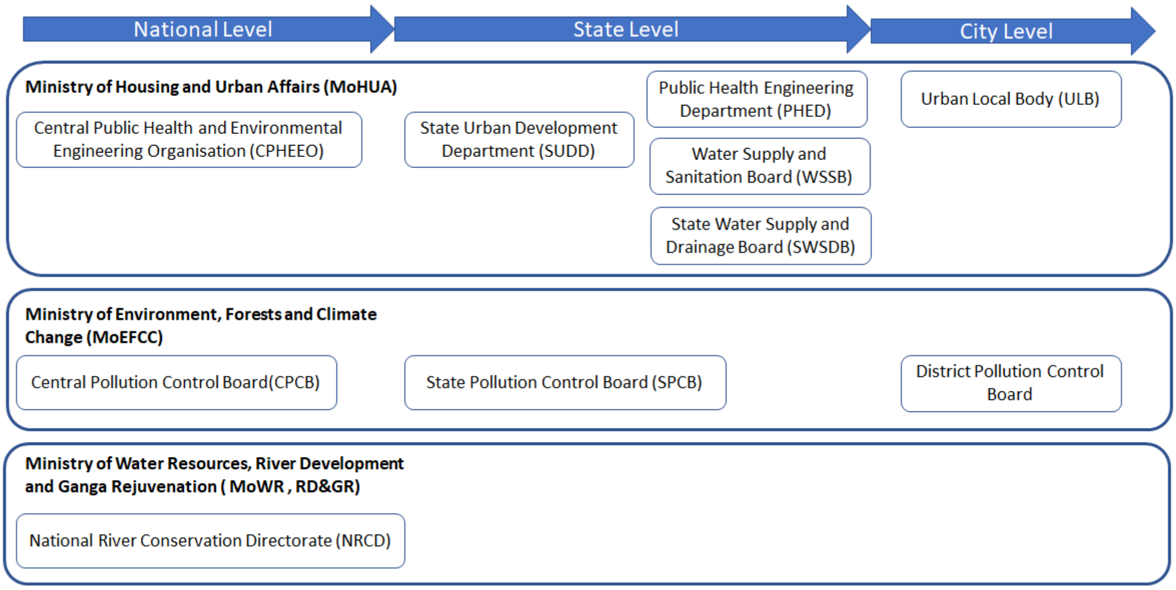


Figure 3.2.1 : Government agencies responsible for urban wastewater management in India

Ministry of Environment, Forest and Climate Change (MoEFCC) and line agencies are in charge of minimizing environmental pollution and planning, promoting, and coordinating environmental policies and programs in the country. They are responsible for setting environmental standards (especially the discharge standards for treated wastewater). The Central Pollution Control Board (CPCB) was constituted under the Water Act in 1974 as a line agency of MoEFCC with the responsibility to prevent, control, and diminish environmental pollution and to set the wastewater discharge standards for the entire country. All the sewage treatment plants (STPs) in India should adhere to the standards issued by CPCB. At the state level, state pollution control boards (SPCBs) are responsible for the implementation of legislation related to environmental pollution. In addition, SPCBs are provided the freedom to toughen the regulations enforced by CPCB. SPCBs are accountable for monitoring the performance of all wastewater discharging entities (buildings, industries, large and small-scale sanitation systems).

The National River Conservation Directorate (NRCD) in the Ministry of Water Resources, River Development and Ganga Rejuvenation (MoWR , RD&GR) is implementing the Centrally Sponsored Schemes of National River Conservation Plan (NRCP) and National Plan for Conservation of Aquatic Ecosystems' (NPCA) for conservation of rivers, lakes and wetlands in the country. The pollution reduction works taken up under the NRCD include:

interception and diversion works/ laying of sewerage systems to capture raw sewage flowing into the rivers through open drains and diverting them for treatment; setting up of STPs for treating the diverted sewage; construction of low cost sanitation toilets to prevent open defecation on river banks; construction of electric crematoria and improved wood crematoria to conserve the use of wood; river front development works, such as improvement of bathing ghats; and public participation and awareness and capacity building.

The Central Government acts as an intermediary in mobilizing external assistance in the water supply and sanitation sector and routes the aid via the State plans. It also provides direct grant assistance to some extent to water supply and sanitation projects in urban areas under the various programs of the Government of India.

3.2.1 Initiatives of the Government of India

Water (Prevention and Control of Pollution) Act of 1974 (amended 1988): This Act laid the foundation for establishing the Central and State Pollution Control Board (CPCB and SPCBs) to advise, monitor, and enforce sewage and industrial effluent treatment and disposal regulations. All the STPs in India should adhere to the standards issued by CPCB (https://cpcb.nic.in/wqstandards/).

Environment (Protection) Act of 1986: This Act regulated the discharge standards STPs. It prescribes limits of various pollutants be discharged to different environmental zones (land, surface water bodies, marine coastal areas, etc.).

Ganga Action Plan (GAP-I 1985, GAP-II 1993) and National River Conservation Plan: Under GAP-I and GAP-II, cleaning of River Ganga and its major tributaries, Yamuna and Gomti was initiated. It was expanded to cover other rivers under the National River Conservation Plan in 1995. Under GAP, 1098.31 MLD sewage treatment capacity was created (Dutta, 2020). The pollution reduction works taken include: (i) interception and diversion of sewerage systems for treatment, (ii) setting up of STPs, (iii) construction of low-cost toilets, (iv) riverfront development works, (v) public participation and awareness and capacity building.

National Plan for Conservation of Aquatic Ecosystems' (NPCA) (2015): The NPCA aims to provide a framework for conservation and sustainable management of wetlands, with the objectives: (i) Developing policy guidelines, (ii) Supporting, promoting, and strengthening conservation of wetlands, and (iii) Facilitating the development of a national inventory, and (iv) Strengthening the capacity of wetlands managers and stakeholders.

National Urban Sanitation Policy (2008): This policy made local governments responsible for behavioral change, total sanitation, and 100% safe waste disposal. It envisages that cities will implement city sanitation plans, prioritizing areas and implementing long-term plans in parallel, emphasizing mobilizing all city stakeholders. It is the responsibility of the state governments to draft state urban sanitation policies, under which the cities can develop their own sanitation strategies.

Other essential flagship national programs launched by the Government of India: Namami Gange program launched in 2015. Under Namami Gange Programme, Government has sanctioned 161 sewage management projects at 245.81 billion INR for creation and rehabilitation of 5501 MLD sewage treatment capacity and laying 5,134 km of sewerage network. Out of these, 92 projects have been completed resulting in creation and rehabilitation of 1,643 MLD of STP capacity and laying of 4,156 km sewerage network (PIB, 2022). It also includes sectoral programs to improve un-sewered and sewered sanitation, such as the Swachh Bharat (Clean India) Mission 2014-2019, the AMRUT Mission 2015-2023 and the Smart City initiative 2017-2023.

3.3 Current technologies and practices in UWM

In India, UWM is performed in two ways (i) On-site systems and (ii) Off-site systems. An on-site system retains wastewater in the vicinity of the toilet in a pit or tank, and the produced sludge is removed periodically to the faecal sludge/septage treatment system. While an off-site system removes wastewater from the vicinity of the toilet for disposal elsewhere. An off-site system comprises of a sewerage network to transport sewage to a sewage treatment plant (STP); the treated wastewater's solid content is disposed to drying beds, and liquid is disposed to waterbodies. Such treated wastewater is being used for different applications like (a) Irrigation, (b) Toilet flushing, (c) Industrial use, (d) Fish culture, and (e) Indirect and incidental uses (CPHEEO, 2012). The storage, transport, and treatment steps followed in an off-site and on-site system are depicted in Fig. 3.3.1. These two systems are explained in detail in the coming sections.

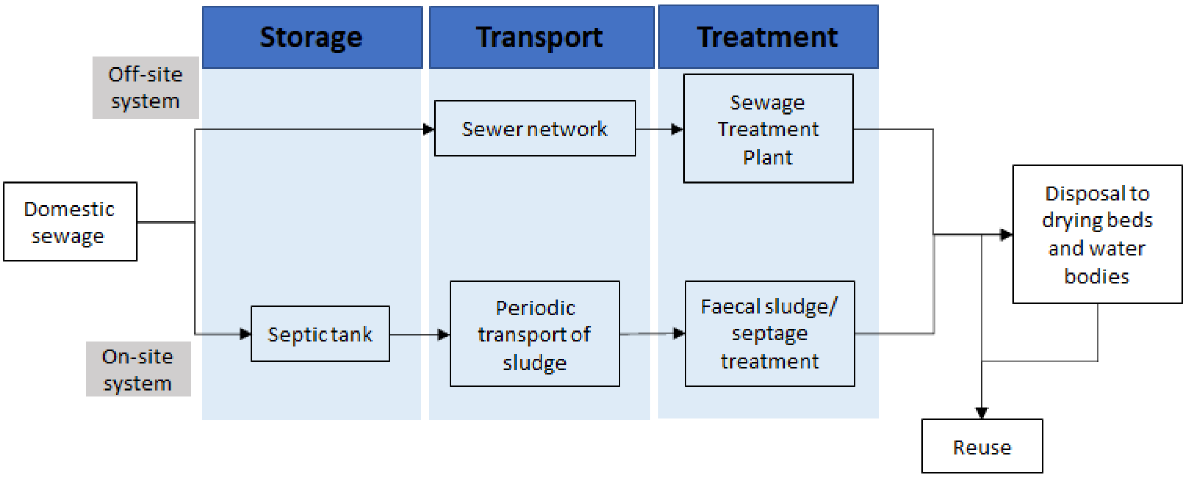


Figure 3.3.1 : Storage, transport, and treatment mechanism of an off-site and on-site wastewater treatment system

3.3.1 Off-site system

Sewage collection system: Wastewater collection can be done using two systems (i) Separate system, which collects sewage and stormwater in separate drains, and (ii) Combined system, which collects sewage and stormwater together in the same drain. In India, almost all the sewer networks are designed for separate systems, which satisfies the technical and economic advantages. However, old sewerage systems which were developed during British rule have a combined system like in Kolkata (Murmu et al. 2021).

Sewage treatment facilities: In India, under an off-site treatment system, domestic sewage is transported to STPs. The STPs are designed based on the influent characteristics like total suspended solids (TSS), Biochemical oxygen demand (BOD), and Faecal coliform (FC). At present, 1,469 STPs (as of 2020 – 21) have been installed in the urban centres of 28 states and union territories in India, with a total installed capacity of 31,841 MLD, Compared to the 2014 assessment by CPCB, the number of STPs has almost doubled, and the capacity increased by 41% in 2020 (Table 3.3.1). Of the 1,469 STPs, 102 STPs are non-operational, and 274 STPS are under construction. Another 162 STPs with a capacity of 4,827 MD are proposed. So, currently, the total treatment capacity is 36,668 MLD; however, only 26,869 MLD is the operational capacity (CPCB, 2021b).

Table 3.3.1: Comparative STP status with respect to number and capacity for years 2014 and 2020

S.No.	STP Status	2014		2020	
		Number of STPs	Capacity (MLD)	Number of STPs	Capacity (MLD)
1	Operational	522	18883	1093	26869
2	Non-Operational	79	1237	102	1406
3	Under construction	145	2528	274	3566
4	Proposed	70	628	162	4827
	Total Installed (1+2+3)	**746**	**22648**	**1469**	**31841**
	Total Treatment (1+2+3+4)	**816**	**23276**	**1631**	**36668**

Data Source: CPCB. (2021)

In an off-site system, sewage treatment is composed of three stages (i) Primary treatment, (ii) Secondary treatment, and (iii) Tertiary or advanced treatment, as depicted in Fig. 3.3.2.

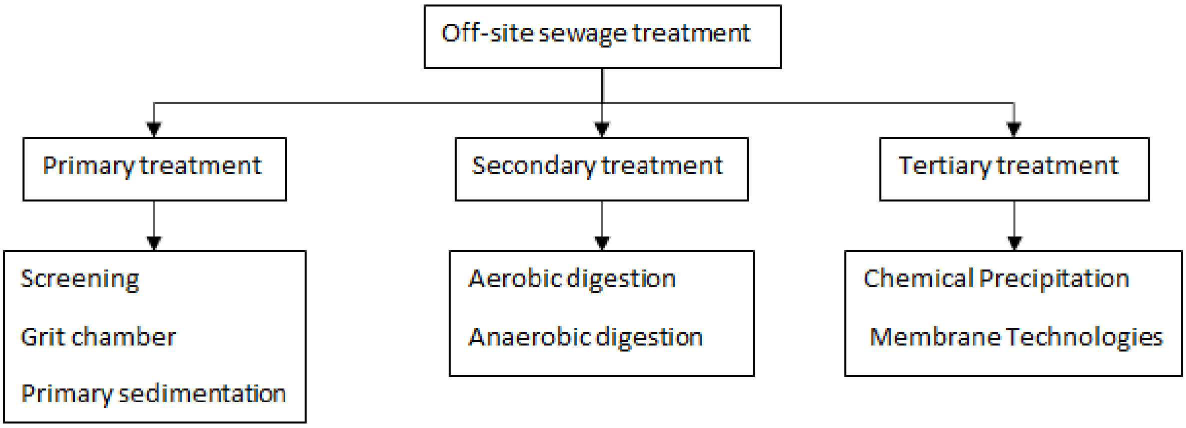


Figure 3.3.2 : Primary, secondary, and tertiary treatment methods of an off-site wastewater treatment system

i. Primary treatment involves a preliminary filtration process that removes physical and chemical pollutants like suspended solids. This process also removes some organic nitrogen, phosphorus, and heavy metals. However, it provides limited removal of microbial pathogens. The first step of primary treatment is screening, which removes the solid waste of wastewater, like pieces of cloth, hair, paper, wood, cork, and kitchen solids. The screening element may consist of parallel bars, rods, or wire mesh, and the openings may be of any shape. It is recommended that three sequential stages of screens shall be provided coarse, followed by medium, and followed by fine screens. Then sewage goes to the grit chamber, which removes grit to protect the moving mechanical equipment and pump elements from abrasion and damage. After the grit chamber, primary sedimentation is done in a sedimentation tank, also called settling tanks and clarifiers. Sedimentation is used to remove (i) inorganic suspended solids, (ii) Organic and residual inorganic solids, free oil and grease, and other floating material, and (iii) chemical flocs produced during chemical coagulation and flocculation. If the sedimentation is insufficient to cause the settlement of suspended solids, certain chemicals (such as alum, starch, iron materials, activated silica, and aluminium salts) are added to cause the settlement of the solids by coagulation. The wastewater flow through the primary treatment unit is depicted in Fig. 3.3.3.

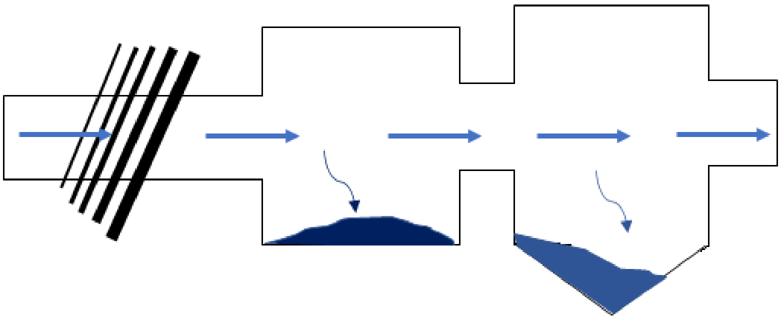


Figure 3.3.3 :Wastewater flow through different units involved in primary treatment

ii. Secondary treatment includes biological digestion to remove organic content, leading to a reduction in BOD of up to 85%. Secondary treatment can be aerobic or anaerobic. Aerobic decomposition is done in the presence of dissolved air or oxygen in wastewater by the aerobic or facultative bacteria, causing a reduction in or removal of BOD, COD, dissolved and suspended organics, volatile organics, nitrates, phosphates, and other substances. However, it results in vast amounts of biosolids as waste, requiring costly treatment and management practices. Anaerobic decomposition occurs without dissolved oxygen or air, and anaerobic and facultative bacteria carry it out. In this process, prolonged retention time can give better results by degenerating organic contaminates (through nitrification and denitrification processes) (Hasan et al., 2019). The arrangement of primary and secondary treatment units for wastewater treatment is depicted in Fig. 3.3.4.

iii. In India, various treatment technologies, from conventional to advance to natural, are used for secondary treatment purposes. The technological distribution with respect to the number and the capacity of the installed STP is given in Table (3.3.2). SBR (30%) and ASP (20%) are the prevailing technology adopted by ULBs.

Table 3.3.2 : Technological distribution with respect to number and the capacity on installed STP capacity

Technology	Technology type	Number	Capacity (in MLD)
Activated Sludge Process (ASP)	Conventional	321	9,486
Extended Aeration (EA)	Advanced	30	474
Fluidized Aerobic Bed Reactor (FAB)	Advanced	21	242
Moving Bed Biofilm Reactor (MBBR)	Advanced	201	2,032
Oxidation Pond (OP)	Natural	61	460
Sequencing Batch Reactors (SBR)	Conventional	490	10,638
Upflow Anaerobic Sludge Blanket (UASB)	Advanced	76	3,562
Waste Stabilization Pond (WSP)	Natural	67	789
Any other		364	8,497
Data Source: CPCB. (2021b)			

iv. Tertiary treatment is the removal of constituents beyond the ability of secondary treatment. It includes chemical precipitation and membrane technologies. Chemical precipitation is required to remove phosphorous to control eutrophication, salt to use the treated sewage for industrial purposes, and heavy metals. Membrane technologies are the alternative to the removal of hardness, but they result in the removed salts as a reject solution, which will need either ocean disposal or thermal evaporation. Besides, they require extensive pre-treatment to eliminate suspended solids.

After tertiary treatment, disinfection of treated sewage is done when the coliforms may affect the receiving water quality. Chlorination is the most widely used disinfection technology for sewage treatment. As the treated sewage is fresh from secondary aerobic biological treatment, the chlorination of such effluents does not result in hazards. In the case of effluents from anaerobic processes like UASB, the provision of an aerobic polishing treatment is mandatory before chlorination.

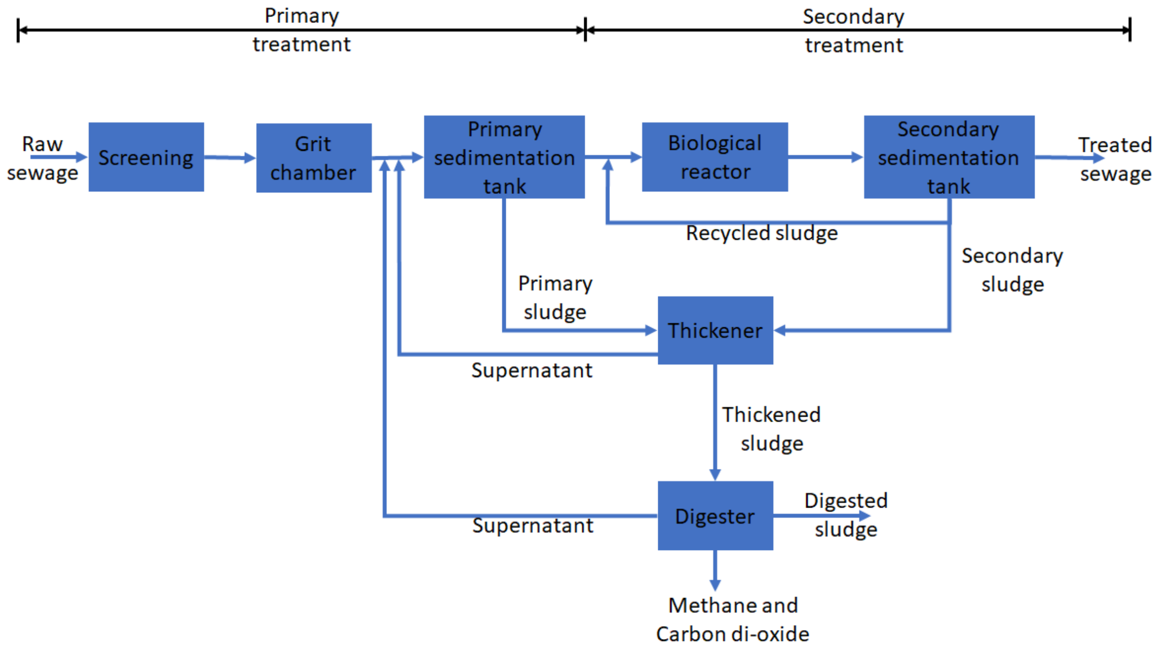


Figure 3.3.4 : Sewage flow through the primary and secondary treatment units of an STP (Source: CPCB, 2013)

Sludge management: In STP, sludge means primary sludge when the suspended solids of raw sewage settle in a primary clarifier, secondary sludge when the mixed liquor (sewage aerated in aeration tanks) is settled in secondary clarifiers to separate the microorganisms by gravity. Return sludge, a major portion of the secondary sludge is returned to the aeration tank for seeding the microorganisms. Excess sludge, a small portion of secondary sludge is wasted. When raw sewage or secondary treated sewage is subjected to chemical precipitation, the resulting sludge is called chemical sludge. The concentration of settled out organics and microorganisms from primary settling or secondary settling or both is carried out in sludge thickeners. After this, if the thickened sludge is put through anaerobic digestion to produce Methane, it is called an anaerobic digester. If it is oxidized, it is called an aerobic digester. In both cases, the digested sludge will have to be dewatered. There are many types of equipment like centrifuge or filter press or natural solar drying beds for this purpose.

3.3.2 On-site system

In India, about 60% of the population is dependent on the on-site sewage management system. The on-site sewage treatment systems treat sewage within the premises of its generation and are also termed non-sewered sanitation. Conventional Septic tank with soaking options like soak pit and dispersion trenches is India's most commonly used on-site sewage treatment system. A septic tank is a buried chamber that collects and stores domestic sewage and partially treats it under anaerobic conditions. Effluent from the septic tank should be discharged to an on-site infiltration system like a soak pit or drain field, as shown below in Fig. 3.3.5. In the septic tank, solids settle and digest anaerobically, which reduces sludge volume and enables overflow effluent to infiltrate into the ground in the soak pit without clogging the leaching system. In practice, many premises do not have a soaking arrangement due to space constraints and lack of awareness. Thus, they discharge pathogenic effluent directly into open drains, posing a public health risk.

