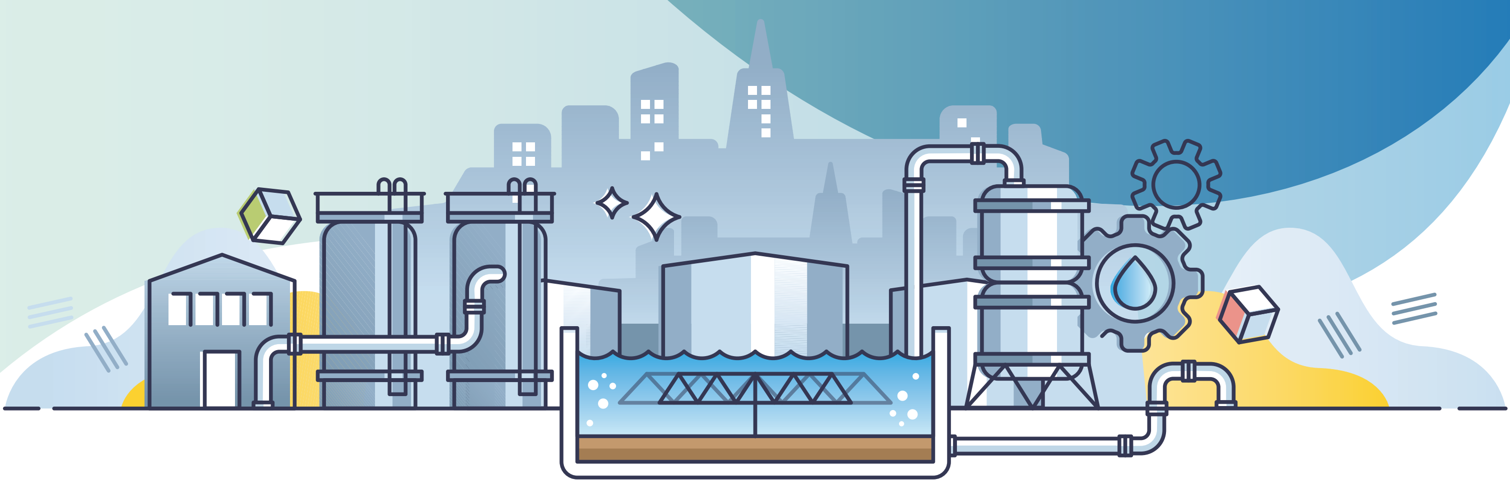
NITI Aayog

ATAL INNOVATION MISSION

URBAN WASTEWATER SCENARIO IN INDIA



ICDK

RuDRA

NAMAMI GANGE

URBAN WASTEWATER SCENARIO IN INDIA

SEPTEMBER 2022

Contents

LIST OF FIGURES

LIST OF TABLES

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 seven SDGs are directly linked to clean water, and five 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
Parameswaran Iyer
मुख्य कार्यकारी अधिकारी
Chief Executive Officer

सत्यमेव जयते

भारत सरकार
नीति आयोग, संसद मार्ग
नई दिल्ली - 110 001
Government of India
National Institution for Transforming India
NITI Aayog, Parliament Street,
New Delhi - 110 001
Tel. : 23096576, 23096574 Fax : 23096575
E-mail : ceo-niti@gov.in

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

डाॅ. चिंतन वैष्णव
Dr. Chintan Vaishnav
मिशन निदेशक
Mission Director
Tel. : 011-23096580
E-mail: chintan.vaishnav@gov.in

भारत सरकार
नीति आयोग
अटल इनोवेशन मिशन
संसद मार्ग, नई दिल्ली-110001
Government of India
NITI Aayog
Atal Innovation Mission
Sansad Marg, New Delhi-110001

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.

Chintan Vaishnav

(Dr. Chintan Vaishnav)
Mission Director

(डॉ. चिंतन वैष्णव)
(Dr. Chintan Vaishnav)
मिशन निदेशक, अटल इनोवेशन मिशन
Mission Director, Atal Innovation Mission
नीति आयोग
NITI Aayog
भारत सरकार/Govt. of India

स्वच्छ भारत
एक कदम स्वच्छता की ओर

MESSAGE

Avinash Mishra
Adviser (WR & LR), NRE,
Tourism & Culture Panchayati Raj, I & B

Telefax (O) : 011-23096732
E-mail : amishra-pc@gov.in

सत्यमेव जयते

भारत सरकार
नीति आयोग, संसद मार्ग
नई दिल्ली - 110 001
Government of India
NATIONAL INSTITUTION FOR TRANSFORMING INDIA
NITI Aayog, Parliament Street,
New Delhi - 110 001

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

स्वच्छ भारत
एक कदम स्वच्छता की ओर

MESSAGE

ग्रामीण क्षेत्र हेतु
प्रौद्योगिकी विकल्प केंद्र (सितारा)
भारतीय प्रौद्योगिकी संस्थान मुंबई
पवई, मुंबई-400 076, भारत

Centre for Technology Alternatives
for Rural Areas (CTARA)
Indian Institute of Technology Bombay
Powai, Mumbai-400 076, India

Tel : (+91-22) 2576 7870
(+91-22) 2576 7871
Fax : (+91-22) 2572 3480

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.

Pennan Chinnasamy
Indian Institute of Technology
Rural Data Research and Analysis lab (RuDRA)

ACKNOWLEDGEMENTS

The authors acknowledge all the Government and non-government agencies for sharing the data on urban wastewater generation and treatment scenarios. We acknowledge all the authors for their valuable case study examples for understanding the importance of site-specific conditions. We acknowledge Central Pollution Control Board (CPCB),

all State Pollution Control Boards, State water agencies, Ministry of Education, Ministry of Urban Development Government of India, Presidency University (Bengaluru), India WRIS for providing a database of hydrological variables, Indian Space Research Organisation (ISRO) for spatial data and Central public health and environmental engineering organization (CPHEEHO) for providing the guidelines and manuals for the waste management and sewage treatment systems.

LIST OF CONTRIBUTORS

No.	Name	Designation
Indian Institute of Technology, Bombay		
1	Prof. Pennan Chinnasamy	Assistant Professor
2	Ms. Meeta Gupta	PhD Scholar
3	Ms. Neetu Singh	PhD Scholar
4	Mr. Pranadh M.	PhD Scholar
5	Mr. Gokul Prasad	PhD Scholar
6	Mr. Pravin Kolhe	PhD Scholar, Superintending Engineer at Water Resources Department, Pune
7	Mr. Mohamed Kasim Khan	PhD Scholar

No.	Name	Designation
NITI Aayog		
1	Mr. Avinash Mishra	Adviser (WR and LR, NRE, Tourism & Culture, Panchayati Raj, I&B), NITI Aayog
2	Dr. Chintan Vaishnav	Mission Director, Atal Innovation Mission
3	Mr. Anurag Wasnik	Innovation Lead, Atal Innovation Mission
4	Mr. Arunlal K	Associate (Water Resources), NITI Aayog
5	Ms. Anisha Bhasin	Young Professional, Atal Innovation Mission

No.	Name	Designation
National Mission for Clean Ganga		
1	Mr G Asok Kumar	Director General, National Mission for Clean Ganga
2	Mr. Davendra Pratap Mathuria	Executive Director - Technical, National Mission for Clean Ganga
3	Ms. Sharmi Palit	Institutional Associate, Programme Management Consultant, National Mission for Clean Ganga

No.	Name	Designation
Royal Danish Embassy, India		
1	Ms. Anitha Kumari Sharma	Counsellor, Urban Development with focus on Water

No.	Name	Designation
Innovation Centre Denmark		
1	Mr. Joseph Kurian	Innovation Advisor, Cleantech

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

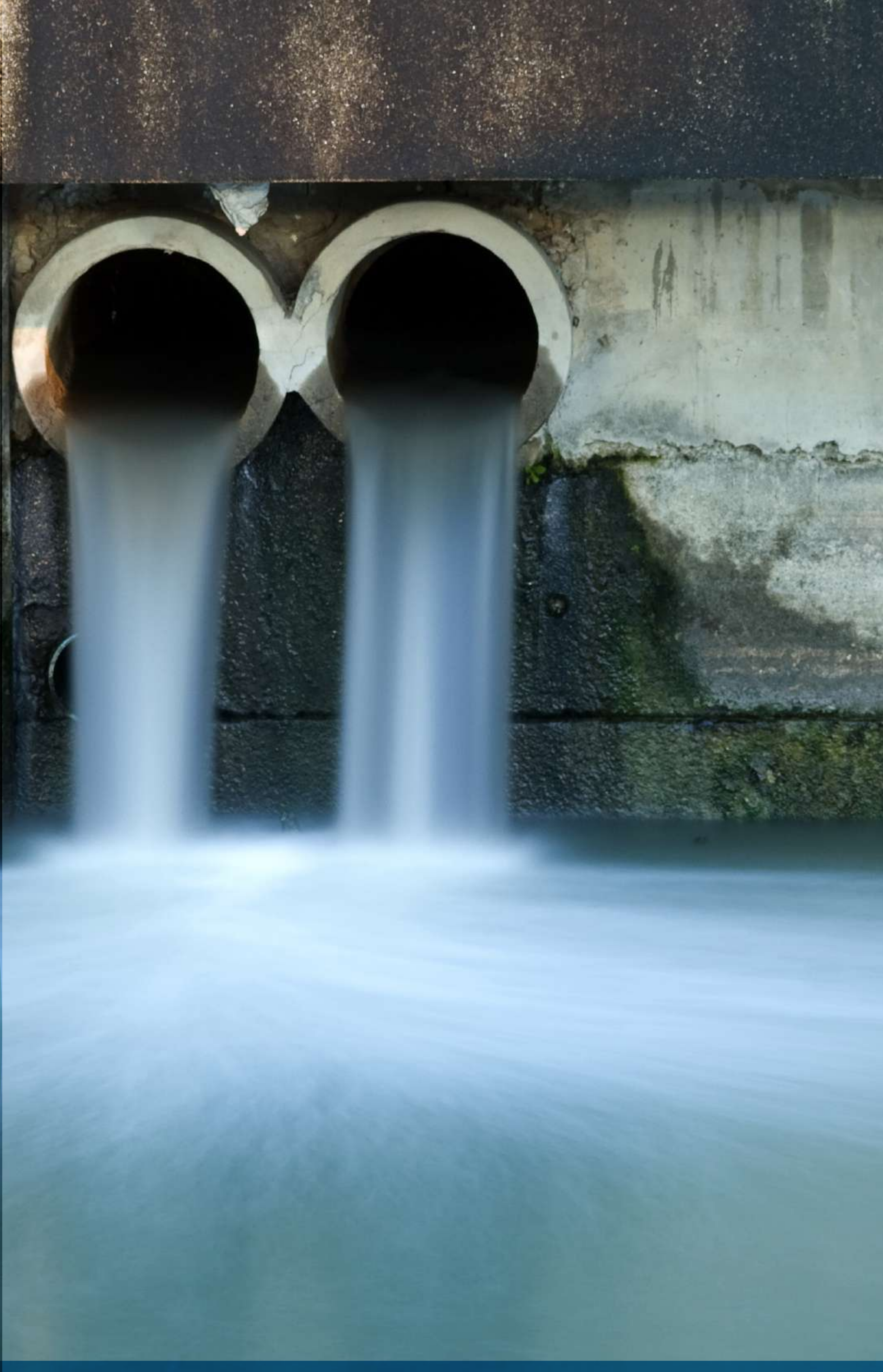
1. Executive Summary

Every nation aims for socio-economic development; however, sustainable development is key. Population growth and urbanization, 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 to wisely use the water resources we have. This whitepaper offers an in-depth, comprehensive review of the urban wastewater situation, which includes the current scenario of wastewater production, collection, treatment and reuse; the existing legal and policy frameworks and institutional setup for wastewater management; the different 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, cutting-edge technologies in the wastewater sector have performed a crucial role in improving the health and hygiene situation at the urban scale, thereby also solving issues related to water security in water-scarce regions. This has brought many countries closer to achieving the targets under Goal 6 of the Sustainable Development Goals. Despite the well-researched benefits, wastewater treatment and reuse techniques and technologies in India require improvement and upgradation, 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 the 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 the public in re- using treated wastewater and absence of collective action between stakeholders from wastewater generation to treated wastewater reuse.