The standard septic tank design incorporates two chambers. Some septic tank designs adopted in India have three chambers. Most of the treatment takes place in the first chamber. A well-managed septic tank could remove about 50–60% of the biological load in the sewage. Further, a well-designed soak pit can remove bacterial load up to the discharge standards. Soak pits are cheap to construct and need no media when lined or filled with rubble or brickbats. The pits may be of any regular shape, circular or square being more common.

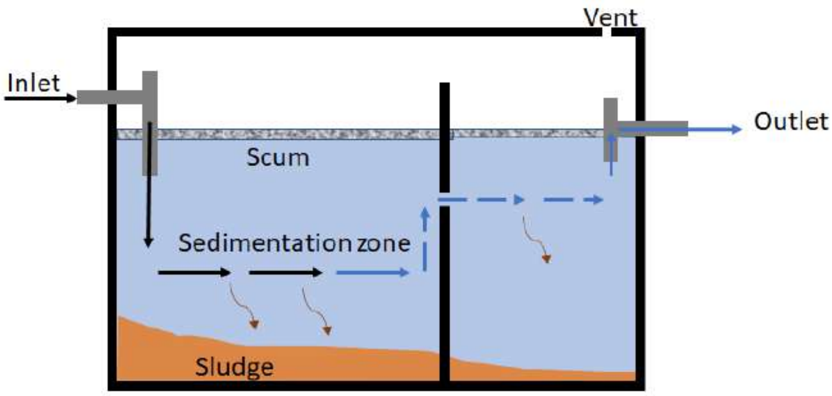


Figure 3.3.5: Septic tank showing three distinct layers (scum (oil, fats, and grease), clarified water, and sludge

On-site sewage treatment methods invariably generate faecal sludge or septage that must be safely collected, transported, treated, and reused/ disposed off. Faecal Sludge and Septage Management (FSSM) assumes significance in the Indian scenario as about 60% of households depend on on-site sanitation systems. On-site sanitation systems in urban India largely consist of double leach pits and septic tanks. A study by the Centre for Science and Environment 2019 in some cities of Uttar Pradesh shows that most (about 80%) containment systems are often not connected to functional soak pits. The situation in other cities in the country is no different. However, drawing inspiration from the National FSSM Policy launched in 2017, states and cities are moving towards scaling up innovative and inclusive urban sanitation service delivery. Managing faecal sludge has gained prime importance in the three states of Maharashtra, Odisha and Tamil Nadu. Almost 500 faecal sludge treatment facilities are already sanctioned in the states mentioned above, and these units shall cater to more than 600 cities and towns. However, there is a scope and support from the government to enhance these treatment facilities keeping in mind the future demands and ways to convert waste to wealth as successfully implemented in developed nations.

3.3.3 *Reuse of sewage*

Considering increasing load of untreated sewage, there is a need to realize sewage as a resource that can be treated as per requirement and utilized for non-potable purposes and industrial utilities. In the recent past, different ULBs of India have focused on reusing treated sewage and initiated the reuse of treated sewage in horticulture, irrigation, non-contact impoundments, and washing and utilization for industrial activities.

The wastewater reuse examples of India include:

i. The Government of Punjab has notified "*The State Treated Wastewater Policy 2017*" to promote recycling and reuse of treated sewerage for non-potable applications. Till date, 47 projects have been completed by the Department of Soil and Water Conservation for using 243.3 MLD treated wastewater of STPs. These projects have been implemented by laying underground pipeline system for irrigation water conveyance covering an area of 7652 hectares (DECC, 2020).

ii. The Indian Agricultural Research Institute, Karnal, has researched sewage farming and recommended an irrigation method for sewage-fed tree plantations.

iii. The Government of Karnataka has issued an official directive to take all necessary steps to ensure that only tertiary treated sewage is used for non-potable purposes, like all gardening, including parks, resorts, and golf courses.

iv. In major metropolitan cities like Delhi, Mumbai, Bengaluru and Chennai, treated grey water is used for toilet flushing in major condominiums and high-rise apartment complexes on a pilot scale.

v. Secondary treated sewage is purchased and treated for use in cooling water makeup in the industrial sector from as early as 1991 in major industries like Madras Refineries, Madras Fertilizers, GMR Vasavi Power plant in Chennai as also in Rashtriya Chemicals and Fertilizers in Maharashtra and most recently in the Indira Gandhi International Airport in Delhi and Mumbai International Airport.

3.4 Limitations and challenges

The following section explores various challenges phased by domestic wastewater treatment system in India. While they face numerous challenges in setting up and operation, the challenges are grouped under the following issues i) Institutional challenges ii) Regulatory challenges iii) Economic challenges iv) Technological challenges and v) Social challenges.

3.4.1 *Institutional challenges*

The Urban Local Bodies (ULBs) in India are important institutions as far as domestic wastewater management is concerned. They are primarily responsible for the provision and maintenance of wastewater treatment facilities in their administrative area. However, in many cases, they lack the capacity to plan and implement such projects. For instance, the performance audit report of ULBs by the Comptroller and Audit General (2017) in the state of Tamil Nadu finds that the shortage of manpower in municipalities affected the revenue collection and delivery of citizen services. It also revealed deficiencies in planning, financial management, implementation, and monitoring of various projects. Similarly, the CAG performance audit (2016) in the state of Jharkhand found that none of the sampled ULBs had a sewage network. In the absence of the same, around 175 MLD of untreated wastewater is discharged into open drains polluting nearby water bodies (CAG, 2016). Thus, it can be seen that ULBs have suffered from planning, implementation, and financial management. While the management of wastewater suffers from issues as listed, the enforcement mechanism for employing corrective measures suffers from various challenges as follows.

The existing institutional, policy and legal mechanisms to enforce the management of wastewater and control water pollution in the country are not sufficient to address the looming crisis. The performance audit of water pollution by the Comptroller and Auditor General (2011) has found that "*there is no specific policy at both the Central or State level that incorporates prevention of pollution, treatment of polluted water and ecological restoration of polluted water bodies and that without this, government efforts in these areas would not get the required emphasis and thrust*." The enforcement (to the existing laws regarding wastewater management) capacities of State Pollution Control Boards (SPCBs) both in terms of power and resources is limited. The penalty amount enforced against the industries or domestic households for non-compliance or defiance of the provisions of the Water (Prevention and Control of Pollution) Act by the State governments is too low (up to a maximum of INR 5 lakhs as per the latest amendments). The cost of non-compliance/violations is found to be significantly lesser compared to the cost it takes for compliance (CAG, 2017). Out of the total STPs (1,114), 21% do not comply with the standards. While looking at corrective measures for non-compliance, in 55% of the cases no action is taken (pending action), and in 40% of the cases action is restricted to show cause notices (CPCB, 2020).

Staff shortages limit the capacity of SPCBs to monitor water quality and disseminate results to the concerned parties. The shortage of staff is 37.6%, 39%, and 52.3% in Group A, B, and C categories respectively (see Fig. 3.4.1). Shortage includes staff in scientific, technical, and administrative domains. Laboratories play an important role in the analysis of pollution levels for regulatory and research requirements. Labs are not well equipped due to a shortage of manpower and procurement delays in instruments, equipment, and consumables (CPCB, 2020). With an insufficient laboratory setup, delay in water quality testing after the sample collection alters the parameters of water quality (Kumar & Tortajada, 2020), thus failing to give a real picture of the water quality on the ground. Along with laboratory-related shortcomings, the lack of an adequate number of monitoring stations (the present monitoring network comprises 4,484 stations (CPCB, 2022) and their geographical spread (as many of them are located not in cities far or immediately downstream of the pollution hotspots) fail to give the real picture of the extent of water pollution in the country (Kumar & Tortajada, 2020). The Class II towns and stagnant water bodies in the states are not included in monitoring networks (CPCB, 2020). Both centre and many states have not yet undertaken the complete incentivization of water bodies, and have not yet quantified the contaminants or human activities that affect the water quality. There is no environmental or health risk assessment performed to understand the impacts of pollution (CAG, 2011). These knowledge gaps further limit the monitoring and enforcement capacities of SPCBs.

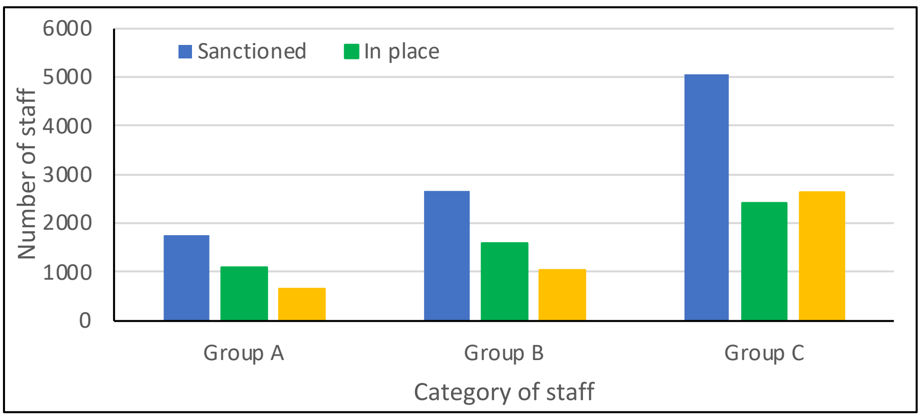


Figure 3.4.1. Human power availability in SPCBs based on category (CPCB, 2020)

Many urban areas with STPs in place suffer from underutilization because of a lack of proper sewerage networks and lack of proper operation and maintenance of the existing plants. As a result, in those areas wastewater will be fed to neighbouring water bodies such as lakes and urban streams capturing the natural drainage or using cesspool vehicles, polluting the water bodies and associated ecosystems (Ravishankar et al., 2018). Further, the efforts to revive such waterbodies suffer from issues related to institutional coordination. There exist multiple institutions in silos to manage stormwater drains, sewage treatment plants, and waterbodies but with considerable overlaps in roles and responsibilities and a lack of coordination (Lele & Sengupta, 2018). For instance, weak institutional mechanisms, absence of proper planning and supervision, and limited databases changed the focus of polluted water body rejuvenation from the preservation of ecosystems and pollution control to enhancement of recreational aspects in urban areas (e.g., in 50% of rejuvenated lakes in Bangalore non-core works exceeded the stipulated 25% of project cost) (CAG, 2020).

3.4.2 Regulatory challenges

Challenges in relation to regulation can occur in three aspects namely, standards, monitoring, and jurisdiction. The regulatory set up in India, related to the regulation of water pollution, consists of Pollution Control Boards (PCB) and an active judiciary including the National Green Tribunal (NGT). The water quality monitoring arena is expanded from just 18 sites in 1978 to 4111 sites by 2020. The major challenges associated with the standard setting of water pollution include i) the diversity of pollutants ii) the variety of targeted uses in which treated/untreated water is being put iii) the amount of dilution that may happen when the pollution load is released to a neighbouring water body (or in other words, polluted water is not used directly in many cases). While the discharge standards presume that enough amount of dilution may take place after mixing with freshwater probably from a rural watershed or forested area, the actual scenario may differ especially in the case of non-perennial rivers or if the upstream areas of the catchment are reasonably urbanized (Lele et al., 2021).

The existing challenges in the set standards include the differences in the standard setting for different uses. For instance, as per the CPCB notified "*General Discharge Standards*", surface waterbody is regulated by 35 parameters while wastewater for land application (or irrigation) is regulated by 10 parameters, not including heavy metals *(https://cpcb.nic.in/displaypdf.php?id=R2VuZXJhbFN0YW5kYXJkcy5wZGY=)*. However, in a mixed catchment, the domestic sewage may get mixed up with other contaminants, hence monitoring more parameters including heavy metals is really important. In addition, the standards are set based on the concentration and not on the load, hence the total amount of pollution entering the receiving water body is not regulated. Also, no standards have been set for the ambient water quality for a surface water body which is probably on the receiving end of treated or untreated domestic sewage and thus misses the goals that need to be set (water quality criteria by CPCB are set based on the uses-). Such lapses basically affect the end users such as downstream farmers. Because, none of the upstream agencies can be made responsible for the quality of discharge, given irrigation is going to be the largest user of treated domestic sewage (Schellenberg et al., 2020). Thus, the lower number of monitoring parameters and lacunas in ambient water quality standards affect the end users, cross-checking mechanisms in discharge regulation, or refrain them from using it since the domestic sewage may contain higher amounts of chemicals such as phosphates in detergents (Comber et al., 2013; Lele et al., 2021). In addition, the standards need to be set based on load, studying the nature of inflows from the catchment in order to avoid complexity and help the potential end users of treated water.

Better defined water quality standards need to be met with rigorous monitoring in order to detect pollution levels, trace them back to the source and estimate the impacts of the same. As shown in Fig. 3.4.2 monitoring has to happen at multiple points including sources, environmental systems, exposure pathways, and finally, the recipients of the pollution loads including human populations. However, as shown in Fig. 3.4.2, monitoring levels and standards are limited. If we consider the domestic effluents, the monitoring is limited since only organic contaminants are monitored properly, while the monitoring of chemical contaminants is conducted on a limited scale. When it comes to water quality standards, in case of release to water bodies standards are set for organic contaminants but not for chemical contaminants. Importantly, in case of release to the soil, water quality standards are not present. In a similar manner, if one considers the exposure pathways and risk involved, monitoring systems are not fully functional and water quality standards are either partial or non-existent.

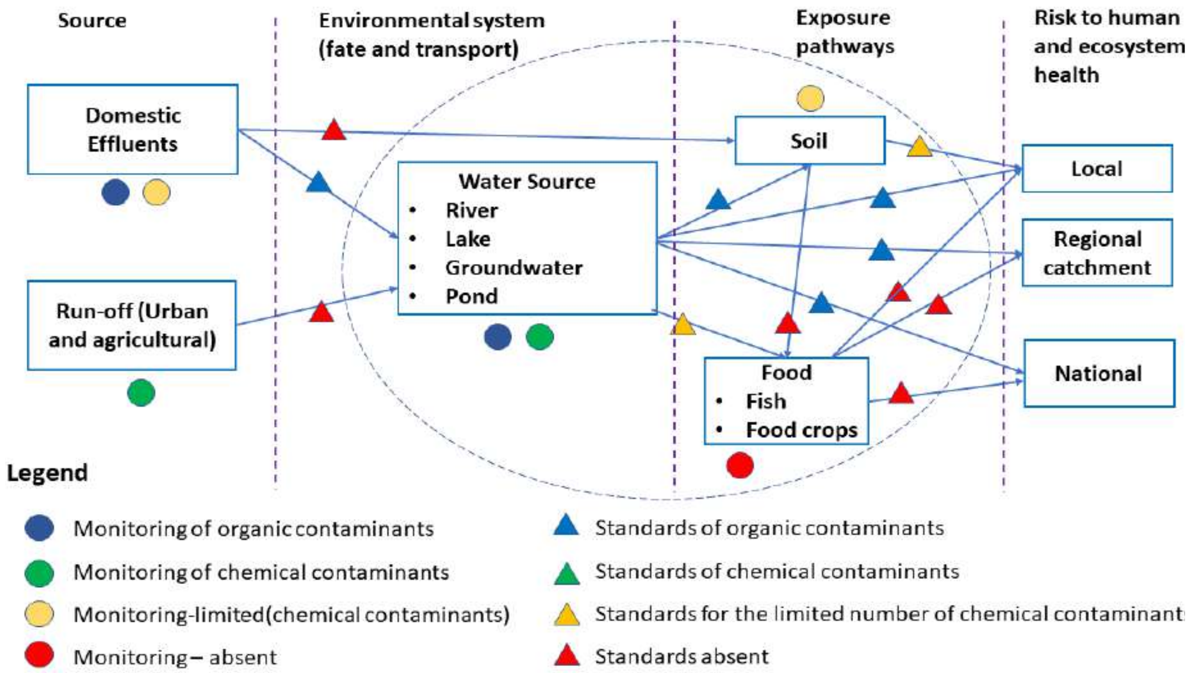


Figure 3.4.2. Framework showing gaps in the water quality monitoring framework in India (Adapted from Lele et al., 2021)

The lacunas present in the monitoring system and the points at which the standards are set are of concern, considering the current treatment capacity is very low. For instance, in the case of domestic sewage, the monitoring is mainly focused on STPs which is also not conducted properly (Jamwal et al., 2015). Importantly, the total capacity gap in domestic sewage treatment is 78.7%, (CPCB, 2022) implying a major part of the sewage is not treated in the STPs. The lacunas in standardization further expand into another tragedy considering the disconnect or gap between monitoring and its use. This is because as per the CPCB's water quality criteria, the water bodies may fall into a class between A and E or below E based on the designated use they are fit for, while ambient water quality standards and not enforced. In addition, the sample collection strategy is limited to the form of one-time samples at a fixed time of the day. However, in many cases round the clock estimates showed higher peaks at night and early morning in urban streams (Jamwal et al., 2021), due to illegal dumping. In the case of jurisdiction, it does not convert into any action, as there is no legal requirement to reduce pollution. In a centralized system, where the catchment of the STPs span across a large geographical area, such gaps increase the adverse impacts.

3.4.3 Economic challenges

As depicted in Fig. 2.2.1, the capacity gap (i.e., the gap between the generated sewage and present treatment capacity) is very large in all classes of towns and cities in India. Also, it can be observed that the gap increases in the order of decreasing the population. Thus, it can be attributed that the smaller cities and towns face difficulty in finding necessary resources for setting up STPs considering the higher capital expenditure and operation and maintenance costs. High capital discourages the entry of private players with an average break-even time span of three to eight years. The cost of the utilities is rarely covered by the revenue from the STPs (may include dried sludge and treated water) due to high uncertainty in demand. Thus, smaller towns find it difficult to install STPs of adequate capacity, and the gap increases in cities and towns with lower revenue. Community participation in Operation and Management (O&M) and multiple income-generating activities like agriculture and fisheries are suggested to improve the economic viability of STPs (CAG, 2017). However, such measures are very minimal. In contrast, with Decentralized Wastewater Treatment (DWWT), centralized systems have higher capital and O&M expenses attributed to more complicity in the systems employed, more technical expertise, and energy requirement (Jung et al., 2018). Finding appropriate land for Centralized Wastewater Treatment (CWWT) is difficult considering the higher land values in urban areas. In addition, the phased investment considering the population growth and land-use pattern is difficult in the centralized STP system, thus altering the opportunity cost and idle capacity (Jung et al., 2018).

The economic viability is the crucial factor hindering the performance of wastewater treatment systems in terms of adherence to environmental standards. The cost of STPs increases substantially with more advanced treatments that ensure reduced pollution. However, the direct economic benefits from the STP derived from the use of treated water in agriculture or fisheries are considerably low. This tempts the municipalities to succumb to the least efficient technologies in terms of environmental performance. Thus, there is a trade-off between environmental performance and economic viability (Kumar & Tortajada, 2020).

The average capital cost for STPs varies between 60 lakhs to 300 lakhs per MLD according to the technology used (CPCB, 2013). The cost of various land-based technologies like activated sludge process, waste stabilization ponds, oxidation ditches, aerobic ponds, and soil aquifer treatments is the function of the land area required for the treatment. The cost of land in Indian cities is exorbitantly high, affecting the economic viability of STPs. The choice of technology also varies with the temperature, altitude, soil, geo-hydrology, and the concentration of pollutant to be treated (Kumar & Tortajada, 2020). Besides the capital cost, operation and maintenance cost estimated per month involves a minimum of INR 30000 per MLD. Conventional treatment technologies (except natural treatment technologies) also need a considerably high amount and uninterrupted supply of energy and a greater number of skilled personnel for their proper functioning (CPCB, 2013). However, most of the fund flows into the newer infrastructure development in the form of capital expenditure and not in the operation and maintenance of existing STPs limiting their treatment capacity (Kakwani & Kalbar, 2020).

The private sector investments in wastewater treatment in India are deterred due to higher upfront capital investment and highly unpredictable revenue streams (FICCI Water Mission and 2030 WRG, 2016). There is a huge demand risk involved with the low water tariffs and little regulation governing user charges which makes the collection of user fees difficult. The water boards in non-metro cities are often financially weaker to pay the contractually agreed annuities further discouraging Public Private Partnerships (PPPs) in wastewater treatment (Nikore & Mittal, 2021). Though few residential complexes of higher income groups in India have started having an STP of their own, higher expenses limit their establishment in most of the housing areas. Moreover, the value of water is often underrated. The users are unaware of the relationship between public health, hygiene, land, and water pollution (Kumar & Tortajada, 2020).

3.4.4 Technological challenges

India has an over-dependence on older technologies for handling wastewater (FICCI Water Mission and 2030 WRG, 2016). The limited funds and higher expenditures push the government to choose technologies with lower capital costs despite their poor performance parameters. The limitations of municipalities in handling wastewater lead to sewerage adulteration with industrial effluents, impairing treatment functions, and a further increase in avoidable repair costs (Nikore & Mittal, 2021). The lifecycle cost comparison is not performed to choose between the available technologies. The knowledge gap along with the ignorance regarding newer technologies further leads to the perpetuation of outdated and inefficient technologies (FICCI Water Mission and 2030 WRG, 2016).

The land area requirements of most of the wastewater processing technologies further impede its development. It is very difficult to avail land in most of the urban areas in the country where land is a limited and highly contested resource. The cost of land in urban areas is also phenomenally high. Moreover, people show resistance to setting up a wastewater treatment plant nearby their living area (Not in My Backyard Syndrome (NIMBY) (Fu et. al, 2022). The requirement for an uninterrupted and huge amount of power supply further affects technological choices (Kumar & Tortajada, 2020). The possibilities of alternate nature-based and decentralized technologies are yet to be explored (Kakwani & Kalbar, 2020). While setting up of plants and technological choices face many hurdles, there are many operational challenges as well. STPs are majorly run by personnel with inadequate knowledge about the running of STPs and know only the operations of basic equipment in the plant (e.g. pumps and motors). In such a state, operational parameters and day-to-day variation in performance are not monitored (CPCB, 2022). Such limitations bring additional challenges in the handling of domestic sewage. For instance, the flow of pathogens and organic constituents that are able to pass through the conventional WWTPs pose a threat to public health (Voulvoulis, 2018).