Efforts are required to design guiding frameworks for the adoption of appropriate technologies and practices in accordance with the needs of each urban centre (city/ town/community/building/individual). Additionally, it is equally important to strengthen the institutional capacity and monitoring capabilities to increase user certainty and trust in the quality of the treated wastewater. This will generate demand for treated wastewater for different purposes and ultimately help protect 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 reusing 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 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 *"world's second most populous country"*. 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, and therefore there is a need for immediate attention to managing wastewater due to rapid urbanisation.

Currently, *"urban areas accommodate more than half of the world's population",* and by 2050 it is predicted that this percentage will increase to 70%. Rapid urbanisation 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 an unprecedented pace. With an increase in the population of such cities, it is important to identify water resources to sustain such expansion. An increasing set of sustainable but unconventional water resources, such as wastewater, holds immense potential to close the water demand-supply gap and achieve a water-secure future (Jones et al., 2020). Though in many countries, wastewater is now being used as an alternate water source, especially for supplying irrigation water in farmlands; however, in many developing countries like India, wastewater is considered as "untapped" and "undervalued" resource (WWAP, 2017).

The aim of treating the wastewater is to improve the wastewater quality to meet the quality standards of designated reuse or reduce the environmental impact arising from return flows. Apart from reuse, the treated wastewater can also act as a freshwater source and be useful in maintaining the river flow during drought situations (Luthy et al., 2015). However, it has been observed that the quality of wastewater being reused is poor. On the other hand, the demand for clean water is rising faster than wastewater treatment solutions and quicker than technological advancements in institutions providing safe wastewater access (Sato et al., 2013). One of the biggest hurdles to clear while encouraging reuse is to guarantee human health and ecological safety and ensure that wastewater is of appropriate quality before being used or released into the environment. If this hurdle is not cleared, wastewater will still be considered waste and not treated or recycled or reused. Thus, a major shift in the water resource management approach is needed in which wastewater is considered a "resource" to meet the water, food and energy requirements rather than being called "waste." (WWAP, 2017; Qadir et al., 2020). However, challenges exist globally.

2.1. Urban wastewater as a growing global challenge

The spatio-temporal data on the volumes of wastewater generated, collected, treated and reused for different sectors are either infrequently monitored and published or are scattered due to institutional fragmentation (Mateo-Sagasta et al., 2015). These statistics are vital for water-food-energy-related sustainable development at a time when the world is attempting to achieve goals and targets set under the United Nation's 17 Sustainable Development Goals (SDGs). In particular, SDG 6.3 target is focused on wastewater and *"aims to halve the proportion of untreated wastewater discharged into the waterbodies 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; SDG 6. a – *"to expand international cooperation and capacity-building support to developing countries in water-and sanitation-related activities and programmes"* ;

SDG 7. 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 11.3 – "*enhancing inclusive and sustainable urbanisation*"; SDG 12.5 – "*reduction in the waste generation through prevention, reduction, recycling and reuse*", and SDG 13.2 – "*to increase our adaptive capacity to climate change*". Therefore, it is important to understand wastewater generation and associated measures to reuse.

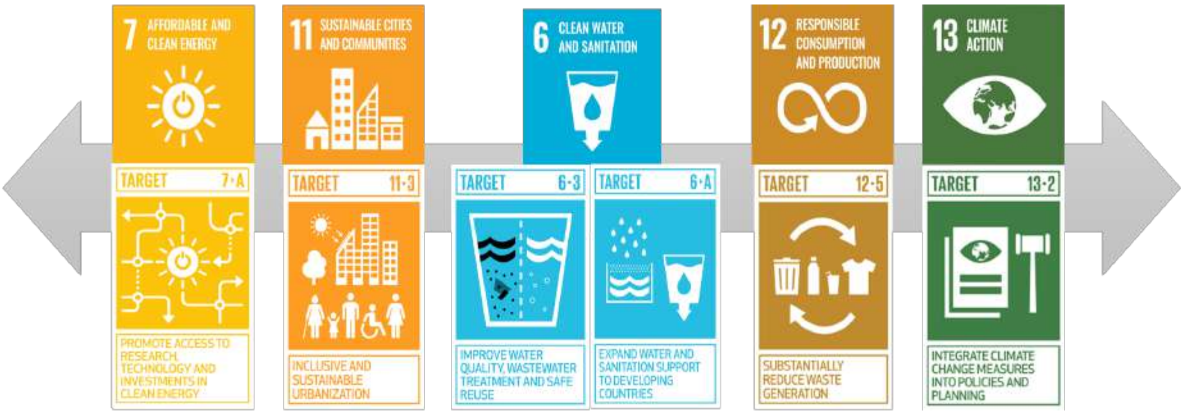


Figure 2.1.1: SDG interlinkages with respect to wastewater treatment and management (Adapted from UN SDGs)

Recently, few global studies have been carried out to estimate wastewater volumes and make predictions for the future. For example, Qadir et al. (2020) estimated that 380 billion m3 of wastewater is generated annually across the world. Based on the rate of population growth and urbanisation, the daily wastewater generated is predicted to increase by 24% (470 billion m3) by 2030 and 51% (574 billion m3) 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 m3) of the wastewater globally. It is expected that by 2030 there will be an increase in wastewater generation to 44%, and hence needs attention.

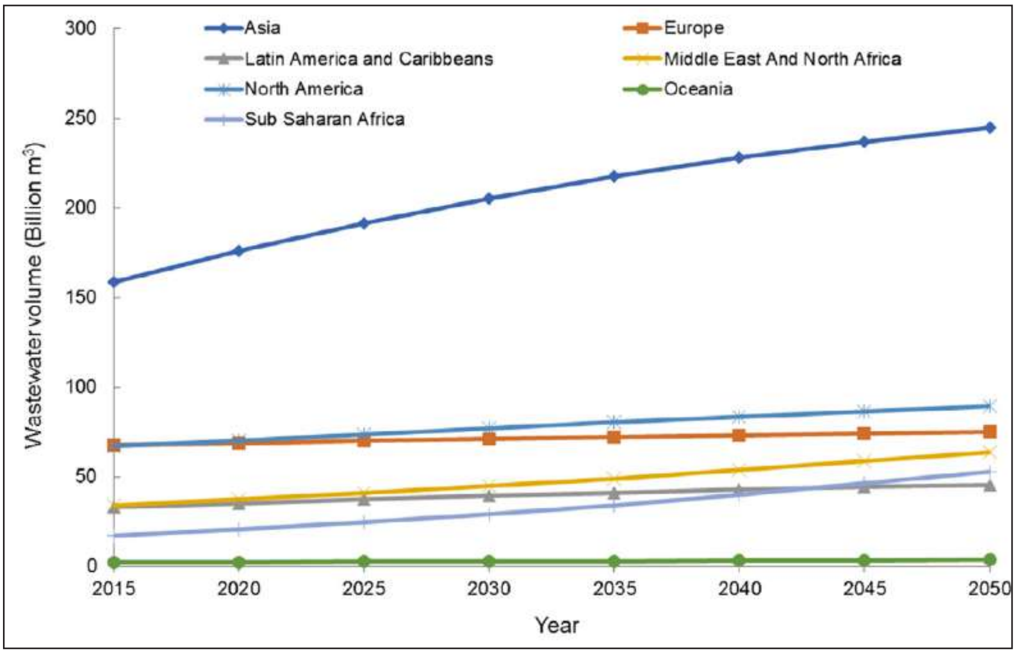


Figure 2.1.2: Wastewater production across the different regions of the world for 2015-2050 (Source: Qadir et al., 2020)

Jones et al. (2020) conducted a similar analysis, estimating global annual wastewater generation at 359.4 billion m3. Of the total wastewater generated, 63% (225.6 billion m3) is collected, and 52% (188.1 billion m3) is treated. Annual wastewater reuse is estimated at 40.7 billion m3, representing 11% of the total wastewater generated and 22% of the treated wastewater for direct reuse. This means that nearly 40% (171.3 billion m3) of wastewater is released directly into the environment without treatment (Fig. 2.1.3).

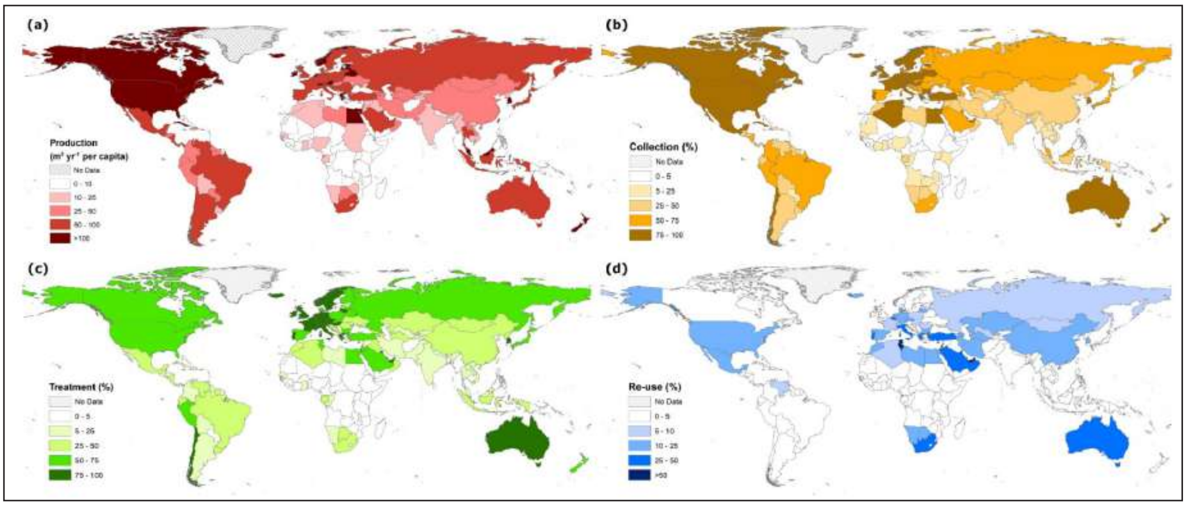


Figure 2.1.3: Global wastewater estimates at country scale: a) Wastewater production (m3/year per capita), b) wastewater collection (%), c) wastewater treatment (%), and d) wastewater reuse (%) (Source: Jones et al., 2020)

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 82% and treating 74% of the majority of their wastewater generated, while low-income countries 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 countries. In the case of wastewater reuse, the percentage of treated wastewater reuse is higher in the upper middle (25%) and lower

middle income (25%) countries than in the high-income countries (19%); while the low-income countries are only able to reuse 8% of the treated wastewater. Regionally, East Asia and the Pacific generate the largest volume of wastewater, which coincides with the highest population proportion (31%) (Fig 2.15). Western Europe had the highest rate of wastewater collection and treatment, whereas Southern Asia had the lowest. 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.

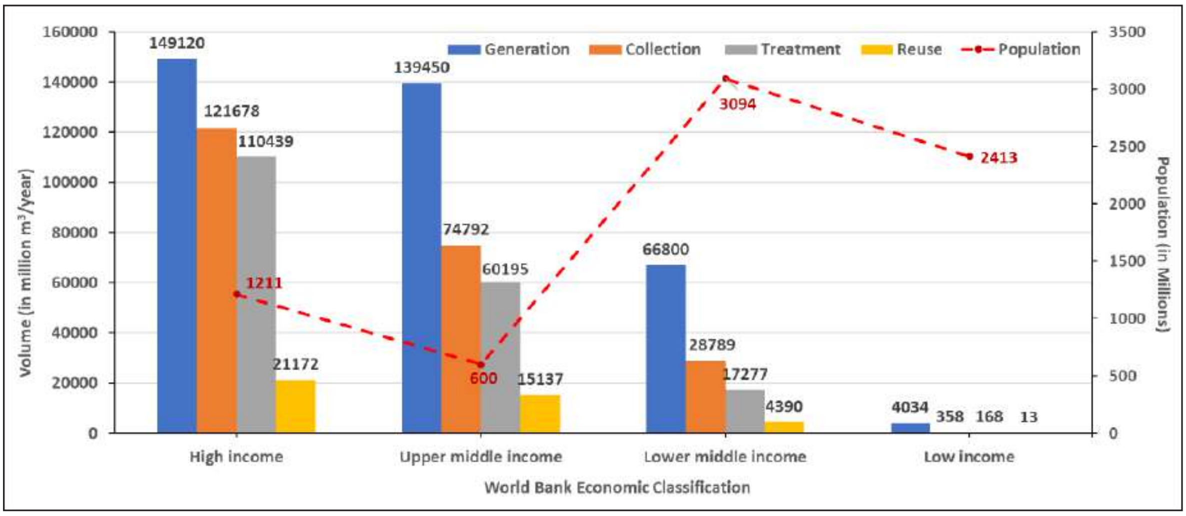


Figure 2.1.4: Wastewater statistics as per World Bank economic classification for the year 2015- 2050 (Data Source: Jones et al., 2020)

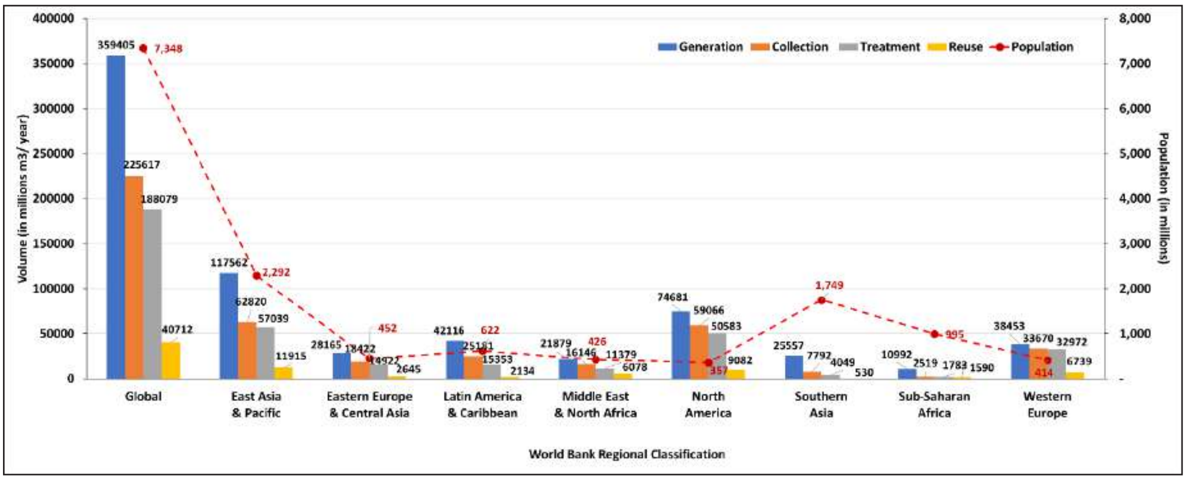


Figure 2.1.5: Wastewater statistics as per World Bank's regional classification for the year 2015 (Data Source: Jones et al., 2020)

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 metropolitan centres are seeing aberrant expansion as a result of new economic reforms and migration. Its population, 1.38 billion (as of 2020), is now rapidly settling in cities in search of a better source of income 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 the 2011 Census, 53 cities in India had a population of more than a million people. 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 in urban cities. This unsustainable expansion in urban population places great strain on city planners, notably in terms of providing utility services, particularly 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 increasing incessantly, with irrigation, domestic requirements, electricity, and industry all looking for larger quantities to satisfy expanding demands. According to India's 2050 forecasts, 1,447 km^3 of water would be required, of which 74% of which will be used for agriculture and the remainder will be used for drinking water (7%), industry (4%), energy (9%), and others (6%) (Amerasinghe et al., 2013). However, due to the aforementioned fast-paced urbanisation in Indian cities and towns, the need for drinking water is also increasing and takes precedence over competing rural water demands, such as irrigation. Many of these developing cities are located in important river basin catchments, consuming large quantities of freshwater and discharging wastewater back into the catchments, thus contaminating irrigation water. This has raised serious concerns and challenges for urban wastewater management for urban and rural water managers, planners and decision-makers.

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 is 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. Even with this added to the current installed capacity, there remains a 35,700 MLD (49%) gap between the wastewater generated and the capacity available for treatment. CPCB, 2021b).

Looking more closely at the city-scale assessments, the wastewater generation from Class I cities and Class II towns (as per the 2001 census) is estimated as 29,129 MLD, and under the assumption of a 30% decadal increase in urban population, it is expected to be 33,212 MLD at the current time. (Fig. 2.2.1). Against this, the existing capacity of sewage treatment is only 6,190 MLD. There is still a 79% (22,939 MLD) capacity gap between sewage generation and existing sewage treatment capacity. Another 1742.6 MLD wastewater treatment capacity is being planned or built. Even with this added to the current capacity, there is still a sewage treatment capacity shortfall of 21,196 MLD (equivalent to 73%). (CPCB, 2021c).

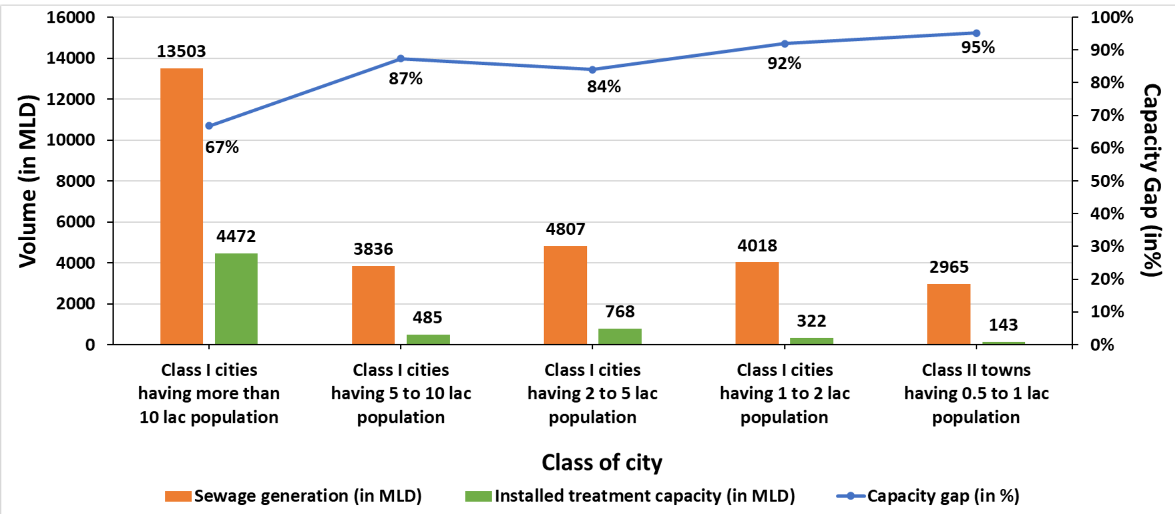


Figure 2.2.1: Wastewater generation and treatment capacity gap at city level in India (CPCB, 2022)

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 indicates that they are severely polluted, and 17 % of the stretches in Priority 2 and 3 are moderately polluted. Aside from high BOD and COD levels, many regions have significant amounts of heavy metals, arsenic, fluorides, and toxic compounds, particularly 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	>30 mg/L	45
2	Moderately polluted	20 to 30 mg/L	16
3	Moderately polluted	10 to 20 mg/L	43
4	Mildly polluted	6 to 10 mg/L	72
5	Clean	3 to 6 mg/L	175
Total			**351**
Data Source: CPCB. (2018)			

With the rapid increase in population and urbanisation 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 an understanding of these concerns and test 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 that have successfully tested these technologies and implemented 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 practised worldwide that India can learn from and tailor as per the requirements of land, natural resources, energy, and cost and in accordance 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 centralised 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 decentralised 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