Conventional centralized wastewater treatment plants are designed only to remove Biological Oxygen Demand (BOD), Nitrogen (N), and Phosphorous. With rapid urbanization, the nature and type of contaminants are changing along with the emergence of new challenges. The knowledge gap regarding these changes and the scalability of newer technologies in the Indian context is a major challenge (Kakwani & Kalbar, 2020). Hence, it is clear that in the emerging catchments where more mixing of sewage with other contaminants took place, choice of technology is vital. Centralized systems with large upfront costs set limitations in choice of technology. In such occasions, decentralized systems offers arenas to phased investments, quicker adoption of technology based on the specific needs of urbanizing catchments.

3.4.5 Social challenges

The citizens are usually not well informed about the issues related to water scarcity and the positive outcomes of water reuse and recycling. In many cases, despite the awareness created, people are reluctant to use reclaimed water for both potable and non-potable purposes (Kakwani & Kalbar, 2020). Recycled water is very less likely to be accepted for drinking purposes compared to its non-potable purposes like irrigation of parks (Rodriguez et al., 2009; Villarín & Merel, 2020). People often have negative emotions of fear and disgust when it comes to the usage of recycled wastewater. These are deeply entrenched within individuals but are also linked with wider societal processes and social representations (Smith, et al., 2018). The negative attitude towards the usage of treated wastewater is also stemmed from the concerns related to associated health risks

(Saliba et al., 2018). The communication policies in place, end-market demands and requirements also affect social acceptance of wastewater reuse (Salgot & Folch, 2018). Aesthetic aspects of reclaimed water, such as colour, odour, and taste, and the cultural and religious background of consumers are other crucial factors that shape the public acceptance of treated water (UNESCO, 2017).

In many parts of the world, water reuse schemes are rolled back due to public opposition. However, with effective public engagement, the proportion of people in support of potable reuse increased considerably (Smith et al., 2018). Certain experiments show that there is a significant improvement in public perception with the change in terminologies used. In Singapore, the use of the term recycled water (marketed as NEWater) instead of wastewater resulted in a 74% social acceptance of to reuse of water (Timm & Deal, 2018).

Identifying and obtaining the location of wastewater treatment plants (WWTPs) is another crucial challenge as people do not prefer living near them (Huh et al., 2020). Despite the risks related to health, odour, noise, and aesthetic impacts, they are also likely to suffer from economic damage due to the depreciation of land values (Wang & Gong, 2018). In China, a huge deterioration of land values by around 7.5 times led to the promotion of underground WWTPs that are sealed underground to tackle the Not In My Backyard (NIMBY) sentiment (Wang & Gong, 2018). Underground WWTPs help eliminate negative environmental impacts (like noise, odour, and aesthetics), and sometimes people do not even notice their existence which helps to greatly avoid the resistance. However, the cost and complications involved in such processes increase the cost of implementation of WWTPs (Hu et al., 2020). The NIMBY sentiments and public litigations are quite common in India too since people do not trust the waste management services provided by the urban local bodies (CPCB, 2019). CPCB has introduced buffer zones around waste management facilities to protect people from the impacts of pollution/odour/noise and to ensure safe operations of these plants by maintaining their island nature. But there is no scientific basis available for the provision of buffer zones (CPCB, 2019), and buffer zones are limited to solid waste management facilities with no mention of WWTPs. Thus, one of the key lessons to improve the social acceptance is better delivery of services (or meeting standards) along with public participation.

Conventional centralized systems in India for wastewater treatment thus suffer from various challenges and there are planning and monitoring challenges at the institutional level. Multiple institutions working on the same entity-STP without coordination and overlapping roles increases the complexities. The complexities are further enhanced due to the larger spatial spread of catchments of STPs. In addition, with the diverse set of pollutants, regulatory mechanism suffers with the issues related to monitoring as well as in defining and enforcing proper standards with less parameters. Since the standards are set based on the pollution concentration and not with load, in larger catchments (in other words centralized STPs) pollution load gets bypassed taking advantage of large amount of freshwater (if available) from runoff or other inflows.

Centralized systems in India, also suffer from issues of higher upfront and O&M costs, while the demand (or market) for treated water is not developed. Thus, smaller towns and cities find it difficult to manage the wastewater, where decentralized systems help them by cost reductions provided proper demand need to be in place. Also, decentralized systems offer arenas to phased investments, quicker adoption of technology based on the specific needs of urbanizing catchments.

To summarize, centralized treatment systems suffer from issues of land acquisitions (large land requirement), local resistance due NIMBY sentiments and lack of social acceptance related to reuse of treated water. In such occasions, participatory approaches with the inclusion of local people provides a key to improve the delivery of services. For instance, in a decentralized system with less institutional overlaps, stakeholder participation can help in easy setting up of plants (in addition to less upfront costs), better monitoring of water quality (thereby overcoming the staff shortages) and thus improves overall arena of wastewater treatment and reuse. The scope of such decentralized systems which is high in class 2 cities and small towns is yet to be explored in India.

4. Global innovative, cost-effective and sustainable solutions for UWM

4.1 Decentralized approach for UWM

The management of wastewater systems in developing countries is exacerbated by accelerating urbanization, and inadequate management and disposal of wastewater (Chirisa et al., 2017). Thus, the sanitation arrangements focused on centralized systems are unfeasible for many regions worldwide. Centralized systems collect and treat large wastewater volumes for entire communities and industrial/residential platforms (using large pipes, pumping systems, various access routes, constructions, equipment and treatment facilities) at one treatment establishment. While, decentralized systems individually collect, treat and dispose of, or on-site reuse the treated wastewater at, or near the generation source also allowing for flexibility in management (Sharma et al., 2013). From an ecological and economic perspective, treating wastewater as close as possible to its source is beneficial and without the need to construct extensive and often expensive sewer systems. The utilization of decentralized wastewater treatment systems (DWWTS) has become a focus of interest in places lacking sanitation services. The decentralization level of domestic wastewater treatment has several scales: from individual on-site systems (fully decentralized) to semi-centralized plants treating the effluents of isolated neighbourhoods (Iribarnegaray et al., 2018).

DWWTS can be divided into three types, (i) Natural treatment systems, (ii) Aerobic systems, and (iii) Anaerobic systems. Natural wastewater treatment systems, as part of nature based systems (NBS) can provide economical solutions for wastewater treatment. The simplest system is a pond system, where the algal–bacterial symbiotic relationship is used for wastewater treatment. Other standard systems work with natural media like soil and plants for filtration and biochemical reactions. These systems can be used either as a secondary treatment or as a combination of primary and secondary treatment. Some have also been used for tertiary treatment, such as duckweed pond systems (DPS), WSP, facultative pond, and constructed wetlands (CWs). These technologies are explained further in Section 4.2.

Aerobic treatment methods involve the use of oxygen by microorganisms for the degradation of organics into the simplest degradation products, i.e., carbon dioxide and water. These systems' footprint is small compared to natural systems, but the energy consumption is high. Compared with natural systems, aerobic systems can provide good quality effluents that can easily meet the effluent discharge standards. The most significant advantage of aerobic systems is that they require only semi-skilled personnel, which makes them a good choice of wastewater treatment technology in low-income and developing countries. Some well-documented and full-scale implemented aerobic systems include EA, MBBR, oxidation ditches, membrane bioreactor (MBR), submerged aerobic fixed film (SAFF) reactor, rotating biological contactor (RBC) and SBR.

Anaerobic treatment systems are low energy consuming biological treatment systems. Despite the low organic and nutrient removal capabilities, anaerobic treatment systems are cheap and simple and can be energy providers. However, these systems achieve only poor to moderate effluent quality and take a long time to start up (around 3–4 months), while aerobic systems have a much shorter start-up time (approximately 2–4 weeks). Most anaerobic treatment systems are followed by aerobic systems to meet the discharge standard. Examples of these types of system include UASB, anaerobic baffled reactor and septic tank, but most of the anaerobic systems are practiced with other aerobic/natural processes.

Case studies:

i. In India, 77 Decentralized Wastewater Treatment Systems (DEWATS) were installed until the year 2017 by the Bremen Overseas Research and Development Association (BORDA). The common treatment module is a settler, followed by an anaerobic baffled reactor (ABR) and anaerobic filter (AF). In a DEWATS plant installed by BORDA in Pune with a treatment capacity of 35 m^3/day, the wastewater from different sources is collected in decentralized septic tanks. The effluent from all the septic tanks is collected in a common collection tank near the treatment system, which consists of the settler, baffled reactor, anaerobic filter, planted gravel filter, and collection tank, as shown in Fig. 4.1.1. This plant has been operational since 2005 and serves a population of 300. The sludge of this plant is removed once a year and used as manure after treatment. Treated wastewater is used for gardening. The capital cost of this plant is Rs. 1.9 million, and the annual maintenance cost is Rs. 12,000 (Singh et al., 2019).

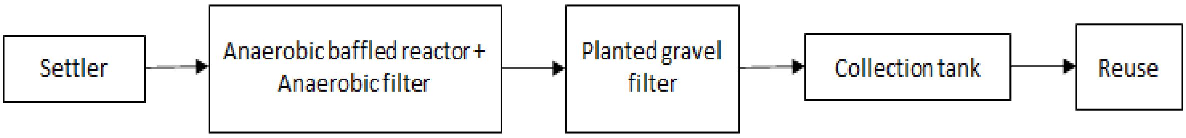


Figure 4.1.1 : Schematic representation of the DEWATS plant of Pune

ii. Soil Biotechnology is a terrestrial system for wastewater treatment that is based on the principle of trickling filters. In this system, a combination of physical processes like sedimentation, infiltration and biochemical processes are carried out to remove the suspended solids, organic and inorganic contents of the wastewater.

iii. A soil biotechnology unit has been operational at Gole Market, New Delhi, since 2017. It is a part of the New Delhi Municipal Council project of building ten decentralized sewage treatment plants across the city on the Public Private Partnership (PPP) model to reduce wastewater discharge into rivers. The system comprises an Inlet Chamber/Grit Chamber through which water enters the plant. Then, water goes into the raw water tank. This tank is further divided into three parts. The first part of the tank is fitted with a honeycomb like screen to filter out solid waste. The second part of the tank has tube settlers installed which help in further water treatment, then final storage of the tank collects water from the last two chambers. Then, water is pumped to the Bio Reactor I, which gets delivered to the plants with the help of sprinklers. Around 60% of treatment gets completed by the time the water flows out of the Bio Reactor I. The bio reactor is made up of different layers of brickbats, aggregates, and cultural catalysts. The water under the influence of gravity percolates through the bio reactor and gets collected in the Collection tank I. A motor then delivers the water to the Bio Reactor II. The Bio Reactor II is identical to the Bio Reactor I and intends to facilitate another filtration cycle. The water from the Bio Reactor II percolates into Collection tank II. The soil biotechnology set-up and site plan at Gole Market, New Delhi, are depicted in Fig. 4.1.2 and Fig 4.1.3. The design capacity of this unit is 200 m^3/day. Its capital cost is Rs. 2 million and annual O&M cost is Rs. 0.2 million (CSE, 2017).

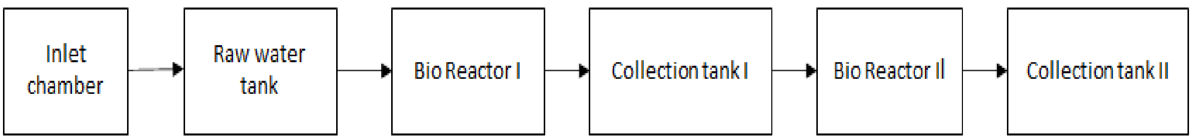


Figure 4.1.2 : Schematic representation of the soil biotechnology unit of Gole Market, New Delhi

Figure 4.1.3: Site location and plan of Soil biotechnology at Gole Market, New Delhi (Source: CSE, 2017)

4.2 Nature-based Solutions

Nature-based solutions (NBS) are defined by IUCN as "*actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*" (Cohen-Shacham et al., 2016). They can also be defined as "*living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social, and environmental benefits*" (European Commission, 2015), including in wastewater management, with low inputs of energy and chemicals. More specifically, NBS are techniques that mimic natural processes in urban landscapes that use plants, soil, bacteria, and other natural elements and processes to remove pollutants from wastewater; this reduces chemical use and saves energy. To treat wastewater, these approaches are cost-effective, energy extensive, efficient, low-impact, simple and environmentally friendly. The developing countries can benefit from using these solutions under the decentralized wastewater treatment approach in areas with limited, low capacity or no access to the public sewage system or in water-scarce regions.

Over the last three decades, different NBSs have been implemented, including constructed wetlands, floating wetlands, green roofs, living walls, waste stabilization ponds, high-rate algal ponds, and vermifiltration (Fig. 4.2.1). Research on performance evaluation has been done through experimental tests on pilot scale systems and full-scale applications and simulations.

Figure 4.2.1: Nature-based solutions a) constructed wetlands, b) floating treatment wetlands, c) Green roofs, d) living walls, e) waste stabilization ponds, f) high-rate algal ponds, and g) vermifiltration

4.2.1 Constructed wetlands

Constructed wetlands (CW), also known as reed beds, artificial wetlands, planted soil filters or vegetated submerged beds, were the first nature-based solution adapted for wastewater treatment. CWs are artificially engineered systems designed and constructed to utilize the natural processes suitable to remove the pollutants from contaminated water within a more controlled environment.

The CW system comprises water, plants, growing media (substrate), soils, and microorganisms and utilizes complex processes to decontaminate wastewater. The wetland plants are herbaceous plants with rapid growth, high biomass and strong absorptive abilities. They can be classified according to their capacity to adapt to life in water as emergent, submerged, and floating macrophytes. Usually, CWs are planted with rooted emergent macrophyte species. Most commonly used plant species are cattails (Typha sp.), reeds (Phragmites sp.), bulrushes (Scirpus sp.), sedges (Carex sp.) and several broad-leaved species. CWs are categorized as free water surface (FWS), and subsurface flow (SSF) constructed wetland systems based on the water flow characteristics. In an FWS, the water slowly flows above the substrate medium, thus creating a free water surface and a water column depth of a few centimeters. On the other hand, in SSF systems, water flows inside a porous substrate. Based on the flow direction, the subsurface flow systems are further categorized as horizontal and vertical flow units.

The pollutant removal mechanism of constructed wetland includes physical, chemical and biological processes and is given in Fig. 4.2.2 and Table 4.2.1

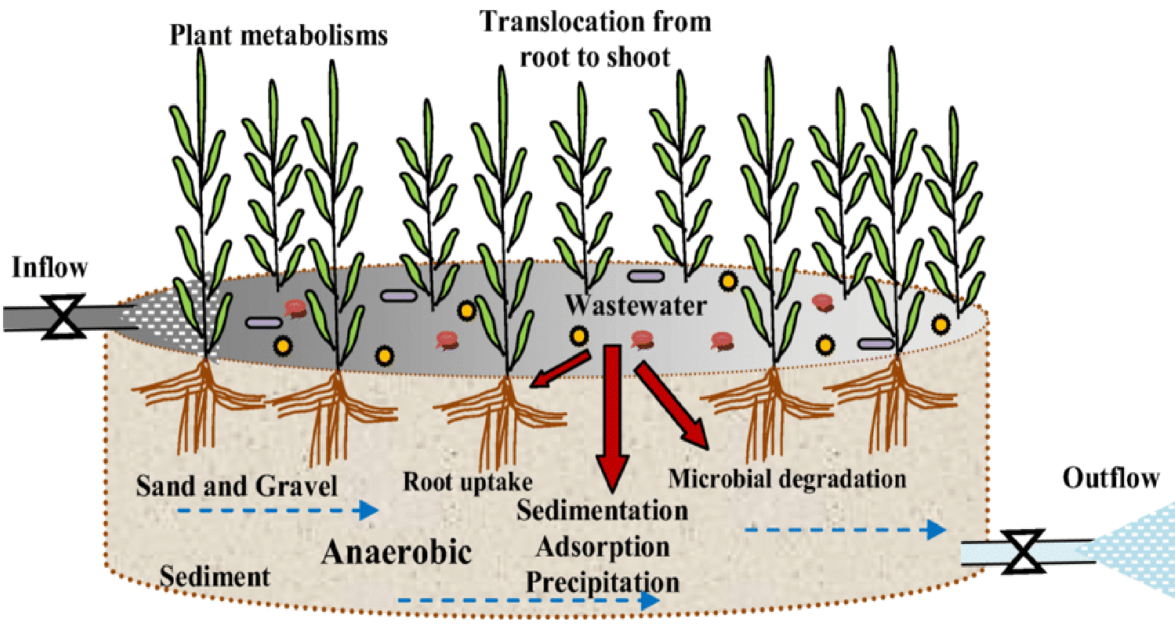


Figure 4.2.2: Pollution removal mechanism for constructed wetlands

Table 4.2.1: Processes for pollutant removal mechanism

Wastewater constituents	Removal Mechanism
Suspended solids	Sedimentation, Filtration
Soluble organics	Aerobic/ anaerobic microbial degradation
Phosphorus	Matrix sorption, Plant uptake
Nitrogen	Ammonification -Nitrification – denitrification, plant uptake, volatilization
Heavy Metals	Adsorption, plant uptake,
Pathogens	Sedimentation, filtration, natural decay, predation, excretion of antibiotics from roots of macrophytes

4.2.2 Floating treatment wetlands

Floating treatment wetlands (FTW) are an in-situ treatment option for the revival of water bodies that frequently receive wastewater. The structure of the FTW is similar to the other traditional wetlands, except that, in FTW, the plants are grown on a free-floating mat, and their roots are extended down to the contaminated water that acts as biological filters (Fig. 4.2.3).

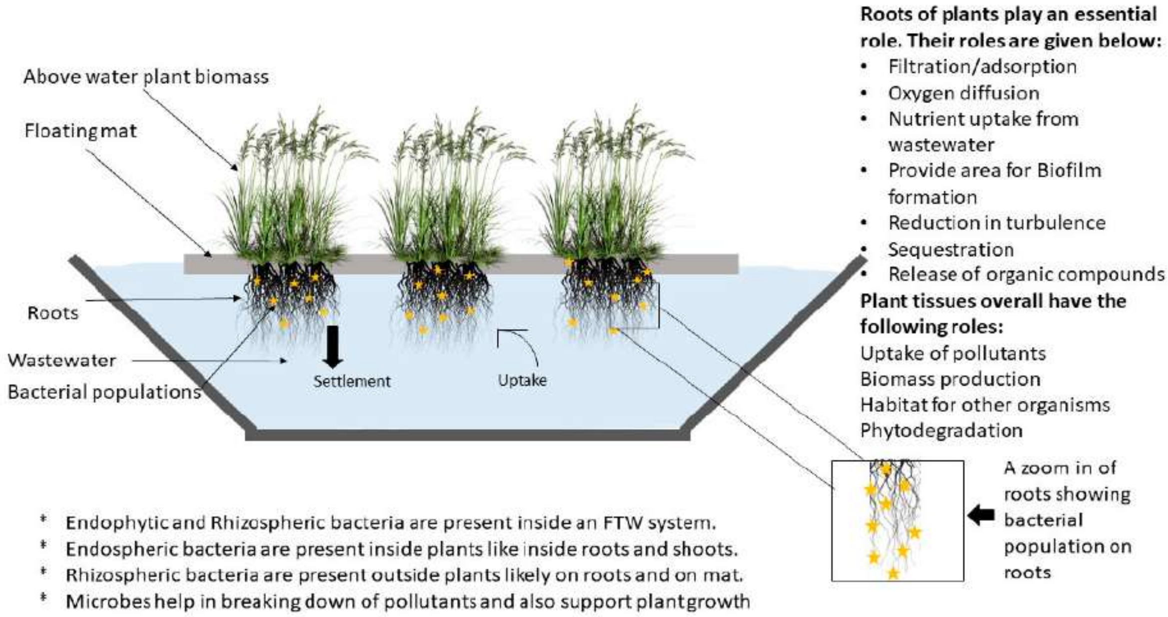


Figure 4.2.3: Schematic diagram of floating treatment wetland (Source: Wei et al., 2020)

The most commonly used floating macrophytes in the FTW are water hyacinth (*Eichhornia crassipes*) and duckweed (*Lemna minor*) for efficient contaminant removal. Though water hyacinth is an invasive plant, it is effectively used as a resource for wastewater management. It propagates and grows very rapidly. It can reproduce itself in 5-15 days under favourable conditions. The roots of water hyacinth participate actively in the treatment of wastewater where uptake of contaminants takes place. Water hyacinth has proven to survive in severe nutrient concentrations and assist in nutrient removal, along with removing faecal coliforms, suspended particles and heavy metals.

Duckweeds are smaller in size and are naturally present in almost all water ecosystems. The family consists of four genera–Lemna, Spirodela, Wolffia and Wolffiella. The growth rate of duckweed is almost three times faster (4 days) than the water hyacinth. Duckweeds contain at least twice as much protein, fat, nitrogen and phosphorus as water hyacinth and are more tolerant to cold. However, due to small size, they cannot form an extensive root mat as water hyacinth thus, limiting their role in treatment. Most of the biological activity is then caused by the microbes and other flora suspended in the water column.

The FTW are designed to maximize the formation of a biofilm. A combination of aerobic, anaerobic, and anoxic conditions occurs beneath the plants. The plant roots aid in achieving increased values of dissolved oxygen, whereas the plants and biofilm contribute to the uptake of nutrients and heavy metals, which also results in BOD and COD reduction.