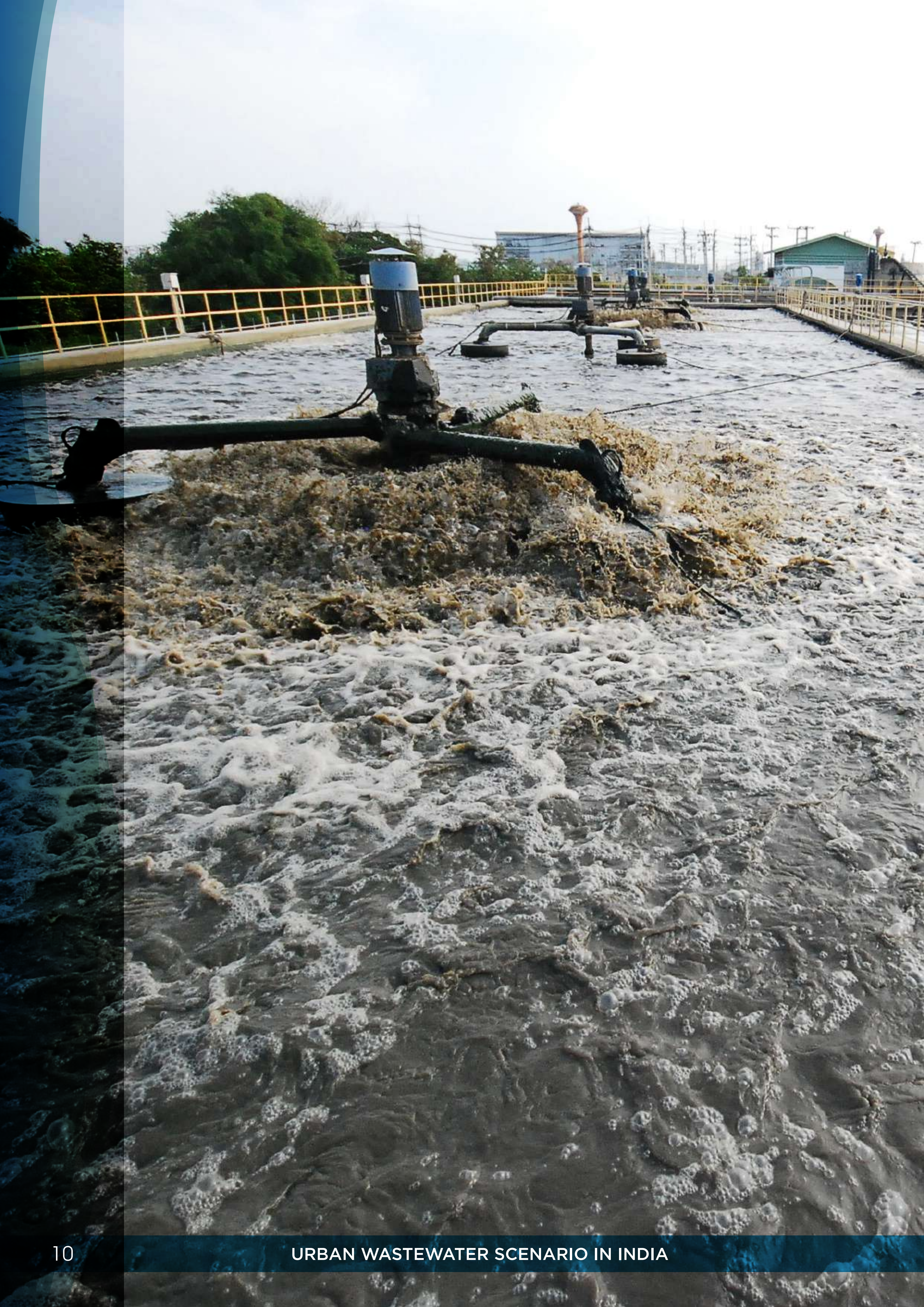
treated wastewater in light of the "National Framework on the Safe Reuse of Treated Wastewater-2020". The need and scope of upgradation in traditional septic tanks and possible technological advancements have been explained using case studies. Further, how these solutions can be promoted and adopted at the institutional, community and individual levels are discussed using Public Private Partnerships and Public Private People Partnerships.

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 sensitisation of the public/community to face 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 regulatory framework for UWM

The "water" is a State subject, according to Schedule Seven of the Indian Constitution. However, when it comes to interstate waters, Parliament has the authority to enact laws, whilst the State has the authority to establish policies and legal guidelines on the usage of water inside the State. The 1993 enactment of the 74th Constitutional Amendment decentralizes control of water supply and sanitation from the state government to Urban Municipal Councils (UMC).

There is no single Act in India that addresses wastewater management specifically in terms of devoted legislation. However, the "Prevention and Control of Pollution Act of 1974" contains laws that report wastewater as a source of pollution. This act established the Central and State Pollution Control Boards, which are in charge of preventing and managing water pollution. There are legal restrictions on polluting water that enters streams, wells, sewage systems, or the land. The Central Pollution Control Board (CPCB) establishes "*Water Quality Standards*" and "*Industrial Effluents Standards*" for various classes of water; however, these must be continuously updated using worldwide standards and taking emerging pollutants into consideration. Municipal ordinances provide restrictions on the discharge of sewage into sources of drinking water.

"The Water (Prevention and Control of Pollution) Cess Act, 1977", which went into force in 1992, levied taxes on industrial water consumption in order to fund the Central and State Boards. The Act makes a provision for a 1/4th rebate on the payable cess in order to encourage wastewater treatment.

"The Environment (Protection) Act, 1986" allowed the Central Administration to set sewage and effluent regulations and oversee compliance. The "polluter pays principle" is codified into Indian environmental policy through this umbrella environmental protection act. The Environment (Protection) Rules of 1989 specify industry-specific criteria for emission and effluent disposal. Among other things, Waste and sewage treatment operations are governed by the "Wastes (Management and Handling) Rules, 1989".

"The National Environment Policy, 2006" emphasizes the reusing of wastewater prior to discharge into water bodies as a direct and indirect cause of pollution of surface (such as rivers and wetlands), groundwater, and coastal areas. The policy lays out the action plans for metropolitan communities to combat water pollution through suitable legislative frameworks and technological advancements for the treatment, repurposing, and recycling of urban wastewater prior to final discharge into water bodies.

"National Urban Sanitation Policy, 2008" emphasizes recycling and reuse while focusing on the hygienic and secure disposal of human waste. The 2012 National Water Policy of India implemented integrated water resources management in planning, development, and management. Decentralized sewage treatment facilities, planned tariff systems for recycling and reusing treated water, and subsidized treatment of industrial effluents are all encouraged by this policy. The draught revised National Water Policy, 2020, which emphasises the necessity of recycling and reuse, focuses on minimizing water pollution.

"National Faecal Sludge and Septage Management Policy, 2017" focuses on attaining integrated urban sanitation, safe faecal waste disposal, and strict environmental discharge regulations. It also specifies these goals and encourages an acceptable, affordable, and progressive method to reach these standards.

"The Model Bill for Regulation of Groundwater Development 2016" based on this model bill, many State Governments established the Ground Water Development

Act, which regulates groundwater in both urban and rural regions. These Acts establish regulations for the use of chemical fertilisers and pesticides, as well as for the burial, injection, and disposal of waste and industrial effluent and the protection of groundwater quality.

"The Prohibition of Employment as Manual Scavengers and their Rehabilitation Act" restrict the cleaning of a septic tank and sewage cleaning, aims to eradicate unhygienic latrines manually, and seeks to rehabilitate recognised manual scavengers with alternative jobs.

"The Coastal Regulation Zone Notification" intends to preserve the way of life for households who depend on fishing, save the ecosystem of coastal areas, and spur economic activity there. Additionally, this tries to lessen garbage disposal in coastal areas.

"The National Water Mission" encourages the reuse of sewage to meet metropolitan areas' water demands. According to the Ministry of Power's Tariff Policy, 2016, thermal power stations must use treated municipal waste if they are within 50 kilometres of a sewage treatment facility for an urban local authority. According to the Ministry of Housing and Urban Affairs (MoHUA) Service Level Benchmarks, 20% of sewage in urban areas must be recycled or reused.

"The National Water Quality Monitoring Programme of India" provides central and state governments with advice on the prevention, control, and elimination of water pollution through its network of SPCBs, and it establishes standards for the water quality of streams and wells. The National Building Code's 2016 Guidelines place a strong emphasis on the reuse of treated sewage and sullage in commercial or residential multi-story complexes for horticulture, flushing toilets, and firefighting. Additionally, it advises using separate distribution pipes and storage tanks.

"The National Guidelines on Zero Liquid Discharge developed by CPCB" for industrial sectors highlights the zero effluent discharge. In order to prevent any risk of groundwater contamination, the CGWB plan for Artificially Recharging Groundwater in India, 2013, emphasises careful monitoring of the treated urban wastewater. The Krishi Sinchayi Yojana of the Prime Minister places a strong emphasis on determining whether it is possible to salvage treated municipal wastewater for peri-urban agriculture.

Accordingly, necessary recommendations are made in the framework. The vision stated 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).

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

The legislative authority on water resources was granted to the state government under Article 246 of the Indian Constitution (water supply and treatment, wastewater treatment, water storage and water power, irrigation and canal management). As a result, the states are given the constitutional power to plan, carry out, oversee, and maintain projects related to water supply and sanitation, as well as to recover costs. The law grants local authorities, such as the municipal corporation, municipality, and notified area committee for city, town, or specialised state/regional agencies, local control at the local level. A flow chart of the organisation is shown in Fig. 3.2.1.

The Public Health Engineering Department (PHED) is the primary organization in charge of planning and implementing programs for water supply and sanitation at the State level. In a number of states, the functions of PHEDs have been taken over by Legislative Water

Supply and Sanitation Boards (WSSBs). Increased accountability and the introduction of the concept of commercializing management in the water supply and sanitation sector were the key drivers for the creation of WSSBs. The Ministry of Housing and Urban Affairs develops sector policy guidelines for urban water supply and sanitation (MoHUA). It provides the required technical direction to local bodies and states. The Central Public Health and Environmental Engineering Organization (CPHEEO) assists the MoHUA in developing policies and offers technical guidance, recommendations, reviews and evaluations of programs, and promotion of cutting-edge water supply and sanitation technologies, including municipal solid waste management. In addition, State Water Supply and Drainage Boards (SWSDBs) were set up at the state level to help ULBs organize, build, and set up the infrastructure required for sewage collection and wastewater treatment. SWSDBs are financed by the federal and state governments. They may construct wastewater plants and then turn them over to ULBs for Operation and Maintenance (O&M)

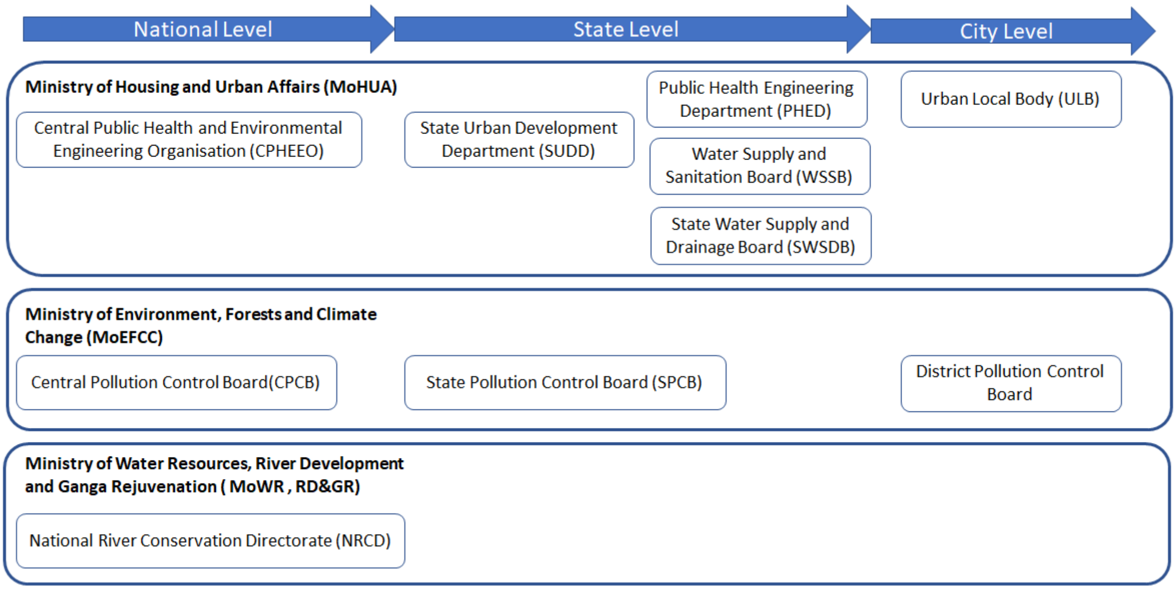


Figure 3.2.1: Government agencies responsible for urban wastewater management in India

Planning, promoting, and coordinating environmental policies and activities across the nation to reduce environmental pollution are the responsibilities of the Ministry of Environment, Forest and Climate Change (MoEFCC) and its lead agencies. They are in charge of establishing environmental standards, majorly for the discharge standards for treated wastewater from treatment plants.