One of the largest FTW in India has been installed in Neknampur Lake, Hyderabad, to clean the lake and support living species (Fig. 4.2.4). Previously the lake had been receiving untreated sewage from the nearby Alkapur township apartment, and residents of the surrounding area were also dumping waste in it. Dhruvansh, an NGO, along with the Hyderabad Metropolitan Development Authority (HMDA) and district authorities, installed a 3000 sq. ft. raft with 3500 sampling of cleaning agents on FTW such as *-vetivers, cattails, canna, bulrush, citronella, hibiscus, fountain grass, flowering herbs, tulsi and ashwagandha*. The treatment has thereby improved the quality of the lake.

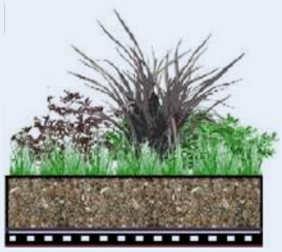
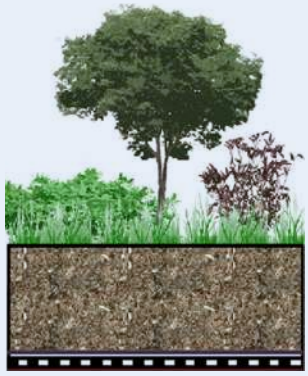
Figure 4.2.4: Floating treatment wetland at Neknampur Lake, Hyderabad

4.2.3 Green roofs and living walls

Green roofs and Living walls represent effective systems for urban reconciliation ecology (Francis & Lorimer, 2011) and are becoming integrated parts of modern architecture in many countries because the land for green infrastructure is very limited. They offer numerous ecological and social benefits to densely populated urban areas, such as improving aesthetics and liveability by cooling buildings and the surroundings, filtering pollutants from the air, managing stormwater, providing space-efficient urban greening and biodiversity conservation. Recently, their application of the use of greywater for irrigation as well as greywater treatment for other non-potable purposes has added another valuable water source to manage water scarcity and quality challenges in water-scarce regions.

Green roofs are a horizontal vegetation system consisting of a vegetation layer in a growing medium (substrate), a geosynthetic filtration layer, a drainage layer and a waterproof protective layer. A wide range of options are available for the type of planting, roof age and size, and growing media type that can be tailored to specific regions, their requirements and the purpose of use. Based on the depth of the growing media layer, green roofs are categorized as extensive, semi-intensive, and intensive green roofs, the characteristics explained in Table 4.2.2.

Table 4.2.2: Categories of green roof systems and their characteristics

Diagrammatic representation of types of green roof			
Types of Green Roof	**Extensive Green Roof**	**Semi-Intensive Green Roof**	**Intensive Green Roof**
Type of plants	Grass, shrubs, sedums, and succulents	Grass, shrubs, sedums, succulents, herbs, flowers, and shrubs	Grass, shrubs, sedums, succulents, herbs, flowers, shrubs and trees
Dry weight	60–150 kg/m^2	120–200 kg/m^2	180–500 kg/m^2
Depth of substrate	2-5 inches deep	5-8 inches deep	>8 inches deep
System type	Tray or layer system	Tray or layer system	Layer system
Purpose	Support biodiversity and provide environmental benefits	Support biodiversity and provide environmental benefits, and aesthetical purposes	Support biodiversity and provide environmental benefits, recreational and aesthetical purpose
Maintenance	Minimal	Occasional	Regular
Initial Cost	Low	Medium	High

Living walls, as an NBS, are vertical greenery systems, where a vertical surface, generally attached to internal or external walls of a building, is covered with plants of uniform growth. Living walls allow extensive and rapid coverage of vertical surfaces, reaching higher areas and adapting all kinds of buildings. As the surface area of the walls of buildings is always greater than the area of the roof, and with high-rise buildings, this can be as big as 20 times the roof area (Pérez et al., 2014), the living walls are a better sustainable solution compared to green roofs for wastewater treatment and recycling in the current modern style high-rise buildings setting.

Living walls involve a supporting structure for which different plant attachment methods are available (Fig. 4.2.5a). Living walls can either use a soil-based or hydroponic system for growing media. The living wall is separated from the building wall by a waterproof membrane that prevents dampness problems. As the system is vertical, the water storage capacity is low, and the only water available to the plants is through the growing media. An irrigation system, generally installed at the structure top, is vital for such systems, ensuring permanent wetness of growing media for plant growth. Generally, the choice of plants to be used for the green walls should be made considering the site location, climatic conditions and purpose of the design. The most commonly used plants for living walls are climbers. Climbers can be self-supporting, attaching themselves to the vertical surface (e.g. root climbers and adhesive suckers) or be supported by a structure which they can hold (e.g., twinning climbers/creepers or scrambling plants).

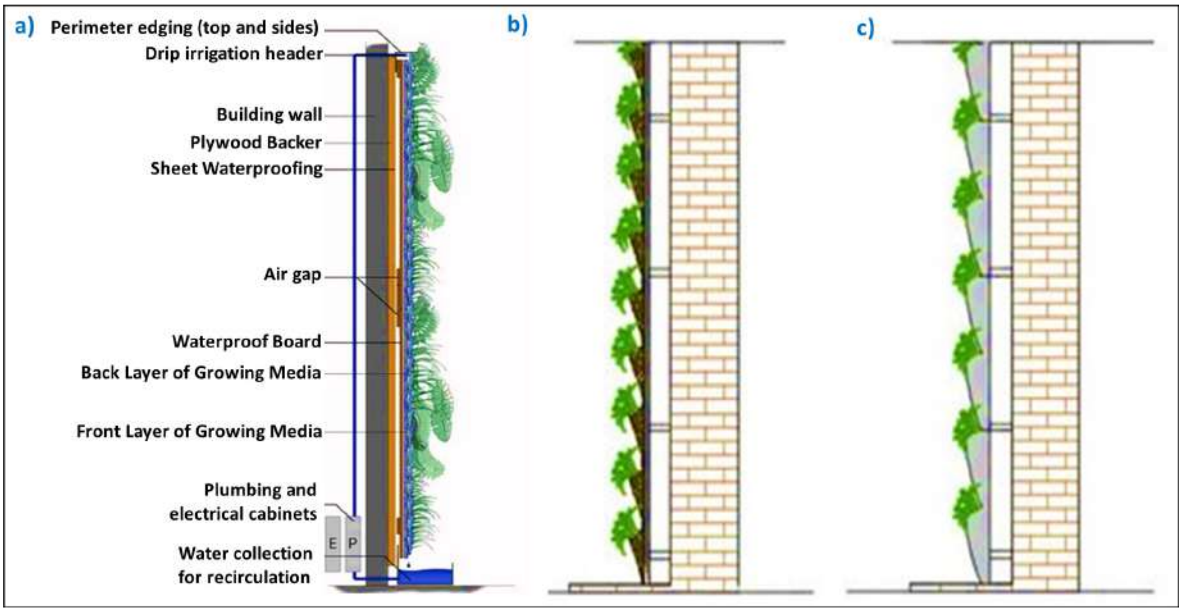


Figure 4.2.5 : Living walls structure and type a) Schematic representation of a living wall b) continuous living wall c) modular living wall

As per their application method, the living walls are classified as:

i. **Continuous living walls** do not have a growing media; instead, the plants are inserted individually in a lightweight permeable screen, supported by a base panel attached to a supporting structure, consisting of a frame that is indirectly fixed to the wall (Fig. 4.2.5b). These systems are commonly based on the hydroponic method, where the screens are constantly moist by the irrigation systems ensuring uniform distribution.

ii. **Modular living walls** have containers carrying substrate inserted into a supporting structure, one above the other (Fig. 4.2.5c). The containers can be trays, vessels, planter tiles, flexible bags or panels. The growing media consists of a mixture of a light substrate with granular material to obtain a good water retention capacity. As per the supporting structure, the irrigation can be provided through either a sprinkler, drip, or holes reaching the containers through tubes or connectors.

Under the Natural Water Systems and Treatment Technologies (NaWaTech) project, green walls are installed at the Maharashtra Jeevan Pradhikaran (MJP) head office in Pune to treat 125-250 litres/day of greywater and recover them for garden irrigation (Fig. 4.2.6). The resulting effluent quality was found suitable for reuse by land irrigation and toilet flushing following Indian regulations.

Figure 4.2.6: Living walls installed at the Maharashtra Jeevan Pradhikaran office, Pune (Source: Masi et al., 2016)

4.2.4 Waste stabilization ponds

Waste stabilization ponds (WSPs) are impoundments into which wastewater flows in and out after a defined retention period. WSPs are more suited for tropical and subtropical climates as sunlight, and ambient temperatures are vital factors in their process performance. Treatment relies solely on the natural processes of biological purification occurring in any natural water body. No external energy other than that derived from sunlight is required for their operation. Compared to other technologies, WSPs appear simple; however, they contain a complex ecological system consisting of algae, bacteria, viruses, fungi, protozoa, rotifers, insects, crustaceans and often chordate animals. Treatment is optimized by selecting appropriate organic loadings, retention periods and pond depths to promote the maximum growth of organisms beneficial to the treatment process.

A WSP system consists of a series of man-made earthen ponds, with each unit achieving the anaerobic, facultative and maturation roles (Fig.4.2.7). An individual pond functions like a complete mix series reactor. A series of ponds function as a series of completely mixed reactors, thereby achieving the benefits of a plug flow reactor. The anaerobic pond (i.e., the initial treatment reactor) is designed to reduce suspended solids and some soluble organic matter. The residual organic matter is further removed through algae and heterotrophic bacteria activity in the facultative pond. The final stage of pathogens and nutrient removal occurs in the maturation pond.

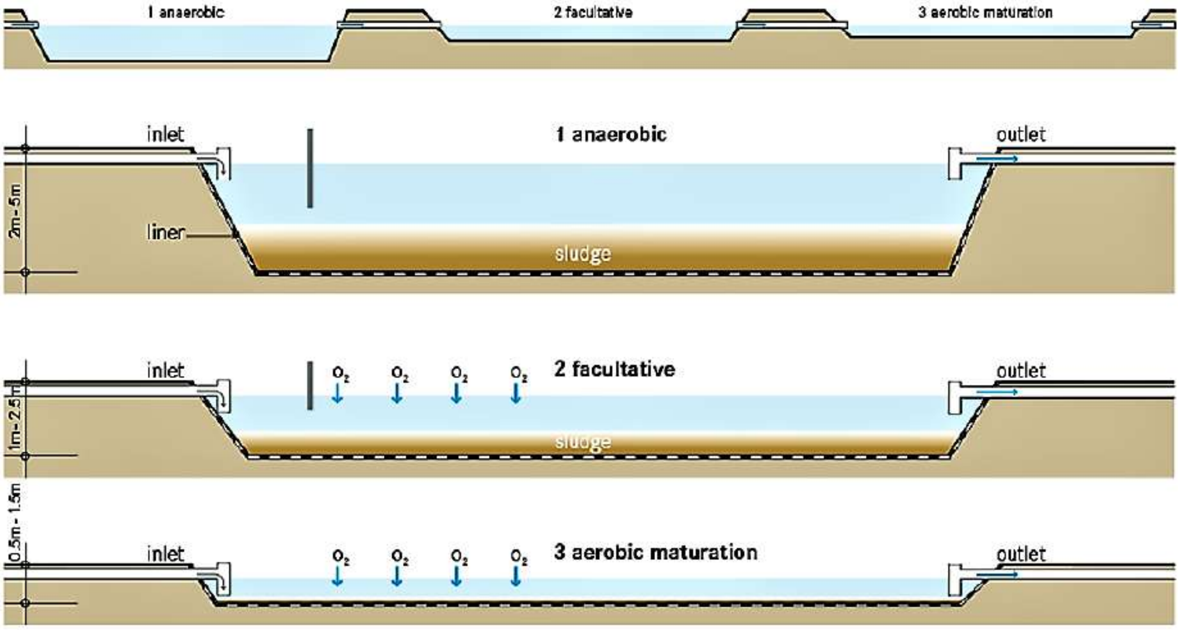
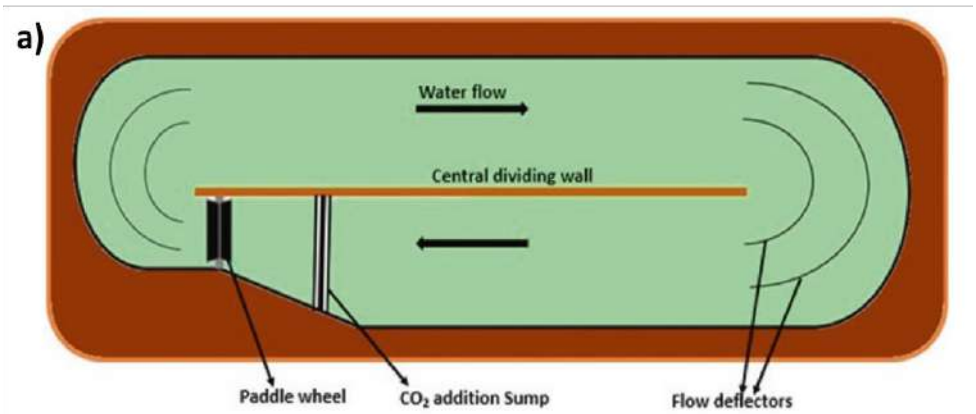


Figure 4.2.7 : Schematic diagram of a waste stabilization system (Source: Tilley et al., 2014)

4.2.5 High rate algal ponds

High-rate algal ponds (HRAP) are shallow, paddlewheel-mixed open raceway ponds used for wastewater treatment using algal species (Fig. 4.2.8) (Ranjan et al., 2019). Mixing in the HRAP is the most prominent factor differentiating it from the WSP. The process of mixing using a paddlewheel is done to achieve a mean horizontal velocity of 0.15 – 0.3 m/s that would assist in avoiding settling of the sludge in the bottom and promote algal circulation culture (Craggs et al., 2014). The HRAP performance is based on a symbiotic relationship between bacteria and microalgae in which the oxygen required for organic matter decomposition by bacteria is provided by the photosynthesis of algae, and the nutrient for algal growth is provided by bacterial decomposition of organic matter. The algal biomass generated during the wastewater treatment can be harvested for biofuel production.



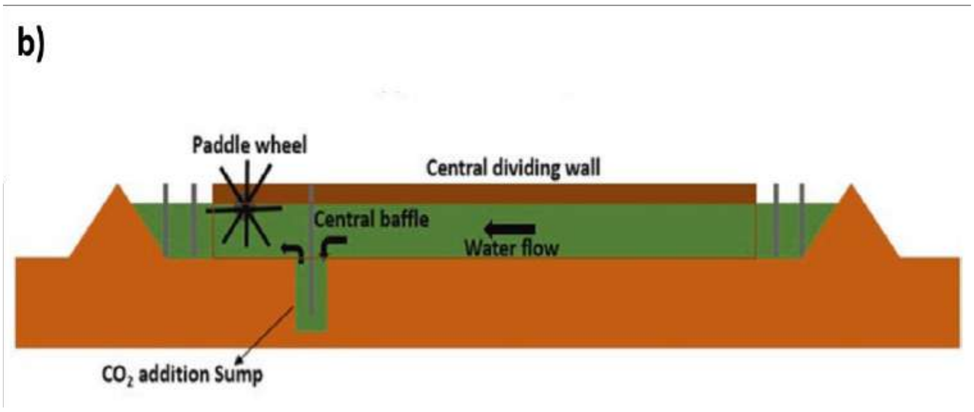


Figure 4.2.8: Schematic diagram of high rate algal ponds a) Paddle wheel in HRAP b) Side elevation view of HRAP (Source: Ranjan et al., 2019)

Comparing the two technologies–WSP and HRAP, it is observed that HRAP can treat the same volume of wastewater to the same level of nutrient and pathogen removal level as WSP, using just 40% of the area (El Hamouri et al., 2003). Cost-wise also, the HRAP are cheaper solution than WSP. The constant mixing in HRAP leads to more algal growth, enhancing pathogen die-off and nutrient removal and provides a more consistent treated water output than WSP.

4.2.6 Vermifiltration

Vermifiltration, a newly conceived technology, is a process of joint action of earthworms and microbes to treat wastewater. The vermifiltration system has two major components: vermibed and earthworms (Fig. 4.2.9). The vermibed made of porous material helps in screening wastewater and trapping solids. They provide a food source to the earthworms, which helps in the growth and reproduction of microbes due to the ingestion activities of earthworms. The most widely used earthworm for vermifiltration systems is Eisenia fetida, also known as the tiger worm or red worm. The species is known to utilize fresh human faeces with high moisture conditions and remove hazardous pathogens efficiently.

Both earthworms and microbes remove BOD, COD, TDS and TSS from wastewater through ingestion, biodegradation, and absorption via the body walls. Earthworms also secrete slimy fluids called 'mucus' from their body, which hosts several enzymes that help in the mineralization of pollutants present in wastewater. Besides, the movement of the earthworms in the filter bed improves oxygen penetration, creates favourable conditions for the aerobic activity of microorganisms and prevents the formation of doors and sludge.

The treatment systems like vermifilters fulfil multiple requirements, like simple design, application of non-sophisticated equipment, higher treatment potential, lesser production of sludge, and comparatively lower operating and capital costs. Vermifiltration is an odour-free process, and the resulting vermifiltered water is clean enough to be reused in parks and gardens and for farm irrigation.

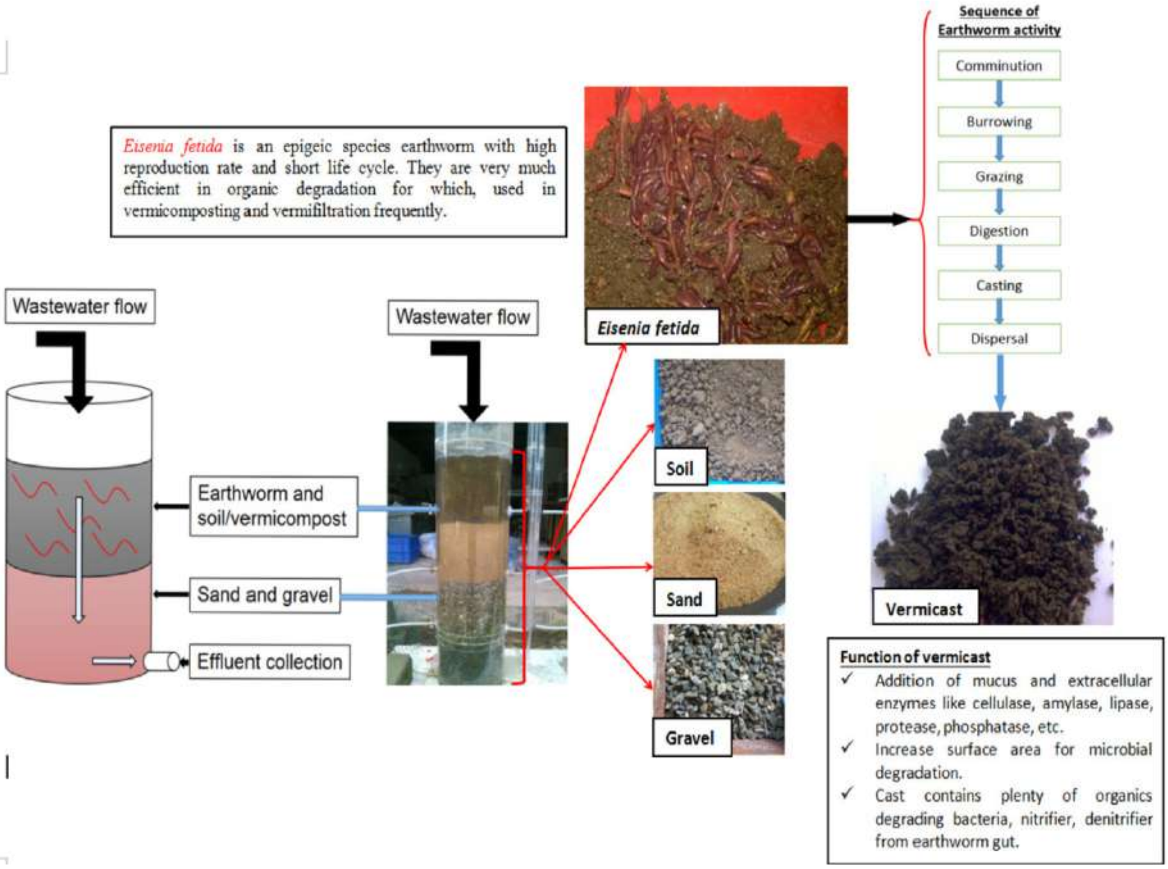


Figure 4.2.9: Schematic diagram of vermifilter (Source: Singh et al., 2019)

Under the toilet to tap project "*Sujala Dhara*" by Delhi Jal Board, Absolute Water company installed an 80 KLD capacity biofilter system at the Keshopur Sewage Treatment Plant, Delhi, in 2015 (Fig. 4.2.10). The plant treats 4000 litres per hour of sewage and converts it to drinking water quality, meeting the WHO and BIS standards, using vermifiltration and nanomembrane technology. The vermifilter can treat 85% of the sewage at the facility. After vermifiltration, treated sewage goes through a feeding tank and finally through membrane treatment and thus producing water fit for drinking.

Figure 4.2.10 : Biofilter treatment facility at Keshopur sewage treatment plant, Delhi

4.3 Innovative applications for wastewater treatment and reuse

4.3.1 Internet of Things (IoT) based applications

Traditional water quality monitoring (WQM) methods for an STP involve the manual collection of water samples at different locations, followed by laboratory analytical techniques to characterize the water quality. These methodologies analyse physical, chemical, and biological agents. However, limited spatiotemporal coverage, labour-intensive, high cost (labour, operation, and equipment), and lack of near-real-time water quality information to enable critical decisions for public health and environment protection limit their application (Katsriku et al., 2015, Vijayakumar & Ramya, 2015). Therefore, there is a need for WQM systems that enable the reliable performance of STPs through effective data management and online near real-time monitoring capability.

The application of IoTs can aid to monitor various types of sewage treatment equipment, the city's sewage treatment nodes, production, and sewage in the running state. Online control of pipe valves by IoT can also solve the shortcomings in the existing sewage treatment model. Establishing the wastewater treatment system based on the IoT can achieve real-time control of treatment production of all kinds of resources by pre-set configurations (Su et al., 2020). It can further enhance the crisis response speed, standardized management, energy saving, and economic efficiency.

In recent years, the vision of the IoT, augmented with advances in software technologies, such as service-oriented architecture, software as a service, cloud computing, and others, has stimulated the development of smart water quality monitoring systems (SWQMSs) (Dong et al., 2015, Geetha & Gouthami, 2016). SWQMS is a new generation of systems architecture (hardware, software, network technologies, and managed services) that provides near-real-time awareness based on inputs from machines, people, video streams, maps, news feeds, sensors, and more. It integrates people, processes, and knowledge to enable collective awareness and decision-making where IoT devices can offer more advanced access to their functionality (Zhou, 2012). As such, event-based information can be acquired and processed on-device and in-network. This capability provides new ground for approaches that can be more dynamic and highly sophisticated, taking advantage of the available context.

Solinas, a deep tech start-up, are leveraging the use of robotics and artificial intelligence to develop solutions for the pipeline and sanitation industry. Their product *"ENDOBOT"* has been designed for internal condition assessment and defect detection in pipelines to identify and analyse leaks, corrosion, sediments, and dents in critical pipeline infrastructure, using Non-Destructive Testing (NDT) techniques. Another product , "*HOMOSEP*", is the first-ever septic tank cleaning robot in India that has replaced manual scavenging and cleaning of septic tanks

Wireless Sensor Networks (WSNs) have proven to be a very effective technology for numerous environmental monitoring applications. WSNs currently enable the automatic monitoring of air pollution (Yi et al., 2015), noise pollution (Noriega-Linares & Navarro, 2016), forest fires (Jadhav & Deshmukh, 2012), climatological conditions (Keshtgari & Deljoo, 2012), and much more over broad areas, something previously impossible. The use of WSNs for WQM is particularly appealing due to the low cost of the sensor nodes. These simple and low-cost networks allow monitoring of processes remotely, in near-real-time, and with minimal human intervention. Applying WSNs to WQM has opened up a new avenue of research toward developing decentralized SWQMSs that evolve with the changing wastewater infrastructure to meet the water requirements of smart cities (König et al., 2015). The advent of WSNs allows the replacement of traditional WQM methods or the expansion of existing wired SWQMS. Many studies have documented the use of such technologies, and it aids to discuss one.

Case study: The study by Martínez et al. (2020) presents the integration of a WSN in a wastewater treatment plant scenario of a low-cost water quality monitoring device in the close-to-market stage. This device consists of a nitrate and nitrite analyser based on the ion chromatography detection method. The analytical device is integrated using an IoT software platform and tested under real conditions in a wastewater treatment plant scenario. A decentralized SWQMS conceived and developed for wastewater quality monitoring, and management is accomplished by doing so. This investigation is part of an ongoing research project called LIFE EcoSens Aquamonitrix, which aims to validate and optimize this solution to achieve a low-cost, fully automated in situ analyser for environmental water monitoring to be launched in the market after the project. The core of the analytical device is a portable ion chromatography system based on the method previously reported by Murray et al. (2019). This system employs a novel design of an ultraviolet light-emitting diode-based optical detector, enabling cost-effective direct in situ detection of nitrite and nitrate in natural waters.

Five different processes are involved in the operation of the SWQMS: system initialization, capture and storage of information, information modelling, data analytics and visualization, and management of information. In the EcoSens Aquamonitrix System (Fig. 4.3.1), the information collected from the sensors is decoded, pre-processed, and modelled for processing, analysis, and knowledge extraction.

This knowledge supports decision-making by government agencies responsible for environmental protection and wastewater plant operators. The achieved behaviour is possible thanks to the orchestration of the IoT services provided by the IoT platform, which allows the resources associated with the IoT devices to be searchable, accessible, and usable, thus maximizing their interaction with the user interface.

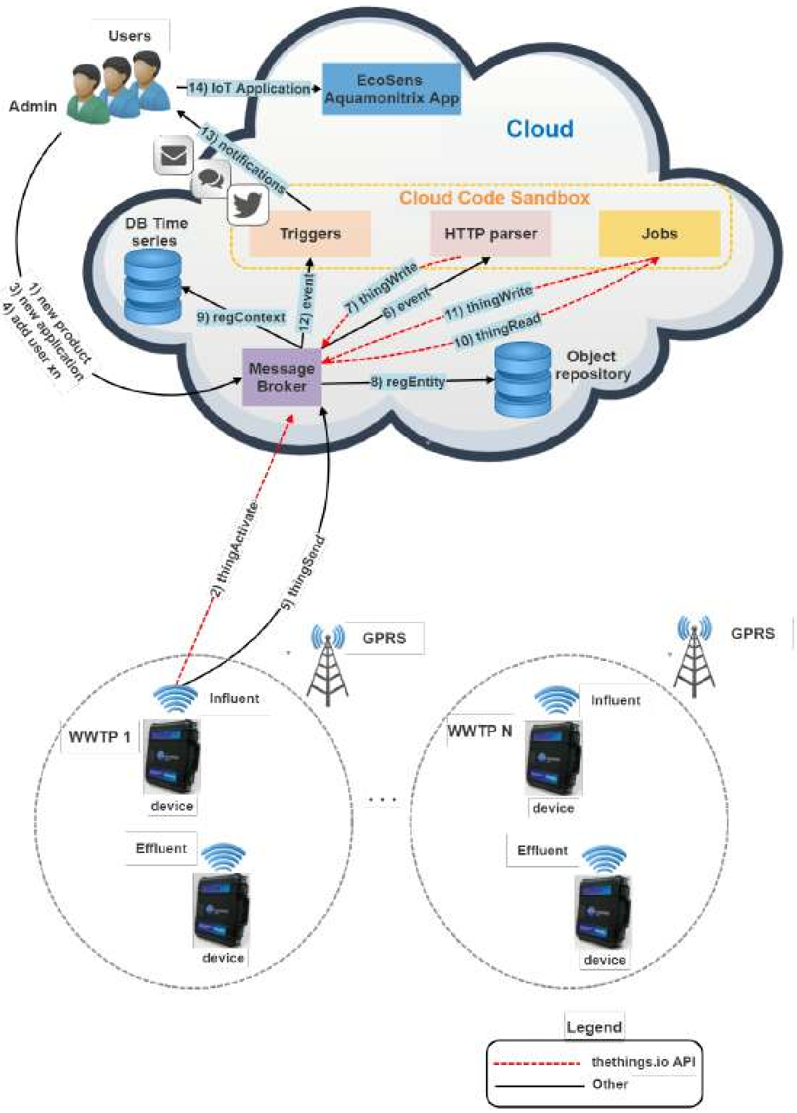


Figure 4.3.1: EcoSens Aquamonitrix Smart Wastewater Quality Monitoring System (Source: Martínez et al., 2020)

The first experiment demonstrated the features implemented at the IoT application level. To do this, eight devices have been deployed in four WWTP located in the Region of Murcia(Spain): Alcantarilla, Molina de Segura, Los Alcázares, and San Pedro del Pinatar. A device has been placed at the influent and effluent of each plant (Fig. 4.3.2). During the test, devices collected data on nitrate and nitrite concentrations during May 2019, twice a day, regardless of their location. This sampling frequency is appropriate for water quality monitoring applications, hence the term near-real-time. The data transmitted by the devices are captured, stored, analysed, and finally represented through the user interface employing different customizations that compose the IoT application hosted in the system platform.

Figure 4.3.2: Device deployment in Alcantarilla wastewater treatment plant (WWTP) (Source: Martínez et al., 2020)

The results from this experiment show that the implemented system provides features for online and near-real-time monitoring and management of wastewater quality parameters. The system architecture is extensible to include other features. Moreover, the scalability of the IoT ecosystem enables an increase in both the number of sensor nodes and storage and processing resources of the IoT platform. Regarding the preliminary validation of the device, the developed method was used to determine the nitrite and nitrate content in STP effluent. The advanced features of the developed IoT integrated system will enable massive sensor deployments in smart city water distribution systems, allowing end users to detect pollution events and adverse trends in near real-time. Thus, the private or public entities in charge of water quality monitoring and management will be able to act more efficiently and effectively to tackle the problems detected (i.e., pollution sources), reacting to the issues more quickly and minimizing the negative environmental impact.

4.3.2 GIS-based approach

Problems related to domestic wastewater management are difficult to monitor and manage due to a lack of quality observation data. Especially in developing countries like India, observation infrastructure is comparatively weak. In the lack of vital widespread information, the regional scale studies fail to provide dependable results. Remote sensing and GIS-based (RS and GIS) approaches to minimize this data gap and support capturing, handing, and transmitting required information in a prompt manner. In addition, they help to acquire information at a fairly low cost compared to conventional techniques (Singh, 2019).

GIS-based approaches are widely used for various purposes in wastewater management including site selection for the construction of STPs, identification of hotspots of pollution, and site selection for treated wastewater irrigation. Various datasets needed for such analysis include topography, land use land cover data, information on geology, distance from major waterbodies and environmentally protected areas, climatic data, and required effluent wastewater characteristics. GIS is used to create and analyse several grids of different themes and finally in highlighting the areas of interest (or the areas which may satisfy the relevant criteria). The sizing and performance methods in GIS aid to compute the area requirement in terms of effluent discharge criteria (or effluent standard) as a function of climatic and demographic factors. The combination of these two methodologies at the study area level makes a simple check regarding the suitability of natural treatment systems and area requirements (Li et al., 2017). On similar grounds, Jassima and Abbasi (2019) conducted a study for the site selection of a wastewater treatment plant in Al Kufa city, Iraq using RS and GIS techniques. Parameters such as residential areas, sewage areas, roads, surface water bodies, green areas, slopes, and land use are considered as part of site selection. In the GIS-based method buffer zones for each parameter (e.g. minimum distance between an STP and a water body) can be added to the analysis based on the regulatory standards of locations. In addition, Analytic Hierarchy Process (AHP) (a multi-criteria decision-making model that employs weighting criteria and helps to build an evaluation model) was used to apply weights to each criterion to get the best result for finding the ideal site for construction. The weights were applied in a linear summation equation for making a unified weight map, which consists of the due weight of each input variable. In the final step, all weighted maps were reclassified in order to obtain the most ideal location for the construction of STPs.

The advantages of RS and GIS techniques can be further expanded to analyse the suitability of treated wastewater for different purposes. Irrigation water availability, distance from the treatment plant, and suitability of farmlands for crop cultivation are considered as the techno-economic sub-criteria while, quality of irrigation, water, soil, crop, and aquifer vulnerability is considered as the environmental sub-criteria in the decision-making process. The limiting factors of wastewater reuse are considered to be topography, land use, soil depth, and technically allowable distance for irrigation, and access to such data is often limited. Remote Sensing based maps following the criteria are prepared in a GIS environment and using the Analytic hierarchy process (AHP), which is a structured approach employing data based on pairwise data comparison. When integrated with GIS, it offers a powerful spatial decision support system in various fields including wastewater management. A detailed flow chart of site selection using the GIS-AHP model is given in Fig. 4.3.3. Weights are allocated for different parameters and final classification (on the suitability of land) is conducted. In addition to the suitability analysis, the model is capable of doing sensitivity analysis of different important parameters such as aquifer vulnerability, and microbial contamination (Zolfaghary et al., 2021).

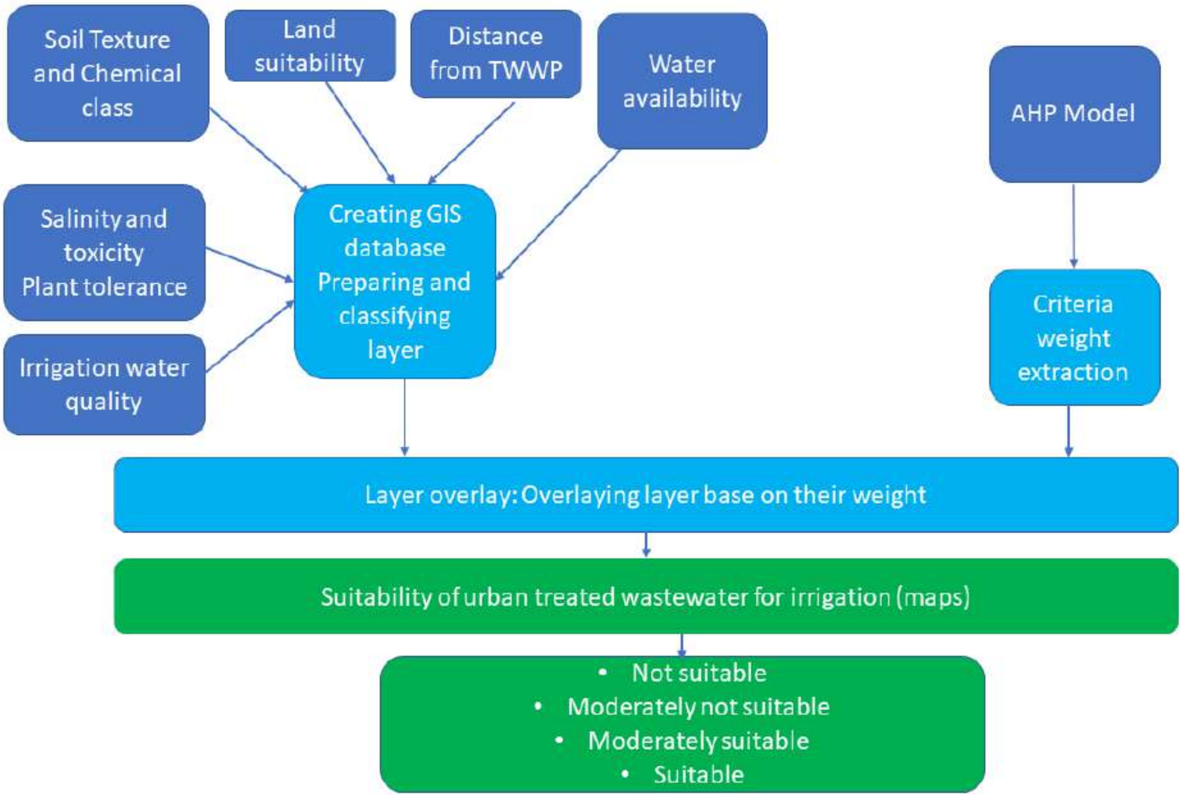


Figure 4.3.3: Methodological flow chart for site suitability analysis using multiple criteria decision making (MCDM) and Geographic Information System (GIS) (Source: Zolfaghary et al., 2021)

Table 4.3.1 shows a list of GIS-AHP techniques used around the world as a spatial decision support system for site selection for irrigation and evaluation of the quality of treated wastewater for irrigation. In developing countries like India, where observation infrastructure and data availability are comparatively weak GIS-AHP techniques can play an important role in wastewater management including reuse.

Table 4.3.1: List of selected works for spatial decision-making on wastewater management

Authors	Year	Method	Description
Anane, Bouziri, Limam, & Jellali (Anane et al., 2012)	2012	Fuzzy Analytical Hierarchy Process (FAHP)-GIS	The rank of suitable areas for treated wastewater irrigation Criteria: Land Suitability Resource Interactions Cost-Effectiveness Social Acceptance Environmental Impacts
Neji and Turki (Neji & Turki, 2015)	2014	Data analysis using a multicriteria decision technique (compromise programming)	GIS-based ranking of desirable areas for wastewater irrigation

Authors	Year	Method	Description
Bozdağ (Bozdağ, 2015)	2014	GIS-Analytical Hierarchy Process (AHP)	Evaluation of quality of irrigation water Based on: Water salinity Soil Permeability Toxicity Crops
Paul, Negahban-Azar, Shirmohammadi& Montas (Paul et al., 2020)	2020	Fuzzy Analytical Hierarchy Process (FAHP)-GIS	Evaluation wastewater irrigation Criteria: Agricultural Land (crop type) Climatic Conditions Irrigation Status Distance to wastewater treatment plants

4.3.3 Upgradation of traditional septic tanks

For the proper functioning of a septic tank, its location is essential. Sites with low porosity soil, high groundwater levels, or proximity to surface water bodies are not suitable for septic tank construction as they may lead to groundwater and surface water contamination by nitrogen, phosphorus, and pathogens. Also, the septic tank's effluent may outflow to nearby soil, groundwater, or surface water. Thus, the pollution problems caused by the poor performance of the septic tanks require new techniques to improve the blackwater treatment efficiencies. These septic tanks are often poorly constructed and tend to leak and overflow in the open environment creating unhygienic conditions and spreading diseases. The size of tanks is often oversized to avoid frequent emptying. Operation and management of soaking arrangements are seldom done. Practical steps should be taken to ensure that these septic tanks (containment systems) do not pollute the environment.

The variant of the conventional septic tank with Anaerobic Baffled Reactor (ABR) provides increased settling and sludge contact (Fig. 4.3.4). In this system, an increased number of chambers and a forced liquid flow through the accumulated sludge results in an enhanced reduction of organics and solids compared to a conventional septic tank.

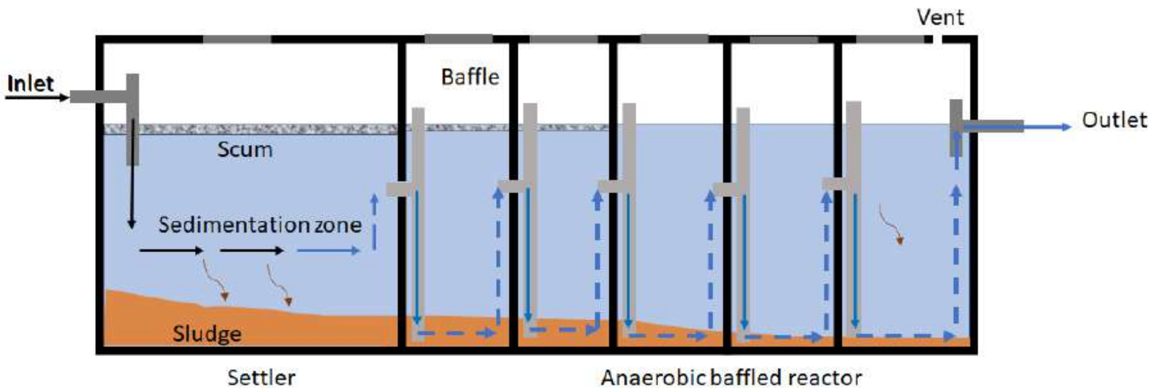


Figure 4.3.4. Anaerobic Baffled Reactor septic tank showing location of baffles and three distinct layers (scum (oil, fats, and grease), clarified water, and sludge (Source: Tilley et al., 2014)

The modified septic tank-anaerobic filter unit depicted in Fig. 4.3.5 is an example of another design to enhance effluent quality. An anaerobic filter is a further adaptation that incorporates a filter media (e.g., crushed rock or manufactured plastic) into a final chamber. After the first chamber, the wastewater is forced to flow through the filter as a final polishing step. Modified septic systems can contain other coupled mechanisms like anaerobic digestion and disinfecting chambers. Some modifications include a vertical baffled septic tank containing a filter and a disinfection chamber (Anil & Neera, 2016).

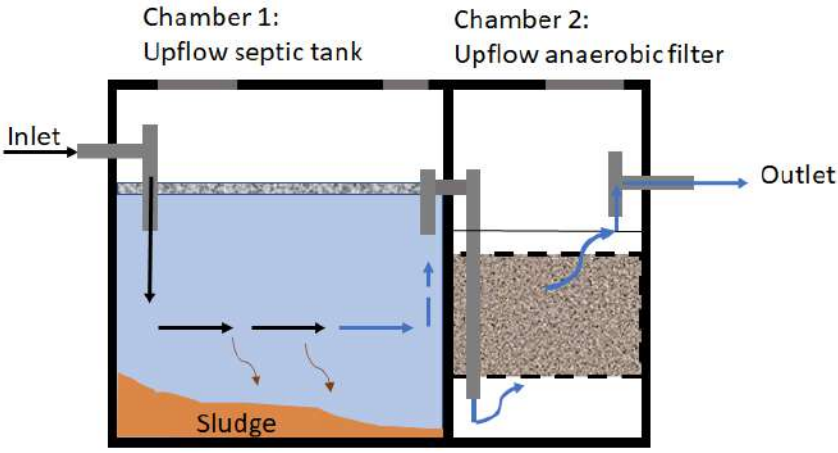


Figure 4.3.5: Modified septic tank-anaerobic filter unit as a two-stage on-site domestic wastewater treatment system

Along with technological advancement, on-site sewage treatment can be improved with management upgradation as mentioned below:

- Periodic audit of toilet facilities: To ensure proper containment and reduce pollution, ULBs need to identify the type of on-site sanitation systems. If they have septic tanks, whether these are connected to soak pits or not.
- Standardization of containment construction: Often, due to a lack of awareness, monitoring, and enforcement, people tend to build oversized tanks to avoid frequent emptying. ULBs must strictly enforce BIS standards of containment system in new/ reconstructed dwellings as part of the building plan approval process. The ULBs can also empanel and train masons to construct toilets, including containment systems according to BIS standards. ULBs can also educate people about their existing septic tanks and soak pits and encourage them to refurbish the same following BIS standards.
- In the case where no sewerage system exists and there is no space for soaking arrangements, overflow effluent from the septic tank may be collected in well-lined roadside drains as an interim measure. Efforts should be made to convey this effluent to a suitable place for off-site treatment through a decentralized wastewater treatment plant using the interception and diversion of these drains.
- Soak pits should be appropriately designed and maintained. ULBs should also highlight the necessity of converting all toilets into improved facilities.