In accordance with the Water Act, the Central Pollution Control Board (CPCB), a lead agency of the MoEFCC, was created in 1974 with the purpose of preventing, controlling, and minimising environmental pollution as well as establishing national standards for wastewater discharge. All sewage treatment plants (STPs) in India must adhere to the standards established by the CPCB.

The National River Conservation Directorate (NRCD) of the Ministry of Jal Shakti and Ganga Rejuvenation is implementing two centrally sponsored schemes to protect the nation's rivers, wetlands and lakes–the "National River Conservation Plan (NRCP)" and "National Plan for Conservation of Aquatic Ecosystems (NPCA)" (MoWR, RD&GR). The NRCD has implemented the following pollution reduction measures; construction of efficient sanitation facilities to control open defecation along the river side, construction of electric crematoria and improved wood crematoria to reduce the use of wood, and development of riverfront areas. And finally, Interception and laying works of sewerage systems to catch raw sewage flowing into rivers through open drains and divert them for treatment. By channelling money through State programs, the Central Government acts as a middleman in the mobilization of outside support for the water supply and sanitation sectors. Through many Government of India initiatives, some direct financial support to water quantity and sanitation projects in municipal areas was provided.

3.2.1 Initiatives of the Government of India

"Water (Prevention and Control of Pollution) Act of 1974 (amended 1988)": The Central and State Pollution Control Boards (CPCB and SPCBs) were established as a result of this Act to provide guidance, oversee compliance with, and enforce laws governing the treatment and disposal of sewage and industrial effluent. The CPCB criteria should be followed by all STPs in India. (https://cpcb.nic.in/wqstandards/).

"Environment (Protection) Act of 1986": The STPs' discharge and standards development were governed by this Act. It establishes limits for the discharge of different pollutants into specific environmental zones (surface water bodies, coastal and sea areas, lands etc.).

"Ganga Action Plan (GAP-I 1985, GAP-II 1993) and National River Conservation Plan": Maintenance of the Ganges and its two main tributaries, the Yamuna and the Gomti, was started under GAP-I and GAP-II. As part of the 1995 National River Conservation Plan, it was extended to include other rivers. 1098.31 MLD of sewage treatment capacity was produced under GAP (Dutta, 2020). The actions adopted to reduce pollution include increasing public engagement, knowledge, and capability, intercepting and diverting sewerage lines for treatment, establishing STPs, and creating affordable restrooms, constructing a riverside.

"National Plan for Conservation of Aquatic Ecosystems (NPCA) (2015)": With the following goals: developing policy guidelines such as promoting and supporting the conservation of wetlands and facilitating the development of a public inventory. And, Strengthening the capacity of wetlands administrators and stakeholders, the NPCA seeks to provide a framework for the conservation and sustainable management of wetlands.

"National Urban Sanitation Policy (2008)": This programme gave local governments control over behaviour modification, complete sanitation, and completely safe garbage disposal. It envisions cities implementing long-term plans concurrently with short-term plans, prioritising regions, and executing city sanitation programmes, with a focus on involving all city stakeholders. The creation of state urban sanitation policies that enable cities to create their own sanitation plans is the responsibility of the state governments.

Other essential flagship national programs launched by the Government of India: In 2015, the "Namami Gange" programme began. For the construction and renovation of 5501 MLD sewage treatment capacity as well as the installation of 5,134 km of sewerage network, the government has approved 161 sewage management projects totalling 245.81 billion INR under the Namami Gange Program. A total of 92 of these projects have been finished, adding and renovating 1,643 MLD of STP capacity and installing 4,156 km of sewer network (PIB, 2022). Additionally, it includes sectoral initiatives like the "Smart City project 2017-2023" and the "AMRUT Mission 2015-2023" that aim to enhance both sewered and unsewered sanitation.

3.3 Current technologies and practices in UWM

There are two ways to perform UWM in India: on-site systems and off-site systems. An on-site system collects wastewater near the toilet in a pit or tank, and the sludge that is created is periodically hauled away to be treated with faeces. In comparison, a system off-site takes wastewater from the area around the toilet for disposal somewhere else. A sewage network is part of an off-site system that transports sewage to a sewage treatment plant (STP). The cleansed wastewater is then disposed of, with the solids going to drying beds and the liquid going to waterbodies. Different uses of this treated wastewater include (a) irrigation, (b) toilet flushing, (c) industrial use, (d) fish farming, and (e) accidental and indirect uses (CPHEEO, 2012). Fig. 3.3.1 shows the procedures for off-site and on-site systems for storage, transfer, and treatment. The next sections provide a detailed explanation of these two systems.

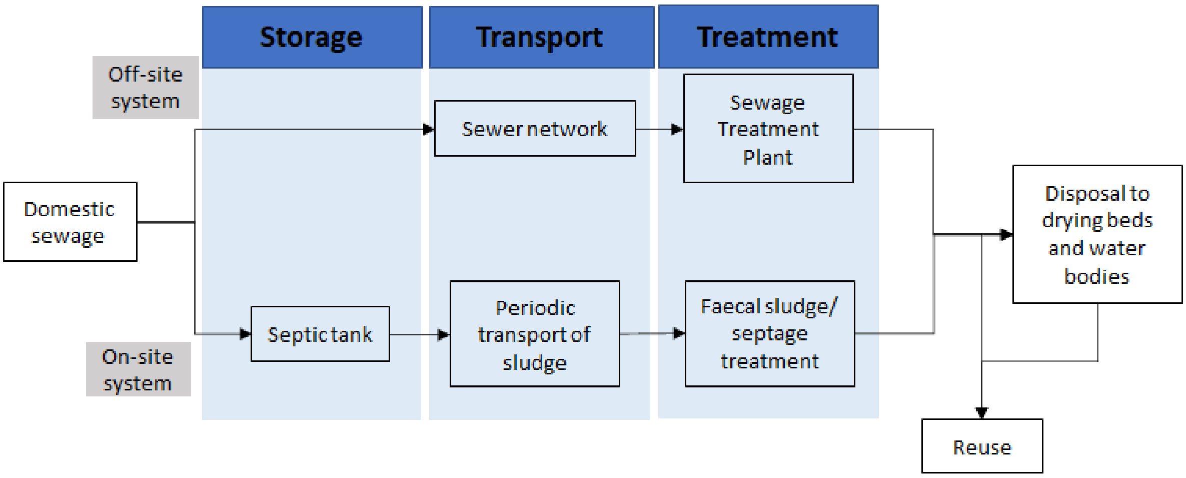


Figure 3.3.1 : Storage, transport, and treatment mechanism of an off-site and on-site wastewater treatment system

3.3.1 Off-site system

Sewage collection system: There are two types of systems: (i) Separate systems that collect sewage and stormwater in separate drains, and (ii) Combined techniques that collect both stormwater and domestic sewage in a single drain. In India, the vast majority of sewer networks are built for specific systems, which is favourable from a technical and cost perspective. But older sewerage systems created during the British occupation feature a mixed system, like in Kolkata (Murmu et al. 2021).

Sewage treatment facilities: Residential sewage is transported to STPs in India using an off-site treatment system. The STPs are built using input characteristics such as Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), and faecal coliform (FC). As of 2020–21, 1,469 STPs (as of 28 states and union territories in India) have been installed in metropolitan areas, with a total installed capacity of 31,841 MLD. The number of STPs has nearly doubled since the CPCB's 2014 evaluation, and the capacity will increase by 41% by 2020. (Table 3.3.1). Of the 1,469 STPs, 274 STPS are being built, while 102 STPs are not in use. There are also 162 other STPs with a 4,827 MD capacity projected. Therefore, the overall treatment capacity at this time 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

S.No.	STP Status	2014		2020	
		Number of STPs	Capacity (MLD)	Number of STPs	Capacity (MLD)
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 steps Primary treatment, Secondary treatment and Tertiary or advanced treatment, as depicted in Fig. 3.3.2.

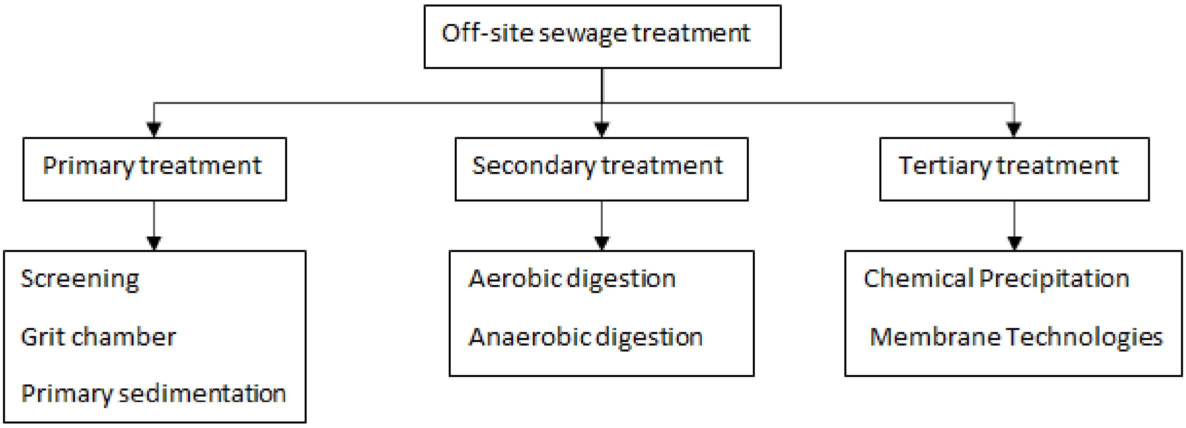


Figure 3.3.2 : Primary, secondary, and tertiary treatment methods of an off-site wastewater treatment system

i. Prior filtering, used in primary treatment, eliminates physical and chemical contaminants like suspended solids. Some organic nitrogen, phosphorus, and heavy metals are also removed during this process. It does, however, only partially remove microbial infections. The first stage of primary treatment, screening, separates solid waste from wastewater, such as kitchen waste and shreds of cloth, hair, paper, wood, and cork. The apertures in the screening element can have any shape, and they can be made of parallel bars, rods, or wire mesh. It is advised to offer screens in three phases, with coarse screens coming first, then medium screens, and finally, fine screens. After that, sewage is sent to the grit chamber, where grit is removed to guard against abrasion and damage to the working mechanical parts and pump components. Primary sedimentation is carried out in a sedimentation tank, also known as a settling tank or a clarifier, after the grit chamber. Sedimentation is used to get rid of inorganic suspended materials, organic and residual inorganic solids, chemical flocs, and various floating debris created during chemical coagulation and flocculation processes. If sedimentation is insufficient, certain chemicals might cause the settlement of suspended materials.

   The wastewater flow through the primary treatment unit is seen in Fig. 3.3.3.

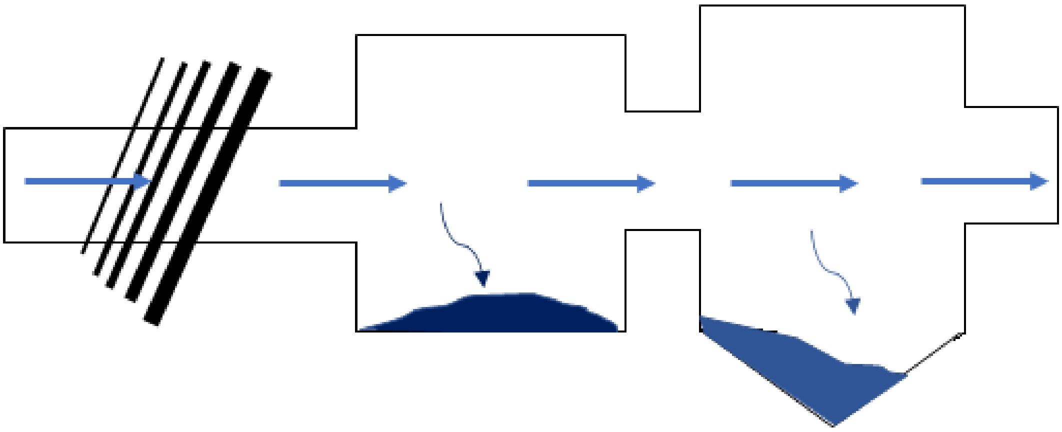


Figure 3.3.3 :Wastewater flow through different units involved in primary treatment

ii. Biological digestion is used as a secondary kind of treatment to get rid of organic matter, which can reduce BOD by up to 85%. Aerobic or anaerobic secondary care is also possible. In the presence of dissolved oxygen, the aerobic or facultative bacteria in wastewater execute aerobic decomposition, which leads to a reduction in or elimination of dissolved and suspended organics, nitrates, phosphates, BOD, COD, and other chemicals. However, it produces a significant volume of biosolids as waste, which calls for pricey management and treatment techniques. Anaerobic and facultative bacteria perform anaerobic decomposition in the absence of dissolved oxygen or air. Longer retention times in this procedure can improve outcomes by nitrifying and denitrifying contaminants that are organic in nature (Hasan et al., 2019). Fig. 3.3.4 shows the configuration of the primary and secondary treatment units for wastewater treatment. For secondary treatment reasons, a variety of treatment technologies, from conventional to advanced to natural, are used in India. Table provides the technological distribution with respect to the quantity and capacity of the installed STP (3.3.2). SBR (30%) and ASP (20%) are the two technologies that ULBs primarily use.

Table 3.3.2: Technological distribution with respect to the number and the capacity of 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)			

iii. The elimination of elements that secondary treatment is unable to handle is known as tertiary treatment. Membrane technology and chemical precipitation are included. Chemical precipitation is necessary to remove heavy metals, phosphorus, and salt from treated sewage in order to prevent eutrophication. As an alternative to removing hardness, membrane technologies produce a reject solution that must either be disposed of in the ocean or evaporated using heat. Additionally, they need a thorough pre-treatment to get rid of suspended particles. When the coliforms may impair the receiving water quality, treated sewage undergoes disinfection after tertiary treatment. The most used method of sewage treatment disinfection is chlorination. Chlorination of such effluents poses no risks because the secondary aerobic biological treatment has only recently been applied to the treated sewage. Before chlorination, an aerobic polishing treatment must be provided for effluents from anaerobic processes like UASB.

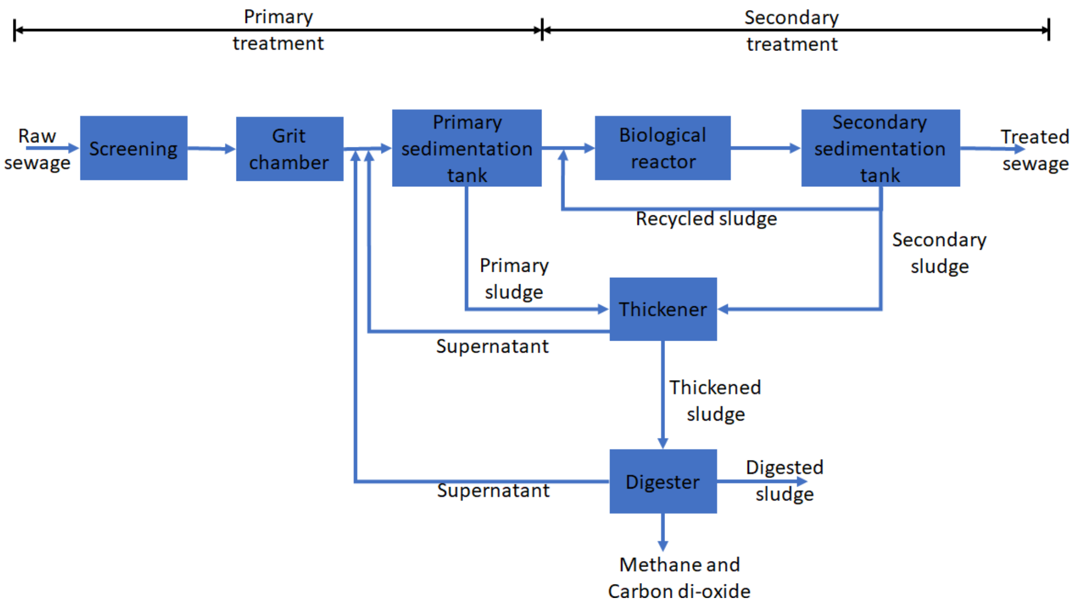


Figure 3.3.4: Sewage flow through the primary and secondary treatment units of an STP (Source: CPCB, 2013)

Sludge management: The terms "sludge" and "secondary sludge" refer to primary and secondary clarifiers, respectively. In a Sewage Treatment Plant (STP), suspended solids from raw sewage and sewage that have been aerated in aeration tanks settle to separate microorganisms by gravity. By sending a considerable amount of the secondary sludge there, return sludge is used to seed the microorganisms in the aeration tank. Extra sludge and a tiny amount of secondary sludge are lost. Chemical sludge is created when secondary treated or untreated sewage is subjected to chemical precipitation. Sludge thickeners are used to concentrate the organics and microorganisms that have settled out during primary, secondary, or both settling processes. After then, a device is referred to as an anaerobic digester if the thicker sludge is subjected to anaerobic digestion to produce methane. An aerobic digester is one that can oxidize food. The digested sludge will need to be dewatered in both situations. For this, a variety of tools are available, including centrifuges, filter presses, and natural solar drying beds

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, also known as non-sewered sanitation, handle sewage on the property where it is generated. The most often used on-site sewage treatment method in India is the conventional septic tank, which also has soaking options, including soak pits and dispersion trenches. A septic tank is a subterranean chamber used to store and partially treat home sewage under anaerobic conditions. Effluent from the septic tank should be released to a soak pit or drain field on-site infiltration system, as indicated in Fig. 3.3.5 below. Solids settle and decompose anaerobically in the septic tank, which lowers the volume of sludge and allows overflow wastewater to percolate into the soil in the soak pit without blocking the leaching system. Due to space restrictions and general ignorance, many locations really lack a soaking arrangement. As a result, they directly pour infectious wastewater into open sewers, endangering everyone's health.

Two chambers are incorporated into the typical septic tank design. In India, some septic tank designs use three chambers. The first chamber is where the majority of the treatment happens. The biological load in sewage could be reduced by 50–60% with a well-maintained septic tank. Furthermore, a properly constructed soak pit can eliminate bacterial loads up to the standards for disposal. Soak pits are easy to build and don't require any media when they are lined with bricks or rubble. The pits may have any regular shape, but square or circular ones are most typical.

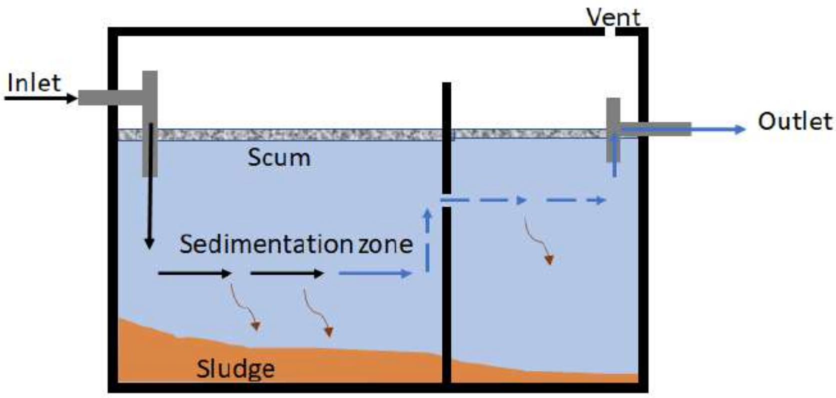


Figure 3.3.5: Septic tank showing three distinct layers (scum (oil, fats, and grease), clarified water, and sludge

All on-site sewage treatment procedures generate faecal sludge or septage, which must be safely collected, transported, treated, and either reused or disposed of. In the Indian context, where over 60% of households use on-site sanitation amenities, in that way Faecal Sludge and Septage Management (FSSM) gains relevance. Double leach pits and septic tanks make up the majority of the on-site sewage disposal systems in metropolitan India. According to a study conducted by the Centre for Science and Environment 2019 in a few places in Uttar Pradesh, the majority of containment systems (about 80%) frequently lack connections to working soak pits. There is no difference in the scenario in other cities around the nation. However, governments and cities are working to scale up innovative and inclusive urban sanitation service delivery, taking inspiration from the National FSSM Policy introduced in 2017. In the three states of Maharashtra, Odisha, and Tamil Nadu, managing faecal sludge has become of utmost importance. In the aforementioned states, about 500 faecal sludge treatment facilities have already received approval; these facilities will serve more than 600 cities and villages. However, there is room for improvement and support from the government, so long as it takes into account future demands and strategies for turning waste into money that has been effectively employed in industrialized countries.