4.4 Reuse of treated wastewater

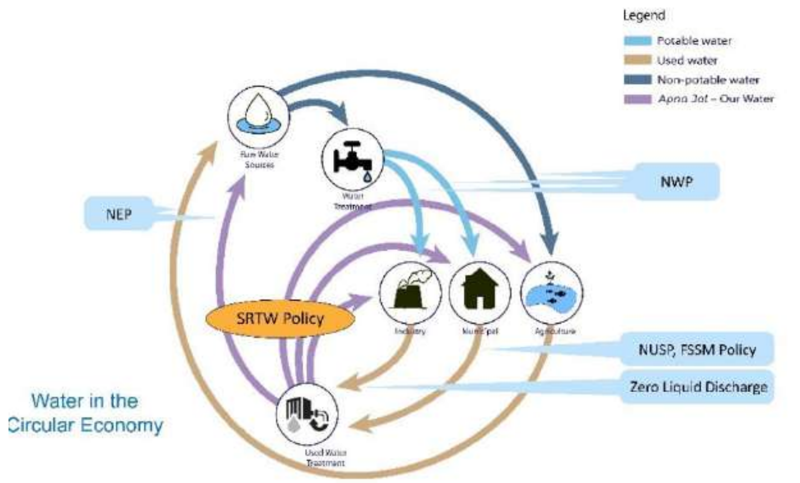
The gap between sewage generation and treatment- reuse is huge and ever-increasing in the case of India.. The treatment capacity to the secondary level is only 37% of the generated sewage and out of which 40% of the capacity is not fully operational. The remaining sewage which is uncollected or untreated is released into water bodies and neighbouring lands (CPCB, 2022). Such practices lead to contamination of natural resources like soil and water and raise public health concerns and become a threat to freshwater systems, especially when the dilution levels are not adequate. Hence, the figures imply that there is a lacuna in the current scenario and in other words, potential for improving the current situation with proper methods. In addition, it is important to understand and create demand for reused water in order to develop the sector for utilization of scarce water resources in an optimal way.

Wastewater is a highly potential source of water for various purposes and is highly underutilized. If the country can utilize 80% of its untreated wastewater from 110 of its most populous cities, then 75% of the projected industrial water demand can be met by 2025. Usage of sludge from treated wastewater can be served to three million hectares of land annually, supplying essential nutrients for plant growth, while reducing the dependency on fertilizers by 40% (Nikore & Mittal, 2021).

Safe Reuse of Treated Wastewater (SRTW) over untreated water is much beneficial. Firstly, on the water quality front, it curbs the issue of soil degradation and groundwater contamination. Secondly, it reduces the human health hazards while dealing with contaminated water and consuming the food items grown from untreated water. Thirdly, it could replace or supplement the groundwater or surface water (or freshwater) irrigation and helps to curb alarming issues such as the over-extraction of groundwater. However, the market for SRTW is not developed even in cities falling under water-scarce regions, despite the fact that treated water is available at a cheap rate or no cost. At most, the treated wastewater is used in urban and peri-urban areas for watering trees and gardens in the urban settlements and partially for irrigation. The challenges can be attributed to the insufficient infrastructure for treatment (to the required level) and transportation of the treated water to areas in demand, possibly energy-intensive, depending upon the terrain. Also, people reject those plans due to concerns about hygiene, psychological aversion, and lack of trust in the public agency concerning water quality standards (Kakwani & Kalbar, 2020; Villarín & Merel, 2020). Therefore, considering the importance of the use of treated water for different purposes, the recent draft of the National Framework on the Safe Reuse of Treated Wastewater-2020 envisions the following:

"Widespread and safe reuse of treated used water in India reduces the pressure on scarce freshwater resources reduces pollution of the environment and risks to public health and achieves economic benefits by adopting a sustainable circular economy approach."

The scope of the policy covers the non-potable reuse of used water, by integrating with existing schemes and policies related to sanitation, re-use of industrial used water, faecal sludge management within a broader umbrella of river basin planning, and actions to address the concerns of climate change. Fig. 4.4.1 depicts the Safe Reuse of Treated Wastewater (SRTW) in relation to related policies and programs in the water cycle in India. As indicated in the figure, it needs to be well connected to various policies concerning water, sanitation, urban development, and the environment while adhering to the standards of various regulatory bodies such as the National Green Tribunal (NGT) and Central Pollution Control Board (CPCB). The distinct functions include non-potable reuse adhering to national standards, incentives (including funding) for uptake of the programs, and preparation of a model policy framework, with the enhancement of existing instruments for policy, regulation, and implementation. In addition, the policy also aims to guide the preparation of successful business models, while providing a better environment for innovation in technologies and institutional arrangements (MoJS, 2020)



Adapted from Water Reuse Europe Review, 2018

Policy	
NEP, 2006	National Environment Policy
NWP, 2012	National Water Policy (under revision)
NUSP, 2008	National Urban Sanitation Policy (under revision)
FSSM, 2017	National Policy on Faecal Sludge and Septage Management
SRTW (draft)	National Policy on Safe Reuse of Treated Water
Programmes	
AMRUT	Atal Mission for Rejuvenation of Urban Transformation
SBM	Swachh Bharat Mission
JJM	Jal Jeevan Mission
NMCG	National Mission for Clean Ganga
NRDWP	National Rural Drinking Water Programme
Standards and Compliance	
CPCB, SPCB	Central / State Pollution Control Board(s)
CPHEEO Manual	Central Public Health Environmental Engineering Organization
NGT	National Green Tribunal (oversight)

Figure 4.4.1. SRTW Framework in relation to related policies and programs in the water cycle (MoJS, 2020)

As depicted in Fig. 4.4.1, the potential areas of reuse of treated water include industries, agriculture, municipal uses (such as toilet flushing, maintenance of public avenues and parks, and fire-fighting, environmental flows, aquifer recharge, construction, vehicle exterior washing, non-contact impounds, public amenities, golf courses, toilets, parks, and gardens in the divider of highways and other important roads). CPCB also recommends the use of treated wastewater for uses in the industrial zones, so that shall treat it further based on the requirement of the industry or plants (CPCB, 2021a). Considering the heterogeneity of uses, the level of treatment (secondary or tertiary) needs to be assessed using a feasibility study.

Other applications of treated wastewater include growing forest tree species and tree cover in urban areas for fuel and timer. This avoids the health hazards caused by sewage-fed agriculture. Also, the deep root systems of such plantations cause the interception of contaminants and improve the economic outcomes with the help of fuelwood production. Establishment of green belts with tree plantations around the cities in order to revive the ecological balance and improvement of environmental quality. It also facilitates the year-round utilization of wastewater. Similarly, treated wastewater can be used for floriculture and other commercial non-food crops (Minhas et al., 2022).

In the direction to achieve SRTW, AgroMorph Technosolutions Private Limited, a DPIIT recognised start-up and the winners of the 2021 AIM-ICDK Water challenge (Atal Innovation Mission – Innovation Centre of Denmark), are using algal technologies to improve the effluent quality, enabling on-site water recycling and rejuvenating water bodies impacted by sewage dumping.

4.5 Approaches for promotion and adoption of sustainable UWM solutions

The previous sections highlighted on increased application of cost-efficient, sustainable, multi-purpose and flexible solutions as a more promising approach to increase cities' resilience and sustainability than traditional grey solutions and, hence, able to effectively address urbanization pressures and water and wastewater challenges. It is to be noted that the adoption and scaling up of these solutions can be achieved by involving private investors, community/end user participation and having defined regulatory mechanisms.

4.5.1 Public private partnerships

Public Private Partnerships (PPP) or P3 are schemes in which a government service or private business venture is funded and operated through a partnership of the government and one or more private sector companies. PPP aims to increase fund flow and efficiency and to improve the quality of service delivery by leveraging the expertise of the private sector and raising the level of satisfaction among users.

PPPs have been common in the urban utility sector, except in the area of water, which is still governed by the state in most cases. Currently, STP projects are put to tender on Engineering Procurement and Construction (EPC) basis and have a limited role for the EPC contractor in the Operation and Maintenance (O&M) of assets. In many instances, the created assets are of relatively poor quality, inadequately maintained and do not comply with the required effluent treatment norms stipulated by the Pollution Control Boards. In order to ensure optimum utilization of funds deployed and proper creation and maintenance of assets, it is desirable to explore the option of PPP contracts wherein the long-term commitment of the private sector participants would be ensured due to the continued deployment of their funds.

Sewerage and sanitation services need huge capital investment, high cost for operation and maintenance of facilities and considerable human resources; this service is becoming increasingly expensive. Besides, the efficiency of the labour force employed in the Urban local bodies (ULB) is far from satisfactory. The high wage structure and inefficiency of the workforce result in a steep rise in the cost of service, yet the people at large are not satisfied with the level of service provided by the ULBs. Therefore, the local bodies must seriously consider private-sector participation in sewerage and sanitation services. With the state and central governments' past challenges in reach and funding, the reliance has been on adopting a collaborative model (Fig. 4.5.1).

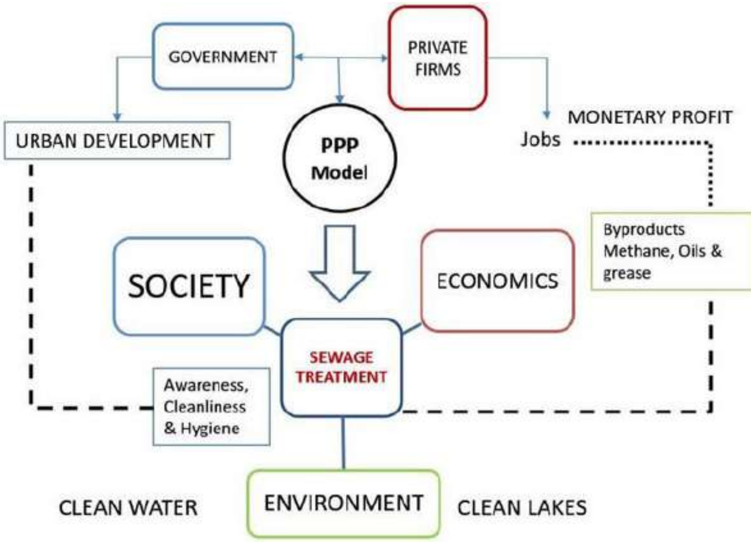


Figure 4.5.1: Public-Private Partnership (PPP) model for the sewage treatment business model (Source: Ashok et al., 2018)

Alandur in Tamil Nadu was the first ULB to attempt a PPP project in this sector. Between 2000 and 2005, about six projects were attempted on a PPP basis, including Alandur, Tirupur and four projects in Chennai. In the period between 2006-2011, the number of PPP projects increased significantly because of the availability of grant funding from the Jawaharlal Nehru National Urban Renewal Mission (JnNURM) and National River Conservation Directorate (NRCD) and the overarching policy thrust on PPPs in the infrastructure sector at the national level which percolated down to the states as well.

The Government of India is committed to improving the level and the quality of economic and social infrastructure services across the country. In pursuance of this goal, the Government envisages a substantive role for PPP as a means for harnessing private sector investment and operational efficiencies in the provision of public assets and services. The promotion of PPP has some advantages as highlighted in Fig. 4.5.2.

Figure 4.5.2: Key benefits of Public Private Partnership (PPP) model

In order to introduce PPP into the wastewater management sector in India, it is vital to look into the fundamentals concerns to increase private sector investments –

- Firstly, increasing water tariffs to a level to ensure that the sewerage system generates sufficient revenues to meet fixed and variable costs.
- Secondly, intergovernmental support, alignment, and oversight are essential for PPP development and managing political, regulatory, and financial risks.
- Thirdly, a credible discretionary regulatory mechanism must be implemented for PPP sustainability.

Recently, another P has been added to the PPP framework, i.e., People, and is now described as Public, Private, People Partnership and the new concept of PPPP or P4, is being applied. PPPP is a people (end-users) oriented approach where all stakeholders, including government, donor agencies, private sector and civil society, work together. It includes the end-user's perspective/role on PPP models. People are actively involved in investments and infrastructure development, aiming to increase a sense of ownership and enhance the sustainability of services.

4.5.2 Community participation

Most wastewater treatment interventions in India follow the top-down approach where the end-user communities neither have a role nor say in the type of service they want and what they are willing to pay for the same. As discussed in section 3.4, institutional framework governing the wastewater sector, the highly fragmented nature of the institutional structures has led to low levels of coordination amongst various agencies and limited citizen involvement in the planning, designing and managing of sewerage services. In order to have successful employment of appropriate technologies deep understanding of the social dynamics of the community is required. This is only achieved through effective public involvement and community participation. Public involvement is best achieved through the participation and involvement of users in all parts of the project cycle, from planning and design to implementation and decision-making, which produces more efficient and sustainable projects/outcomes. When communities have influence and control over decisions that affect them, they have a greater stake in the outcomes and are more committed to ensuring success.

For community participation to be as inclusive and effective as possible, the diversity of people within the same community, in terms of gender, age, educational level, power, wealth, etc., should be acknowledged and dealt with. Effective public involvement begins with early contact with potential users through the actual inclusion of all stakeholders by initiating the listed measures:

- Public meetings, campaigns and awareness programs to define the project's need and the initiatives and benefits promised.
- Providing access to planning documents and other relevant information free of cost.
- Public discussions can help engineers fine-tune the treatment facility plans to fit the community.
- Monthly meetings with residential welfare associations (RWAs) to inform about the progress of the project as well as seek feedback
- Extensive consultations with stakeholders/ End-user community on tariffs and benefits.
- Form advisory committees to establish membership, responsibilities and resources of this committee
- Holding public workshops and training programs to discuss the benefits and risks of reuse
- Creating entrepreneurial opportunities to attract local investments in terms of input materials

Thus, equal participation of all stakeholders in research and project implementation can increase the potential, flexibility and creative innovation in responding to water insecurity.

Along with this, **special incentives and reward programs** can be provided to the end-user community who plan to use nature-based solutions. These could include providing development incentives, property tax reductions, grant money, rebates and installation financing directly to an individual user, property owners or community groups for adopting solutions to their property. Awards and recognition programs for successful examples will help increase public awareness and encourage the public to adopt such treatment systems.

Developing a web-based application for citizen science programs can increase public participation in the adopted solution, assist in on-site monitoring, and generate extensive datasets with spatial and temporal coverage. One such program is the "*Off the Roof Citizen Science Project*" from Colorado State University (USA) which has homeowners across the country testing their roof runoff for pathogens to determine how it could be best put to use. Another successful program is "*Chronolog*", where Birmingham University (UK) installed chronolog stations around the Bartle Constructed Wetlands complex, which involved participants taking a selfie and uploading it on their site. The goal was to create a timelapse compilation to observe seasonal changes in ecosystem processes, such as the greening of plants, water levels, etc., through the submitted selfies.

4.5.3 Performance evaluation of treatment plants

The performance efficiency of the treatment plant depends not only on proper design and construction but also on good operation and maintenance. Performance assessment of a treatment plant using natural/ conventional/advanced technology, is necessary to assess the compliance requirements, present efficiencies of existing treatment facilities and to know the present quality of treated sewage. As per the CPCB assessment, out of 1093 operational STPs, the compliance status of 900 STPs is available and only 578 STPs having a combined capacity of 12,197 MLD are found to comply with the consented norms prescribed by the SPCBs or the Pollution Control Committees (PCCs). In another study by CPCB, performance evaluation was carried out for 152 STPs under NRCD spread over 15 states in the country and having a total treatment capacity of 4,716 MLD. After the study, it was concluded that the plant efficiency utilized was 66% (3,126 MLD). Out of the 152 STPs, 9 STPs are under construction, 30 STPs are non-operational, and the performance of 28 STPs not satisfactory. In terms of the treated effluent quality, out of the 152 STPs, the treated effluent from 49 STPs exceeds the BOD standards, and for COD, 7 STPs are violating the general discharge standards. The study found that lack of maintenance and improper plant design are the key factors that affect the efficiency of treatment processes.. Therefore, to achieve these capacities existing treatment plant needs to be upgraded, which requires performance evaluation to decide the scope for expansion or process modification.

A proper monitoring plan, defining the testing schedules, locations, parameters of importance, testing methods and procedure, and discharge standards have to be established to facilitate performance evaluation. CPCB has published the guidelines for the same. To help in close monitoring of the STP performance, CPCB has developed a mobile-based "*STP Monitoring Application*" launched in September 2020. This App will facilitate information flow from STPs to Urban Local Bodies, States and the Central level, and 1600+ STPs will be linked. This App can be downloaded from the Mobile App Store. Information on capacity and qualitative parameters like pH, TSS, COD, BOD and FC will be reported, and the same will be updated every week.

Citizen science programs can also enhance the monitoring of decentralized and NBS solutions. Interested volunteers/ participants can be trained to monitor the water quality and submit observations through mobile apps or online forms. This can significantly increase the frequency of water quality data available.

5. Capacity building and raising awareness for UWM

To optimize social equity, efficiency, and environmental sustainability, capacity building, is an essential aspect of Urban Wastewater Management (UWM). UNDP (2009) defines capacity building as the *"process through which individuals, organizations and societies obtain, strengthen and maintain the capabilities to set and achieve their development objectives over time".* The aim of capacity building in the UWM sector should focus on raising awareness and building capacity for policymakers and planners who deals not only at the city level but also towards local, regional, and national level in managing wastewater. Through capacity-building activities the number of stakeholders and actors can be attracted or involved in managing wastewater (Ferrero et al., 2018).

5.1 Trainings and knowledge transfer/exchange

The knowledge about UWM and its role in managing the wastewater sector is quite relevant. However, the challenge appears to be in translating this knowledge into practice. One way to do so would require a thorough understanding of the city's wastewater from multiple perspectives–hydrology, governance, institutional mechanisms, economics, and social structures, among others. In general, training is provided to only people involved in operating, such as public or private utility, local government employees, and contractors directly involved in operation and maintenance. However, for a well-managed system, all categories and classes of people should also be included in the process, such as executives, senior managers, technical managers, community committees, and local resident caretakers responsible for wastewater management activities should be trained accordingly (Brown & Farrelly, 2009). Local health agencies should typically be accountable for independent surveillance of city wastewater activities. They should also cooperate with operators and agencies in planning and training preventive risk management methodologies (Ferrero et al., 2018).

5.2 Improving institutional and international collaboration

Out of 17 Sustainable Development Goals (SDG) adopted by UN member states on the 2030 agenda, 12 SDGs and pertinent targets directly link to wastewater management. In the past, most urban cities and towns in India have been able to organize some level of services for their citizens. In recent decades, many have struggled to keep up with the amounts of waste generated. Such an increase in wastewater amounts results from an ever-increasing urban population, primarily due to unprecedented rates of rural-urban migration and economic development accompanied by changes in consumption patterns (Rodić & Wilson, 2016). To facilitate improvement, the urban wastewater management involvement and coordination of all stakeholders and agencies are essential (Fig. 5.2.1). Regarding how to improve institutional collaboration, a few points have been focused on.

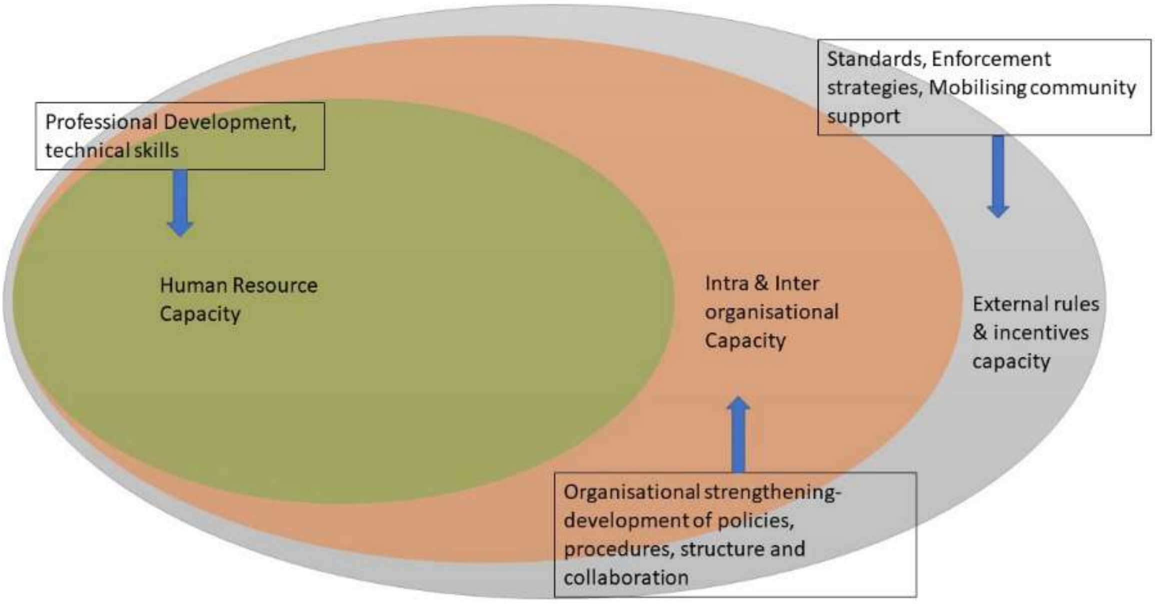


Figure 5.2.1: Institutional capacity-building framework (Source: Brown & Farrelly, 2009)

5.2.1 Formulation of a coordinating agency for managing/leading the efforts at the Municipal/state/national level

Implementing UWM requires a more significant number of actors or agencies in decision making, integration with urban planning, and understanding trade-offs between multiple competing objectives. This becomes far easier if there is an apex body to coordinate and manage these elements (UNESCO, 2021). To tackle these challenges, basic waste management infrastructure must be implemented in waste collection and sanitary landfilling. Furthermore, for people who already take care of waste management in one way or the other but are not yet part of a formalized waste management system should be formalized. This so-called informal sector needs to be recognized and gradually integrated into the formal waste management system. Clear and well-defined rules must be established to enable a level playing field for all parties involved. Introducing reforms gradually in the urban wastewater sector in case of policies, institutions, and practices can help in moving up the on-site and off-site wastewater management ladder (Fig. 5.2.2). Through these reforms the institution and their capacity become more critical in transforming to sustainable development.