3.3.3 Reuse of sewage

There is a need to recognise sewage as a resource that can be treated as needed and used for non-potable applications and industrial utilities due to the rising load of untreated sewage. Diverse ULBs in India have recently prioritised the reuse of treated sewage and started using it for industrial washing, horticultural irrigation, non-contact impoundments, and other purposes. The wastewater reuse examples of India include:

i. The Punjab government announced the State Treated Wastewater Policy 2017 to promote the recycling and reuse of treated sewage for non-potable uses. The Department of Soil and Water Conservation has finished 47 projects so far using STP-treated wastewater totalling 243.3 MLD. These operations were carried out by installing an underground irrigation water conveyance pipeline system that covered 7652 hectares (DECC, 2020).

ii. The Indian Agricultural Research Institute, Karnal, examined sewage farming which led to the recommendation of an irrigation method for sewage-fed tree plantings.

iii. According to the Karnataka government, all necessary steps must be taken to ensure that only tertiary-level processed sewage is used for non-potable purposes, e.g., gardening, including parks, resorts, and golf courses.

iv. In large condominiums and high-rise apartment buildings in major cities like Delhi, Mumbai, Bengaluru, and Chennai, treated grey water is being used on a trial scale for toilet flushing. Since 1991, numerous large businesses have purchased and treated secondary sewage for use in cooling water makeup, including Madras Refineries, Madras Fertilizers, Rashtriya Chemicals and Fertilizers in Maharashtra, and most recently, 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 systems 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 as well as maintenance of urban 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 water bodies in its proximity (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 a major 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 stations are located not in cities or in the proximity of the pollution hotspots) fail to give the real picture of the level of water pollution in the country (Kumar & Tortajada, 2020). Class II towns and stagnant water bodies in the states are not included in monitoring networks (CPCB, 2020). Both centres 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.

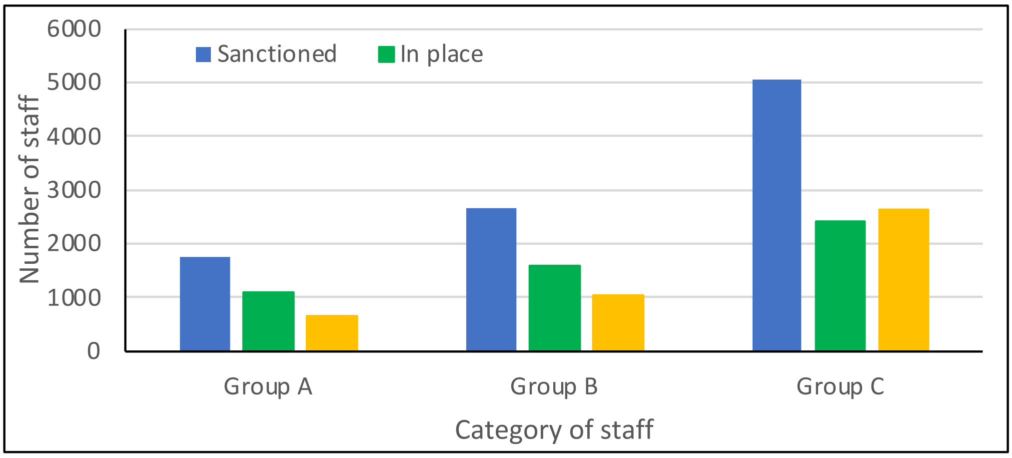


Figure 3.4.1. Human power availability in SPCBs based on category (CPCB, 2020)

Many urban areas with STPs in place suffer from underutilization because of a lack of proper sewerage networks and weak operation and maintenance of the existing plants. As a result, in those areas, wastewater will be fed to neighbouring water bodies such as tanks, ponds, 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 the 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 ten 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 recipient water body is not regulated. Also, ambient water quality standards are absent 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 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.

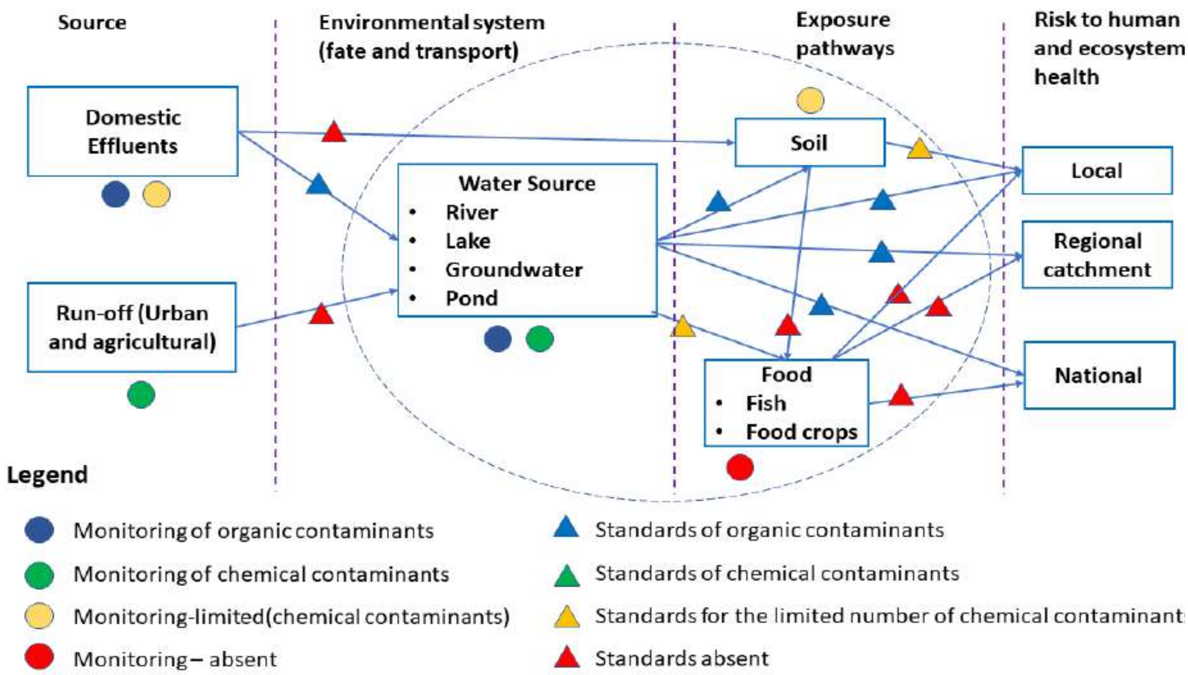


Figure 3.4.2. Framework showing gaps in the water quality monitoring framework in India (Adapted from Lele et al., 2021)

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 since there is no legal requirement to reduce pollution levels. 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 (which means 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).

Economic viability is the crucial factor hindering the performance of urban 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 exists a trade-off between the environmental performance of the system and its 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 concentration of pollutants 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 into 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/minimal 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 a 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 wastewater processing technologies further impede its development. It is very difficult to avail land in most of the urban landscape 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 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 conventional WWTPs poses 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 takes place, choice of technology is vital. Centralized systems with large upfront costs set limitations on the choice of technology. On such occasions, decentralized systems offer arenas for phased investments and 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 concerns are deeply entrenched within individual citizens 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 the social acceptance of wastewater reuse (Salgot & Folch, 2018). The 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, schemes related to the reuse of treated water 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 get affected by economic damage due to the depreciation of the value of land(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 since people do not trust the waste management services provided by the urban local bodies(ULBs) (CPCB, 2019). CPCB has introduced buffer zones around waste management facilities to protect people from the impacts of pollution/ odour/noise and to ensure the 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 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 increase 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 from issues related to monitoring as well as defining and enforcing proper standards with fewer 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 a 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, whereas decentralized systems help them by cost reductions, provided proper demand needs are in place. Also, decentralized systems offer arenas for phased investments and 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 a lack of social acceptance related to the reuse of treated water. On such occasions, participatory approaches with the inclusion of local people provide the key to improving the delivery of services. For instance, in a decentralized system with fewer institutional overlaps, stakeholder participation can help in the easy setting up of plants (in addition to fewer upfront costs), better monitoring of water quality (thereby overcoming the staff shortages), and thus improving the 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

Fast-paced urbanisation, poor wastewater management, and inadequate wastewater disposal all contribute to a worsened situation in the management of wastewater in many developing countries (Chirisa et al., 2017). As a result, sanitation solutions based on centralised systems are impractical in many parts of the world. Centralized systems use massive pipelines, pumping systems, many access routes, equipment, and treatment facilities to collect and treat enormous quantities of wastewater for whole towns and industrial/residential platforms at a single treatment facility. While decentralised systems independently collect, treat, and reuse the treated wastewater on-site at, or close to, the producing source, and they also offer management flexibility (Sharma et al., 2013). From an ecological and financial point of view, treating wastewater as near to the source as feasible is advantageous and avoids the need to build large and sometimes pricey sewage lines. In areas without sanitation services, the use of decentralised wastewater treatment systems (DEWATS)) has gained popularity. A decentralised approach can be taken up at any scale ranging from totally decentralised individual on-site systems to semi-centralized facilities handling the effluents of far neighbourhoods (Iribarnegaray et al., 2018).

DEWATS is categorized as (i) Natural treatment systems, (ii) Aerobic systems, and (iii) Anaerobic systems. Natural wastewater treatment systems, as part of nature-based systems (NBS), are cost-effective methods for the treatment of wastewater. The most basic method is algal-bacterial interactions in a pond which receives the wastewater. Other common systems use plants and soil as natural filters and catalysts for biological processes. These methods can be employed as a secondary treatment or in conjunction with primary treatment. Some methods have also been employed at the tertiary level of treatment which includes – constructed wetlands, floating wetlands using duckweeds or water hyacinths, facultative ponds etc. These technologies are explained further in Section 4.2.

In aerobic treatment procedures, microorganisms use oxygen to break down organic materials into water and carbon dioxide. In aerobic treatment, microorganisms use oxygen to break down organic materials into water and carbon dioxide. Compared to NBS, aerobic treatment procedures have a lower environmental impact and readily produce effluents of high quality that fulfil the regulations for effluent disposal but consume more energy. Additionally, for O&M, these systems require only semi-skilled human power, which makes them an excellent option for wastewater treatment technology in developing and underdeveloped nations. Oxidation ditches, extended aeration processes, membrane bioreactors, sequential bioreactors, and moving bed biofilm reactors are some of the most commonly used aerobic systems.