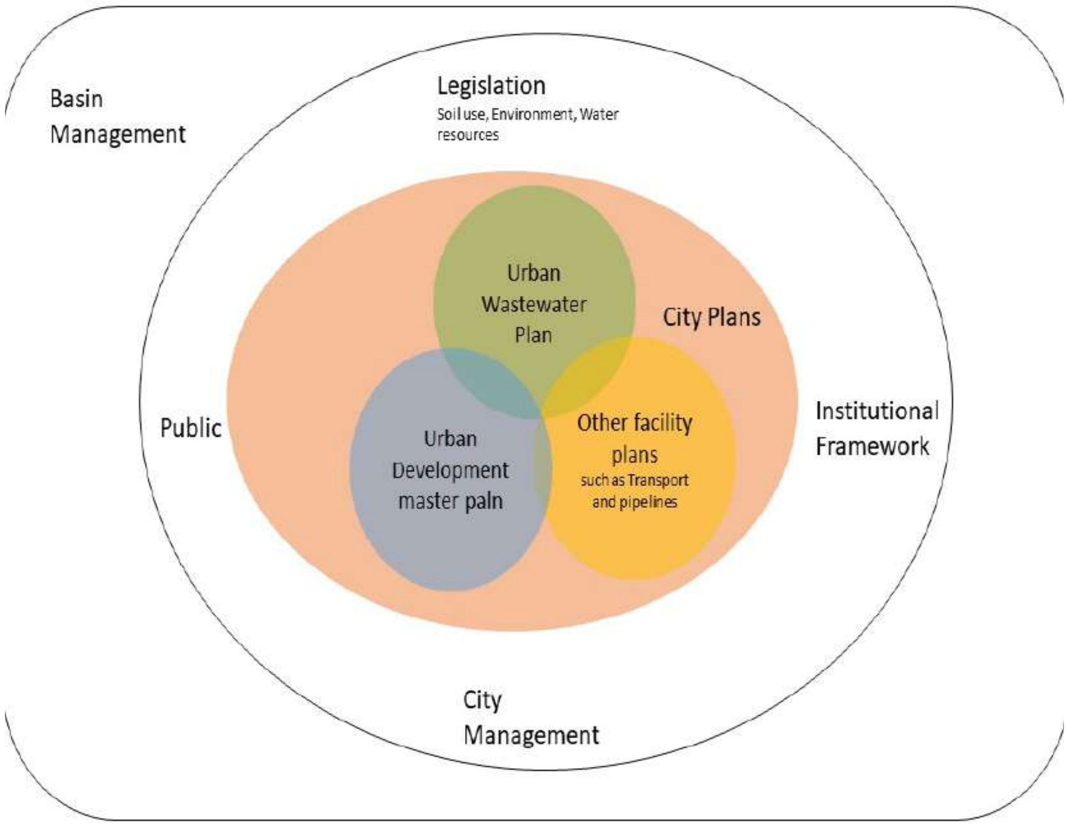


Figure 5.2.2: Institutional framework for UWM planning (Source: Tucci, 2010)

On this note, the following are significant steps taken by Government of India for solid-waste management in India during the last two and half decades:

1. National waste management committee: The main objective of the committee constituted in 1990 was to identify the recyclable contents in solid waste picked up by rag-pickers.
2. Strategy Paper: A manual on SWM has been developed by the MoUD in collaboration with the NEERI in August 1995.
3. Policy Paper: MoUD and the Central Public Health and Environmental Engineering Institute prepared a strategy paper for the treatment of wastewater, appropriate hygiene, SWM, and efficacy in the drainage system.
4. The master plan of Municipal Solid Waste: A stratagem was formulated by the combined efforts of MoEF, CPCB, and ULBs to develop a master plan for SWM with an emphasis on biomedical waste in March 1995.
5. High Powered Committee: In 1995, a High-Powered Committee constituted under the Chairmanship of Dr. Bajaj, to encompass a long-term strategy for Wastewater Management using appropriate technology.

All the above efforts culminated in the preparation of many acts and regulations to protect the environment, which came into force from time to time. The rules relevant to UWM in India are–Hazardous Waste (Management, Handling, and Transboundary Movement) Rules (1989, amended January 2003, August 2010), Biomedical Waste (Management and Handling) Rules (1998), Municipal Solid Waste (Management and Handling) Rules, 2000, The Batteries (Management and Handling) Rules (2001), Plastic Waste (Management and Handling) Rules, 2009, and E-Waste Management and Handling Rules 2011.

5.2.2 Collaborative efforts with local NGOs and CBOs

In India, the collaborative efforts are still nascent, and there is no success story under UWM. However, many companies took the UWM challenge as a business opportunity. About 40 projects are under collaborative efforts for different segments (segregation at community bin, collection, transportation including energy waste) of UWM in India.

Some Indian companies involved in UWM are Zen Global Finance Ltd (RDF), ESSEL Infra (UWM), Enkem Engineers Ltd (bio methanation in collaboration with Entec, Austria), and Future Fuel Engineers (India) Pvt. Ltd (bio digestion in collaboration with ECOTEC, Finland), Global Environmental Engineers Ltd (biodigestion in collaboration with PAQUES Pvt., Netherland), Hanzer Biotech (UWM), Thermax Ltd (Incineration plants in collaboration, Danskrodzone, Denmark and Thermal Process, US), Excel Industries (composting), EDL Power (India) Ltd (Sanitary landfill), SELCO International Ltd (RDF, TIFAC, DST), Ramky (Waste Management Services). Some other international companies working in Indian Market in the UWM sector are Nellemen, Neilsen, and Rauscvenberger of Denmark, Lunde, TBW, and BTA of Germany and Entec, Astria, Hitachi Zosen, Japan, etc. Attributes of a successful partnership are efficient implementation, better services, risk sharing, cost saving, and revenue generation. On the other hand, power sharing, loss of control of ULBs, cost enhancement, unaccountability, political risks, and lack of competitiveness are significant threats.

To overcome the complications associated with UWM, the public and private sectors should contribute vigorously. The efficiency of ULBs in handling Wastewater Management can be enhanced only with the cooperation of both sectors. The relations among various components of the PPP system, viz., sociological, economic, and managerial aspects, should be evaluated. The effectiveness of partnership, well-defined relationships, and clear demarcation of role, accountability, and adaptability due to dynamics among the various stakeholders are elementary necessities to make PPP work for UWM (Joshi & Ahmed, 2016). Kerala is one of the few Indian states that took adequate measures to address the waste menace by launching the Clean Kerala Mission in 2002. Later, in 2007, *the Malinya Mukta Keralam* campaign was launched, creating a conducive environment for a Mission Mode Action Plan to achieve the goal of Clean Kerala. Mission 2002 Strategy revolves around the time-tested Reduce, Reuse, Recycle and Recover slogan. Phase-I was implemented in 5 Corporations and 26 Municipalities.

5.3 Sensitization of the public

A well-informed body of decision-makers knows that waste management is needed as a basic public service for proper wastewater management. Hence, waste management must be an integral part of every locality's political decision process and other primary goals, such as safe drinking water supply, wastewater treatment, and all other elements of public infrastructure. The goal of the sensitization activity should focus on improving sanitation and, therefore, the quality of life for people, and quality of life includes health, privacy, convenience, and employment (Fig. 5.3.1).

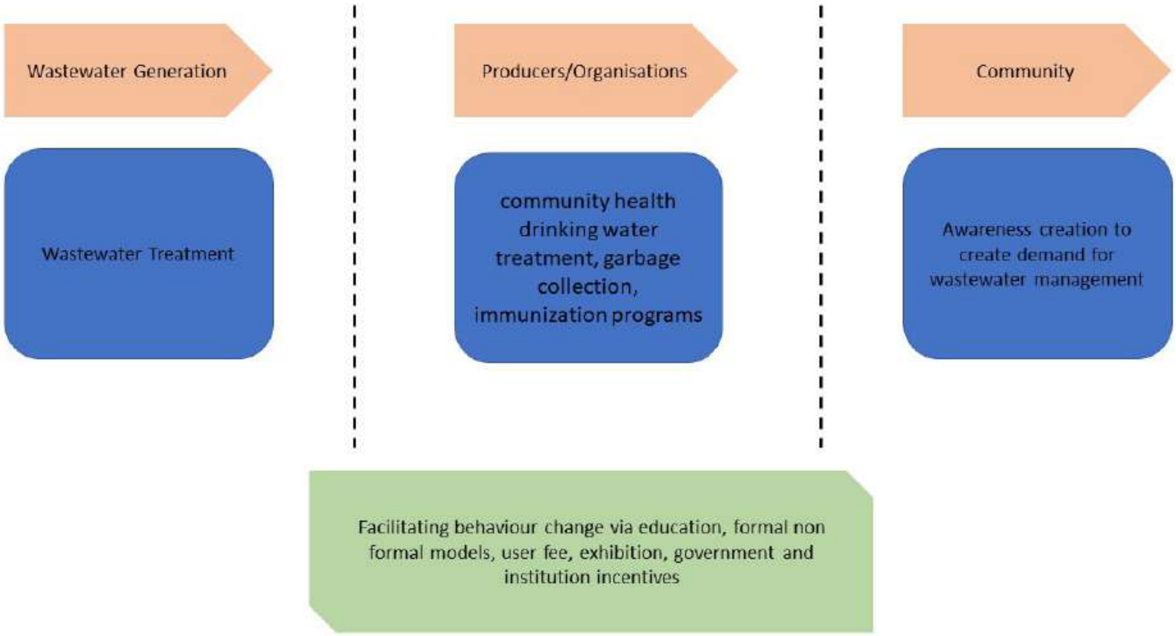


Figure 5.3.1: Sensitization framework for wastewater treatment and management (Source: Schellenberg et al., 2020)

5.3.1 Looking into the long-term benefits of wastewater treatment

Ensuring proper wastewater treatment and disposal is as important for protecting community health as drinking water treatment, garbage collection, and immunization programs. It is important to communicate the long-term benefits of wastewater treatment. Untreated wastewater can spread disease and contaminate drinking water sources. However, most communities give little thought to what happens to their wastewater, and the availability of safe, clean drinking water is often taken for granted. Cholera and other wastewater-related diseases are generally viewed as threats to other, less developed countries. To involve people and spread the benefits of wastewater treatment following measures can be adopted, including community surveys (to obtain a representative set of community opinions), Public meetings and presentations (involve public participation through organizing and presenting fun and interesting presentation), Newsletters (annual, biannual or quarterly newsletter which includes pictures, graphs figure, tables, and chart to attract people's attention), open houses (meetings between Community, employees and public officials to demonstrate their work) and Public service announcements (to promote environmental and safety messages to the public).

5.3.2 Campaign for user fee collection for effective O&M

Many cities in India have user fee collection methods for operation and maintenance (O&M) but suffer from the following contributing factors:

1. Poor ownership and awareness by communities about their rights and responsibilities
2. Poor capacities, willingness, and ownership by panchayats to maintain water supply systems
3. Limited accountability mechanisms for citizens to hold panchayats accountable for the provision of safe water
4. Lack of spare parts and tools
5. Limited availability of mechanics and lack of motivation/incentives.

The following demands can be addressed to improve the user fee collection for better operation and management.

1. The initiatives need to be institutionalized, keeping in view their sustainability, and the community needs to be mobilized to own and sustain these programs on urban water supply.
2. The development agents, like NGOs, CBOs, etc., and the community should be advocated appropriately to ensure effective social mobilization.
3. Considering this, a participatory demand-driven approach is highly warranted with a focus on necessary awareness generation amongst the community on the need for Urban Wastewater Management.

There comes the profound role of development workers/agencies to support the Government approach and activities to pave the way for bearing implementation to implement wastewater treatment plants to prevent water-borne risks and ensure Water Safety and Security for all.

5.3.3 National awareness fest/fair

Awareness raising is needed to involve a minimum level of citizens' cooperation. National awareness programs and fairs can help educate citizens and the Community towards sensitization of wastewater management. One way should be in the form of sanitation drives which can be conducted regularly to sensitize the Community, build engagement, and motivate them to adopt good health practices. The awareness program should also focus on two urgent reasons related to wastewater treatment, i.e., health and the environment, which are often neglected. According to the 2015 report of the CPCB, India can treat approximately only about 30% of its wastewater, most of it in urban India (CPCB 2015). An urgent need for community participation and government and private initiatives such as awareness programs are the needs of the hour.

5.3.4 Wastewater treatment courses at different levels of education

In India, it has been observed that the use of treated wastewater projects suffers with social acceptance. Very few people and the Community are comfortable using treated wastewater for non-potable purposes but are skeptical for personal use. Studies have shown that this can be addressed by sensitizing the people by educating them about the issue (Joshi & Ahmed, 2016). Including wastewater treatment courses at different levels of education can help address these issues.

5.3.5 Formal, non-formal, and informal education modules

The educational concept is based on raising people's awareness. The effective way of raising awareness is contained in formal, non-formal, and informal education. The form and method of teaching differ from each other but target different sections of people in the society (Fig. 5.3.2). The focus should be provided on building the educational concept to point out and resolve the problem we have with wastewater management.

Raising awareness can be achieved in two phases. The first phase of raising awareness would be achieved through the media and the internet. The target group for this phase is adults. Awareness is going to be focused on proper wastewater management and the rationale of the waste hierarchy. This concept is based on content such as demonstrating the main mistakes made, misconceptions related to treatment, and the benefits obtained by correct handling for achieving a higher rate of waste intended for energy utilization. The second phase of awareness is defined for a target group of educators, such as school teachers, waste management experts, or company directors, through informal and non-formal educational mechanisms such as micro-training. Young children act as change makers in spreading awareness to bring about environmental sensitization in neighbouring communities towards natural resources. So, a formal education module to target young minds could be developed to involve school students to create awareness and bring a behavioural and attitudinal change towards wastewater generation, treatment, and reuse. Singapore's model is one example of educating its citizens through informal education. The informal education module involved giving people first-hand experience by having a tour of their wastewater treatment plant and organizing various programs to include students to build a sense of responsibility and acceptance of the treated wastewater. Similar programs have been seen across countries like the United States, Australia, the Netherlands, and China (Filho et al., 2016).

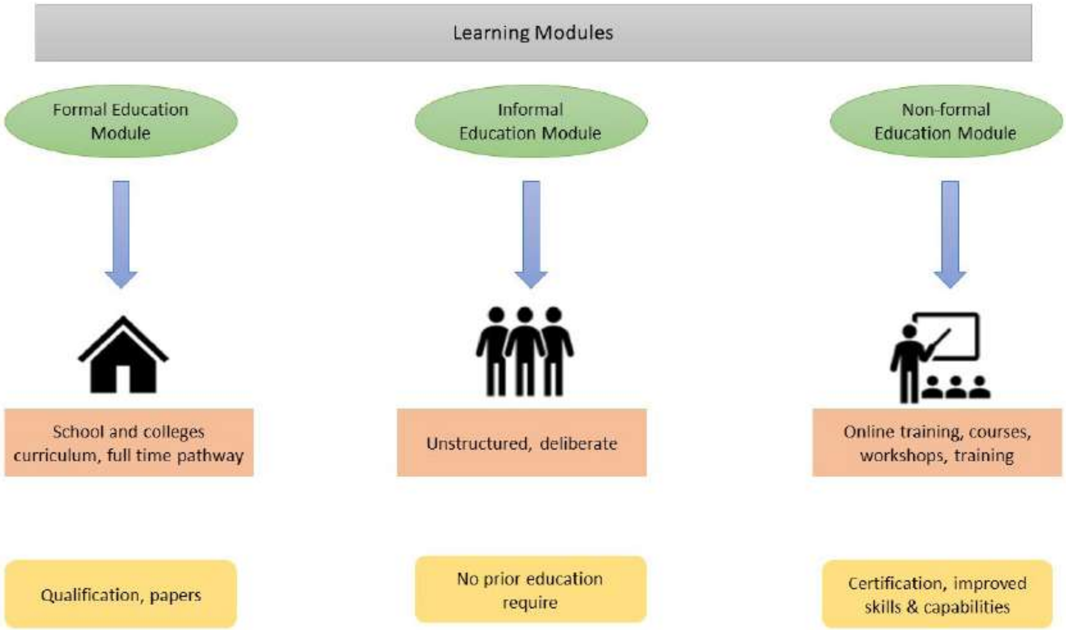


Figure 5.3.2: Formal, non-formal, and informal education modules

5.3.6 School-level exhibitions and competitions

Various studies conducted in India have observed that people are hesitant to accept wastewater treatment due to a lack of awareness and education. Interestingly it has also been observed that the significant source of information for these households was their school-going kids (TERI, 2020). Thus, it is important to create awareness amongst school students to leverage wastewater management in this location as a model for others in India. Various school-level competitions and exhibitions can improve in expanding the knowledge and transfer this knowledge to individual households to educate and sensitize the issues related to wastewater management (Fig. 5.3.3).

Figure 5.3.3: School-level exhibition and competition to create awareness


नमामि गंगे
गंगा स्वच्छता संकल्प दिवस
2 मई, 2017
पुकारे, स्वच्छता का संकल्प लें गंगा किनारे!
संकल्प रैली
गंगा स्वच्छता संकल्प दिवस
उ.प्र. राज्य गंगा नदी संरक्षण अभिकरण
संजय कुमार
अभिलाषा गुप्ता 'नन्दी'

6. Learning from case studies by National Mission for Clean Ganga, India

India's national river – Ganga, represents not just the collective consciousness and sentiments of the country, but is also the source of sustenance and livelihood of its people. The Ganga River Basin is the largest river basin in the country, constituting 26 per cent of the country's land mass, constituting 28 per cent of its water resources and supporting about 43 percent of its population. The main stem of the river traverses five major states namely, Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal and travels a total length of 2,525 kms. In fact, the Ganga River basin, including all its tributaries, covers about a million square kilometres area in eleven states in the country.

Although the trajectory of the efforts to clean the river began as early as 1985, the launch of the Namami Gange mission in 2014-15 has been the game changer. Launched with a budgetary outlay of Rs 20,000 crores, the Namami Gange mission is an umbrella programme with an aim to integrate previous and currently ongoing projects and new initiatives planned as its part. Under the Mission, a total of 378 projects have been sanctioned worth Rs 31,173 crores. The National Mission for Clean Ganga, established as an Authority under the Authorities Order 2016, is the implementing agency of the Namami Gange mission. In 2022, Namami Gange II was approved for Rs 22,500 Cr for the period 2021- 2026. The focus shall be on sewerage infrastructure creation in Ganga tributaries, scaling up of public private partnership efforts, circular water economy model and fecal sludge and septage management.

The Mission comprises of five strategic areas of intervention which include - 'Nirmal Ganga' with a focus on pollution abatement, 'Aviral Ganga' with a focus on ecology and flow of river Ganga, 'Jan Ganga' with an aim of people river connect and 'Gyan Ganga' with a focus on research, policy and knowledge management. The fifth area of intervention is Arth Ganga, which is a self-sustainable economic model based on the symbiotic relationship between nature and society, by strengthening people-river connect, adopting an ecologically conscious sustainable development framework and acting as an economic bridge between the basin and livelihood opportunities of the people. The six verticals of intervention are zero budget natural farming, monetization of reuse of sludge and treated wastewater, promotion of livelihood generation opportunities, increased public participation, revival of cultural heritage and tourism and institutional building.

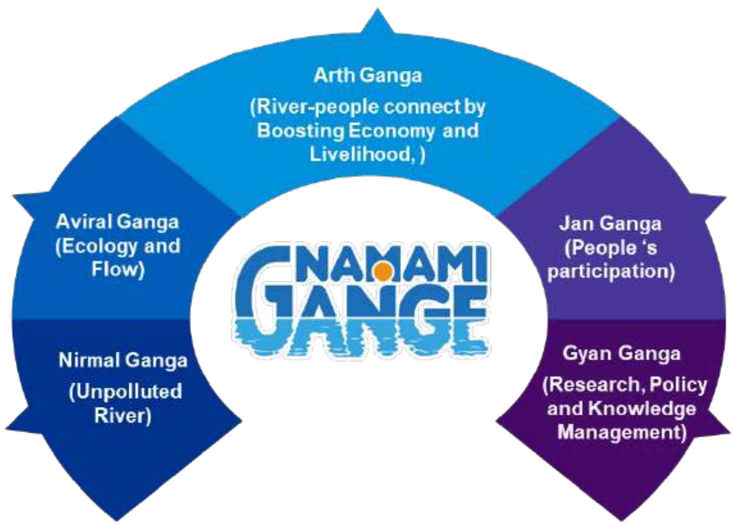


Figure 6.1: Five verticals under Namami Gange Mission

The following sub sections shed light upon some of the key learnings learnt from the

Mission.

6.1 Institutional arrangement of National Mission for Clean Ganga (NMCG)

Addressing the challenges of rejuvenating a transboundary river and driving an institutional reform, the Namami Gange Mission has a five-tier institutional framework with agencies at the national, state and district levels. This institutional arrangement supports NMCG in strengthening its governance structure to ensure successful implementation of its goals.

The roles and responsibilities of the five tier institutional framework has been elucidated below:

- National Ganga Council: The National Council for Rejuvenation, Protection and Management of River Ganga or the National Ganga Council, operates under the chairmanship of the Hon'ble Prime Minister with representatives of the state governments. It provides a platform for better coordination between the Government of India and state governments for river rejuvenation. The first meeting of the National Ganga Council was held on 14th December 2019 at Kanpur under the Chairmanship of Hon'ble Prime Minister and was attended by Members of Union Council of Ministers, Chief Ministers and Deputy Chief Minister of Ganga Basin States, among others.
- Empowered Task Force: The Empowered Task Force, under the Chairmanship of Union Minister for Water Resources, River Development and Ganga Rejuvenation is represented by Chief Secretaries of States on Ganga basin as well as secretaries from concerned departments of Government of India. The Empowered Task Force coordinates and advises on matters relating to Rejuvenation, Protection and Management of river Ganga and its tributaries and require the Ministries, Departments and State Government to frame Action Plan with specific activities timelines and mechanism for their implementation.
- National Mission for Clean Ganga: At the national level, the National Mission for Clean Ganga (NMCG) functions under the supervision and directions of the National Ganga Council and implements the Namami Gange Mission. NMCG is an empowered organization operating as a two-tier management system having interdependent administrative appraisals and approval powers. The Director General of NMCG, heads both the tiers of the organization. He is supported by four Executive Directors namely, Projects, Technical, Finance and Administration and a Deputy Director General. In 2016, the National Mission for Clean Ganga (NMCG) was notified as an authority with statutory powers under the Environment Protection Act, 1986 which gave it regulatory, financial and administrative empowerment.
- State Ganga Committees: The State Ganga Rejuvenation, Protection and Management Committee or State Ganga Committee, were constituted to drive programme implementation in all the five main stem states, through monitoring of the execution of plans, programmes, and projects of all district-level agencies. The State Ganga Committee headed by Chief Secretary of the respective State has representation of Principal Secretaries of relevant Departments of the State besides five experts from relevant fields nominated by the State Government.
- District Ganga Committees: The District Ganga Protection Committees or District Ganga Committees (DGC) have been constituted for district-level implementation and involvement of the local community in river rejuvenation.

The DGC is headed by the District Magistrate of the district abutting river Ganga, which has representation of two nominated members from Municipalities and Gram Panchayats of the District, one member each from concerned Departments such as, PWD, Irrigation, Public Health Engineering, Rural Drinking Water and State Pollution Control Board. The Divisional Forest Officer is Convenor of the Committee. From April 2022 onwards, DGC-4M meetings (District Ganga Committee – Monthly Mandated Minuted Monitored meetings) are being regularly conducted in all districts of the basin. This has increased the people's participation in the implementation of Namami Gange mission.

6.2 Current technologies and practices for UWM

The Namami Gange mission is technology agnostic. While encouraging the adoption of innovative technologies, it mandates that all the guidelines and norms of CPHEEO guidelines are adhered, and the end-products are compliant to the stipulated standards.

The initiatives undertaken by NMCG encompass focused interventions in both rural and urban areas, as well as centralised and decentralized solutions.

Treatment of Sewage

Under Namami Gange mission, a total of 163 sewerage infrastructure projects have been sanctioned (which includes components of sewage treatment plans as well as sewerage infrastructure) for creation and rehabilitation of 5016 MLD of STP capacity and laying of around 5134 KM sewerage network in towns located along river Ganga and its tributaries. Out of these a total of 96 projects have been completed, which has led to the creation/rehabilitation of 1770.85 MLD treatment capacity and 4174.43 km sewer network. The coverage extends to over 100 cities and towns in the basin. The focus is also now on decentralized small scale STPs like the Johkasou model to ensure sewage treatment in smaller towns and even in compact residential colonies in major cities.

Another area of intervention has been bioremediation and in-situ abatement of pollution in various drains flowing in the hinterland. A total of 14 projects have been sanctioned worth Rs 238.38 Cr. Against this, two projects have been completed and the remaining are under various stages of completion.

One of the important pillars under the new initiative of Arth Ganga is the monetization of reuse of treated wastewater and sludge. Also, under the India-EU partnership, a framework for safe use of treated wastewater has been prepared by NMCG.

With regards to decentralized solutions, the Government of India formulated the National Faecal Sludge & Septage Management (FSSM) Policy in 2017 to emphasize the importance of treating faecal sludge from on-site sanitation systems. Resultantly, select State Governments have issued their state level FSSM policies/ guidelines. Several states are also increasingly opting for other sewage treatment technologies such as FSSM, FSTP, phyto-remediation, bioremediation, bio-digesters etc. Successful implementation of FSSM projects has been achieved in States such as Andhra Pradesh, Maharashtra, Odisha and Telangana by adopting combination of FSTP, co-treatment in STP, cluster approach. Odisha has given O&M of the FSTPs to the Self-help women groups which resulted in better utilization of the existing infrastructure. This has also resulted in the improvement in the water quality of rivers in some instances. Thereby, States/ Union Territories which are yet to formulate or implement their state level FSSM policy have also been encouraged to do so on a priority basis.

For instance, in rural areas, concerted efforts have been made for sustainable solid and liquid waste management through adoption of nature-based solutions. Thus, Namami Gange mission has collaborated with the Department of Drinking Water and Sanitation, Ministry of Jal Shakti has constructed over 12.38 lakhs independent household toilets to make 4,507 villages along the Ganga River Open Defecation Free (ODF).

Similarly, in urban areas, efforts are being to make Ganga basin cities river and water sensitive. Some of the initiatives include promotion of Zero Liquid Discharge in context of Ganga Basin cities, setting up Centre of Excellence on Water Reuse, organizing awareness campaigns for strengthening of people river connect and others. In collaboration with our partners such as Centre for Science and Environment and Indian Institute of Public Administration, the mission is also conducting capacity building programs. Several guidelines and strategic frameworks have been released such as *Strategic Guidelines for Making River Sensitive Master Plans', 'A Strategic Framework for Managing Urban River Stretches in the Ganga River Basin: Urban River Management Plans', 'Guidance Note for Environmentally Sensitive, Climate Adaptive and Socially Inclusive Urban Riverfront Planning and Development', 'Urban Wetland/ Water Bodies Management Guidelines'.*

Treatment of Industrial Effluents:

Namami Gange mission has also established/ under process for setting-up Common Effluent Treatment Plants for specific industrial pollution abatement.

- Textile Cluster: Work for upgradation of existing 6.25 MLD CETP in Mathura is under progress. Tender preparation is under progress for 7.5 MLD CETP at Gorakhpur. For Farrukhabad, a new Textile Park has been proposed which will have a 1.5 MLD CETP for effluent treatment, and the Third-Party Assessment for the same has been approved. The Textile Cluster Association has accepted the proposals for CETPs with ZLD based system. For Rooma and Pilkhuwa textile clusters, Detailed Project Reports have been received.
- Tannery: There are 3 main tannery clusters present on the main stem of river Ganga namely Jajmau, Banthar & Unnao; having total of around 400 units) connected to CETP Jajmau Kanpur, Banthar & Site-II Unnao respectively. Under the mission, 20 MLD CETP at Jajmau and 4.5 MLD CETP at Banthar are under construction, and tendering is completed for upgradation of 2.15 MLD to 2.6 MLD CETP at Unnao project.

Under Aviral Ganga, NMCG has also made concerted efforts for industrial pollution abatement which is a major source of concern for River Ganga and its tributaries. Some of the initiatives include release of Charters for implementation of cleaner technology, upgradation of treatment facility and adoption of waste minimization practices in the major industrial sectors such as Pulp & Paper, Distilleries, Sugar and Textile. This has resulted in significant reduction in wastewater discharge and pollution load. Examples include Charter for Water Recycling & Pollution Prevention in Pulp & Paper Industry (Specific to Ganga River Basin States), Charter for Zero Liquid Discharge (ZLD) in molasses-based distilleries, Charter for Sugar.

NMCG also conducts annual inspection of Grossly Polluting Industries through Third Party Technical Institutes comprising of IITs, NITs, CSIR Institutes etc Compliance verification of Grossly polluting industries (GPIs) having potential to discharge into river Ganga and its tributaries is being carried out through third party institutes (TPIs) are carried out since 2017. Stringent action is taken by CPCB/SPCBs Pollution Control Committees against the GPIs discharging into main stem of Ganga River & its tributaries which are non-complying with respect to the prescribed norms. During 2021-22 (5th round of annual inspection of GPIs), an inventory of 1051 Grossly Polluting Industries (GPIs) including 09 common effluent treatment plants (CETPs) operating in five river Ganga main stem states has been updated in consultation with concerned State Pollution Control Board (SPCBs)/Pollution Control Committees (PCCs). Inventory of GPIs for river Yamuna basin was also finalized to 1655 GPIs including 33 CETPs. It was carried out by 24 reputed technical institutes (TPIs).

Action is being taken by seven respective SPCBs/PCC i.e., Uttarakhand, Uttar Pradesh, Haryana, Delhi, Jharkhand, Bihar & West Bengal. All the 2706 GPIs have been inspected. As on 5th August 2022, actions were taken against 2543 GPIs. Out of 2543 GPIs, 2059 GPIs were found operational, 319 GPIs temporary closed and 165 GPIs permanent closed. Out of 2059 GPIs, 1621 GPIs were found complying and 438 GPIs non-complying. Concerned SPCBs/PCC issued show-cause notices to 396 non-complying GPIs and closure direction to 42 non-complying GPIs.

6.3 Approaches for promotion and adoption of the sustainable UWM solutions

The introduction of the Hybrid Annuity based PPP model and One City One Operator model has been a game changer in the wastewater sector in the country and has given a much need push to PPPs in the sector.

- HAM Model: Launched in 2017, the model comprises of 100% central government funding through NMCG, for the development as well as operation & maintenance of the STPs for a period of 15 years. In alignment with the PPP procurement process followed by the Government of India for infrastructure related projects, a suitable concessionaire for the development & operation of STPs is selected through competitive bidding under HAM. 40% of the capital cost is paid during construction and the remaining 60% is paid over a period of 15 years as annuities with interest on outstanding balance along with operation and maintenance expenses. The bidding is based on lowest quote for the development, operations, and maintenance of the STP for 15 years. The rationale behind the increased responsibilities was to sustain the level of the performance and accountability of the project for the entire life cycle. The model's exclusivity stems from the various advantages it offers viz. assured government funding, continued performance, distinct accountability and ownership for performance over an extended period of time. As on date, 30 HAM projects have been sanctioned.
- One City One Operator: The model incorporates the development of new STPs along with the existing treatment infrastructure in the ULBs with the vision of complete elimination of untreated sewage entering River Ganga. The projects have been rolled in various cities such as Kanpur, Prayagraj, Mathura, Patna, Kolkata, Howrah-Bally-Kamarhati-Baranagar Bhagalpur, Farrukhabad, Mirzapur, Ghazipur, Agra, Bareilly, Burdwan, Durgapur, Asansol, etc. and are under various stages of completion.

In addition, NMCG in collaboration with Central Pollution Control Board is closely monitoring emissions and effluents from discharge points of industrial units through the Online Continuous Effluent Monitoring Stations. The analysers are installed on stacks/ chimneys and at the outlets of Effluent Treatment Plants/ Sewage Treatment Plants. The parameters being monitored include – i) for effluents–pH, BOD, COD, TSS, Flow, Chromium, Ammoniacal Nitrogen, Fluoride, Phenol, Cyanide, Temperature, AOx and Arsenic ii) For emission PM, Fluoride, NOx, SO2, Cl2, HCl and NH3.

6.4 Innovative applications and technological solutions for UWM

NMCG has adopted several innovative GIS based approaches and solutions for not just UWM but also to support its holistic river rejuvenation initiatives. Some of such interventions have been mentioned below:

- Catch the Rain Campaing: As part of the nationwide Catch the Rain Campaign, with the tagline Catch the Rain: Where it falls, when it falls, Namami

Gange also took active part in rejuvenation of small streams and rivulets, restoration of lakes and water bodies on the Ganga basin.

- Bhuvan Ganga Portal: In 2015, MoU has been signed between National Remote Sensing Centre, Hyderabad and NMCG for Bhuvan Ganga Geoportal which provides a platform to manage, access, visualize, share and analyse geo spatial data as well as non-spatial data products and services. The platform supports NMCG to achieve its objectives of environmental and ecological improvement within the Ganga River basin. It is being widely used by NMCG in drain monitoring.
- Green Ganga app is being used by NMCG for geotagging of afforestation activities conducted under the mission. NMCG has collaborated with Survey of India, the oldest survey and mapping department of the country, to use GIS technology for mapping Ganga basin in high resolution generating Digital Elevation Models (DEM). Deliverables of mapping include Digital Elevation Model/ Digital Terrain Model, GIS ready dataset, outlet/vent of sewerage and other discharge from all dwelling units, industrial, commercial and all type of other institutions, public drainage network, crematoria, ghats, RFD, solid waste disposal sites, STP/ETP/CETP etc. The models provide valuable information for making urban river plans, identifying the baseline of river flood plains and regulating them for their restoration and preservation critical pollution hotspots and facilitate policy to make informed decisions through the data generated. The mapping area is 43,084 km^2 along the 10 Km buffer of River.
- Sand Mining Mapping: Two projects are being conducted with IIT Kanpur:
    - A pilot project is being conducted using UAV Technology that focuses on a small stretch of the main Ganga River between Raiwala and Bhogpur in Uttarakhand.
    - A research project on "Geomorphic and Ecological Impacts of Sand Mining in Large Rivers as revealed from high resolution historical remote sensing data and drone surveys: Assessment, Analysis and Mitigation.
- Water bodies mapping using UAV technology by QCI: The project "Census Survey of Water Bodies in Ganga Basin" uses drone technology to map of all the water bodies in 31 Ganga districts (3189 villages) of Uttar Pradesh, Uttarakhand, Bihar, Jharkhand and West Bengal for improvement/ rejuvenation of water bodies that are either dried up or working less than their full efficiency.
- Reconstructing the Ganga of the Past from Corona archival imagery is being implemented by IIT Kanpur.
- Spring Rejuvenation using Remote Sensing, GIS & UAV technology
    - Pilot study on spring rejuvenation for Tehri Gadhwal district of Uttarakhand – under implementation by Survey of India/ Central Ground Water Board. CGWB. A schematic mapping of Tehri Garhwal district is being conducted for inventory of springs using LiDAR technology, hydro-geomorphic & liniment studies for identification of different type of springs & their recharge zones and implementation of spring rejuvenation by constructing rainwater harvesting and artificial structures.
    - Rejuvenation of dying springs in Tokoli Gad catchment of Tehri Garhwal District using Geo-chemical & Geo-physical techniques by IIT Roorkee. Under the project, the impact of land use, land cover change and natural or anthropogenic precipitation variability are being assessed.
- GIS based Mapping of Microbial Diversity by NEERI is being conducted to

understand the water quality of river Ganga along the stretch with the specific focus on parameters that indicates the interactions of river with its varied environment.

- Climate change scenario mapping using Weather Research and Forecasting Model by IITD. This will enable NMCG to map out high resolution climate scenarios for basin-scale water resources management. It aims to develop high-resolution (10 km X 10 km) datasets of current climate and future climate scenario and demonstrate its applicability for water resource management problems in the Indo-Gangetic plain.
- Environmental Flow Assessment for River Yamuna is being conducted using GIS, RS, Survey by NIH, Roorkee
- Identification of Critical Soil Erosion Prone Areas and Preparation of Catchment Area Treatment Plan is being conducted by IIT Roorkee.
- A GIS based inventory of small rivers is being created with additional component in form of district wise list of small rivers. Majority of these small rivers are seasonal rivers and often have been hydrologically degraded both due to non-availability of flows during non-monsoon or due to water quality issues. The rejuvenation of these rivers is one of objective of the programme as these small rivers impact the flows, both quality and quantity of River Ganga.
- NMCG in partnership with INTACH is carrying out the cultural mapping of the main stem of the Ganga from origin to Ganga Sagar using GIS technology.
- The GIS Cell of NMCG has developed a prototype geoportal on "Ganga Water Quality information system" with help of ESRI India. This geoportal shall enable NMCG to make informed decision making with regards to compliance and non-compliance status of STP & trend analysis of water quality of Ganga River based on manual water quality monitoring stations.

6.4.1 Improving institutional and international collaborations under NMCG

NMCG collaborates with local NGOs and organizations to reach out at the grassroot level to raise awareness, impart livelihood training and skill development, etc. For instance, it is closely working with Himalayan Environmental Studies and Conservation Organization (HESCO) to promote livelihood opportunities in the Ganga basin and use nature-based solutions for sustainability and restoration of riverine ecosystems. Another example, is the collaboration with Say Earth to share knowledge for rejuvenating, restoring and management of ponds and waterbodies.

With regards to international collaboration, NMCG is closely working with countries such as Denmark, Israel, Netherlands, South Korea and Japan for water partnerships and knowledge exchange. A Memorandum of Cooperation was signed with Ministry of Environment, Government of Japan for the promotion of Johkasou model of decentralized solutions. Teams of officials from central government ministries and state governments have been sent to Israel for training on water conservation and management practices.

6.4.2 Sensitisation of the public under NMCG

Jan Ganga or strengthening people river connect has been a key focus area under the Mission. Regular public outreach programs are organized with the support of the dedicated cadres of Ganga saviours such as Ganga Doots, Ganga Praharis, Ganga Vichar Manch, etc. to raise awareness and sensitize grassroot level communities. Some of the initiatives undertaken include:

- Ganga Utsav (Ganga Festival): Since 2017, Namami Gange has been celebrating Ganga Utsav (River Festival), to commemorate the declaration of River Ganga as the national river. In 2021, Ganga Utsav was organized from 1st to 3rd November 2021, to celebrate not just for River Ganga but all other rivers across the country. The festivities included cultural performances, Ganga dialogues, Kahani Junction, Live Paintings, Photo Exhibitions, etc.

- Ganga Quest: Initiated in 2019, Ganga Quest is a bilingual international quiz competition designed with an aim to sensitize people about the national River Ganga, its significance, cultural and historical values, diversity and its ecosystem. The objective is not just building knowledge among participants, but also to connect them emotionally by sensitizing about rivers' present condition and its past reverence. In the years 2020 and 2021, it drew an overwhelming response with more than a million participants. This year Ganga Quest 2022 had over 7 lakh registered participants, against which around 1.73 lakh participated in the competition from India and 180 countries
- Ghat Main Yoga: In 2022, Namami Gange celebrated International Yoga Day by organizing yoga sessions in Ghats along the river. With over 10 lakh participants, the sessions were organized in over 100 locations across all five main stem states, with the support of 131 District Ganga Committees.
- Ganga Amantram (River Rafting Expedition): A unique social awareness initiative to connect with people, the 34-day long river rafting expedition from Devprayag to Ganga Sagar raised awareness regarding river rejuvenation and water conservation.
- 'Rag-Rag Mein Ganga': In association with Doordarshan (Prasar Bharti), Namami Gange mission aired two seasons of 'Rag-Rag Mein Ganga'-a travelogue series on Ganga on DD National. The travelogue series covered the cultural, mythological and historical aspects about the river from Gaumukh to Ganga Sagar, and the efforts undertaken by the Mission for its rejuvenation.
- Sponsored Thesis Competition–'Re-Imagining Urban Rivers': In collaboration with the National Institute of Urban Affias, Namami Gange mission has organized two editions of a national-level thesis competition. The competition is a first-of-its-kind initiative to engage young minds to research and envisage solutions for urban river issues.
- Ganga Connect Exhibition: Organized jointly by Namami Gange, cGanga and High Commission of India, the Ganga Connect Exhibition was a global exhibition and an outreach platform, which showcased the multiple facets of the river system and connected with a range of interested partners. The 17- day long exhibition began in Glasgow, Scotland and travelled through various cities in the United Kingdom including Cardiff, Birmingham, Oxford and London. The exhibition helped connect the Indian diaspora and international community with the river.

7. The Way Forward

Urban wastewater management, even though local, requires globally co-created solutions. Urban wastewater generation in India is set to continue increasing in the future due to population increase, migrations and development perspectives, which leads to the need to update existing wastewater treatment infrastructures. This whitepaper had documented current trends and had identified scope for improvement and augmentation to support India's development in a sustainable and long-lasting manner. Through this whitepaper, it is understood that there are some documented success stories for urban wastewater management, however it is important to understand that there is "No-one-size-fit-all" solution and availability of land for such solutions is limited. Future infrastructures should aim to bridge the gap of wastewater generation and treatment by using sustainable solutions. Each urban centre (city/town/community/ building/individual) has different requirements of land, capital and human resources and thus require site specific technological solutions. This should include innovations in science and technology with considerations on centralised or decentralised infrastructure, conventional or advanced or nature-based solutions and has to be tailor made keeping the holistic picture of water-land-people and ecosystems.

Holistic urban wastewater management requires data from all key stakeholders and environmental conditions. Monitoring data is one such key data, which is the need of the hour in order to utilise the wastewater as a resource – e.g. for using wastewater before or after treatment. Data driven approach requires large volumes/frequency of data, however, currently the data on wastewater is scarce. Development of affordable data monitoring tools can aid in these scenarios for effective monitoring and also to sensitize stakeholders on load generation/reuse. There is tremendous support from the Government of India on Agriculture 4.0 and Industry 4.0 techniques that require the use of IoT, ICT, IoE with good internet connectivity. Such devices and government support should be used for urban wastewater monitoring, reuse and recycling efforts, which can aid with more water for agriculture and industrial applications. Involvement of techniques using IoTs, WSNs, RS and GIS approaches can also help in providing real- time data and can increase higher spatiotemporal resolutions of the data. A Web-based data-driven decision support system (DSS) can aid policy makers to take scientifically validated best management plans. Public participation is necessary for managing natural resources and in treating waste water. Added local participation and involvement of private sector improves the scale of investment, managing risks and delivering better services at affordable costs. Involvement of the stakeholders/end user community can also fine tune the future infrastructure projects as per the requirements and understanding of its user. The aforementioned data connectivity models (e.g. ICT, IoTs) should be used for increasing public participation in crowd sourcing of wastewater monitoring data and monitoring of waste generation, which can also be used to sensitize the need for urban wastewater treatment solutions and for increased acceptance of reusing and recycling wastewater. Such public participatory engagement can also aid in increasing the capacity building efforts and for improving the training capacity of locals through interactive media (e.g. guided multilingual tutorials). Trainings and awareness programs on promoting the reuse of the wastewater is much needed to manage the water related challenges in water scarce areas, across the globe.

There is a need to setup Apex bodies (with participation from Government agencies, academia, industry and public organisations) to manage wastewater treatment systems through extensive collaborations. It is necessary to update best management practices for urban wastewater scenarios, with active participation from global communities to avoid technology duplications and to quickly learn and reapply from success stories. This whitepaper aims to create pathways for such collaborations and engagements between countries to develop sustainable and affordable urban wastewater management solutions for all.

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Almost 80% of water supply flows back into the ecosystem as wastewater. This can be a critical environmental and health hazard if not treated properly but its proper management could help the water managers in meeting the city's water demand. Currently, India has the capacity to treat approximately 37% of its wastewater, or 22,963 million litres per day (MLD), against a daily sewage generation of approximately 61,754 MLD according to the 2015 report of the Central Pollution Control Board. Moreover, most sewage treatment plants do not function at maximum capacity and do not conform to the standards prescribed.

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