Anaerobic treatment systems are economical, simple, low-energy biological treatment systems that may be utilized to generate energy. Compared to aerobic systems, anaerobic systems have a longer start-up time, usually up to 4 months, while aerobic systems have a considerably faster start-up of up to 4 weeks. Also, anaerobic systems produce low effluent quality and are not able to meet the standard discharge requirements; therefore, the process is often combined with aerobic or natural processes. Septic tanks, anaerobic baffled reactors and upflow anaerobic systems are some commonly used systems.

Case studies:

i. In India, Bremen Overseas Research and Development Association (BORDA) installed 77 DEWATS till 2017. A settler is the first component of the common treatment module, followed by an anaerobic baffled reactor (ABR) and an anaerobic filter (AF). In a DEWATS plant with a treatment capacity of 35m3/day installed by BORDA in Pune, the wastewater from various sources is collected in decentralized septic tanks. As illustrated in Fig. 4.1.1, the effluent from all septic tanks is collected in a single collecting tank near the treatment system, which comprises a settler, baffled reactor, anaerobic filter, planted gravel filter, and collection tank. 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).

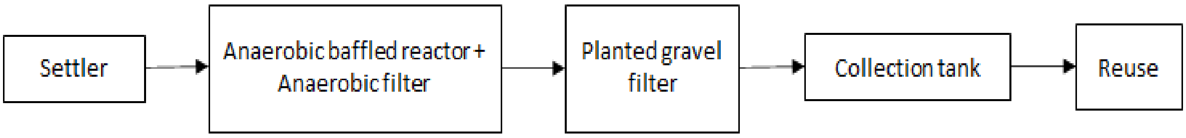


Figure 4.1.1 : Schematic representation of the DEWATS plant of Pune

ii. Soil Biotechnology is a terrestrial wastewater treatment technique based on the trickling filter principle. To remove the suspended particles, organic and inorganic pollutants in the wastewater, this system employs a combination of physical processes such as sedimentation, infiltration, and biochemical processes

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. The water is then pumped into the raw water tank. This tank is separated into three sections. The initial section of the tank has a honeycomb-like screen to filter out solid waste. The second section of the tank has tube settlers placed to aid in additional water treatment, and the tank's final storage takes water from the last two chambers. The water is then pumped to Bioreactor I and distributed to the plants through sprinklers. By the time the water exits Bioreactor I, approximately 60% of the treatment has been finished. The bioreactor is composed of many layers of brickbats, aggregates, and cultural catalysts. Under the effect of gravity, water percolates through the bioreactor and collects in Collection tank I. The water is then delivered to Bioreactor II through a motor. Bioreactor II is identical to Bioreactor I and is designed to allow for an additional filtering cycle. The water percolates from Bioreactor II into Collection Tank II. Fig. 4.1.2 and 4.1.3 show the soil biotechnology setup and site design at Gole Market in New Delhi. This unit's design capacity is 200 m3/day. It has a capital cost of Rs. 2 million and an annual O&M cost of Rs. 0.2 million (CSE, 2017).'

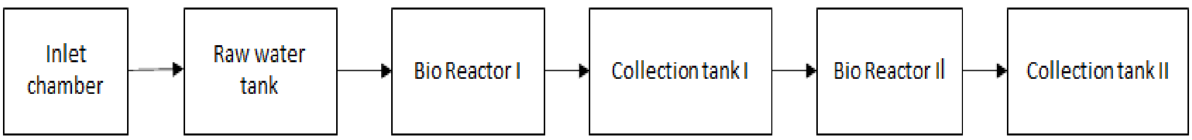


Figure 4.1.2 : Schematic representation of the soil biotechnology unit of Gole Market, New Delhi

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 precisely, NBS are approaches that replicate natural processes in urban settings and removes contaminants from wastewater using plants, soil, bacteria, and other natural materials and processes. These approaches lower chemical use, save energy and offer a cost-effective, efficient, low-impact, simple and sustainable solution for wastewater treatment. Developing countries can benefit from using these solutions under the decentralised wastewater treatment approach in areas with limited, low capacity or no access to the public sewage system or in water-scarce regions.

Different NBSs have been deployed over the last three decades, which include constructed wetlands, floating wetlands, green roofs, living walls, waste stabilisation 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 created systems that are planned and built to use natural processes to remove contaminants from polluted water in a more controlled environment (Ingrao et al., 2020).

The CW system comprises water, plants, growing media (substrate), soils, and microorganisms and utilises complex processes to decontaminate wastewater. The wetland plants are herbaceous plants with fast growth, high biomass and strong absorptive abilities and are categorised as emergent, submerged, and floating macrophytes based on their ability to adapt to life in water. Usually, CWs are planted with rooted emergent macrophyte species. The most commonly used plant species are cattails, bulrushes, reeds, sedges and many broad-leaved species. Based on the water flow characteristics, CWs are categorised as free water surface (FWS) and subsurface flow (SSF). In an FWS, water gently flows above the substrate media, providing a free water surface and a few centimetres of water column depth. On the other hand, water flows inside a porous substrate in SSF systems. SSFs are further classified into horizontal and vertical flow systems based on the flow direction.

The constructed wetland involves physical, chemical and biological processes for pollution removal, and this has been described in Fig. 4.2.2 and Table 4.2.1

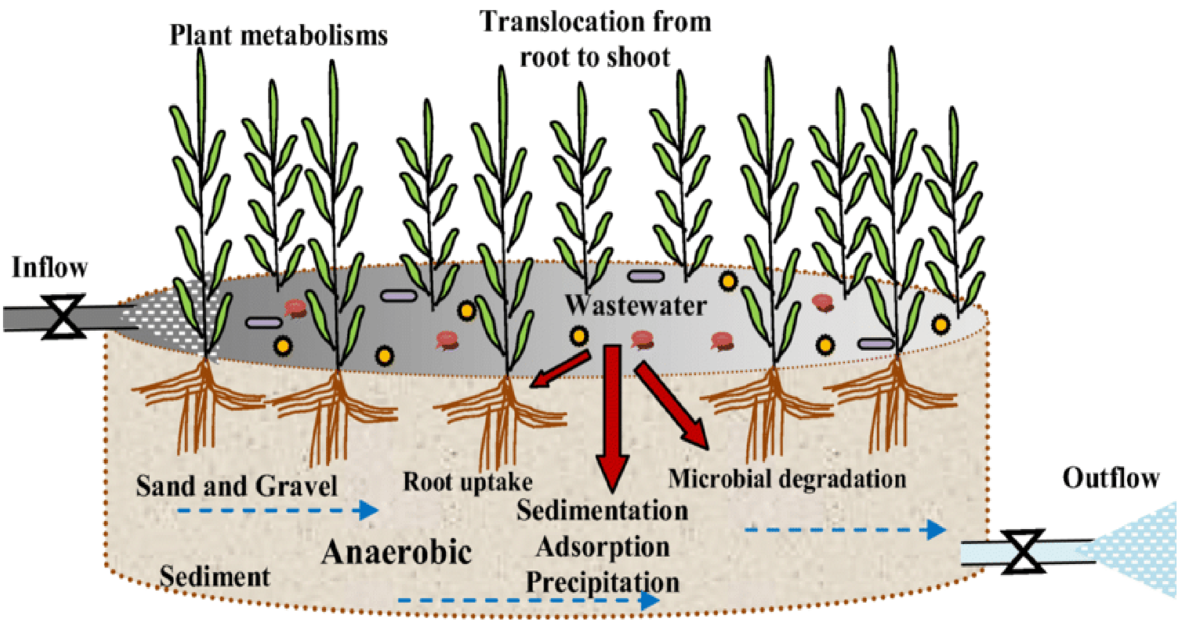


Figure 4.2.2: Pollution removal mechanism for constructed wetlands

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).

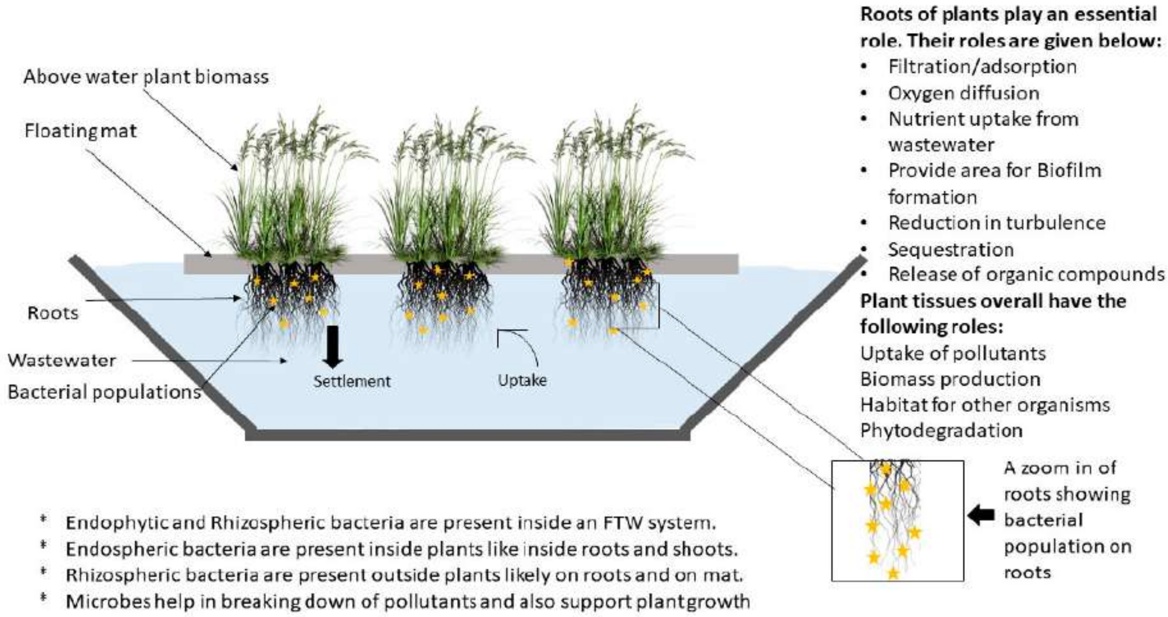


Figure 4.2.3: Schematic diagram of floating treatment wetland (Source: Wei et al., 2020)

The most commonly used floating macrophytes in the FTW are duckweed and water hyacinth for efficient contaminant removal. Despite being an invasive plant, water hyacinth is a valuable resource for wastewater management. It spreads and grows quite quickly. Under ideal conditions, it can reproduce in 5-15 days. Water hyacinth roots actively assist in wastewater treatment, where the uptake of pollutants occurs. 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 their 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 maximise the formation of a biofilm. A combination of aerobic, anaerobic, and anoxic conditions occurs beneath the plants. The plant roots contribute to achieving increased DO levels, while plants and biofilm contribute to nutrient and heavy metal uptake, resulting in lower BOD and COD levels.

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

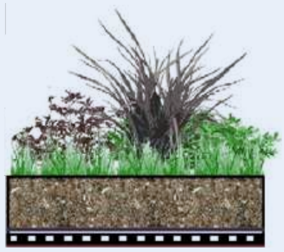
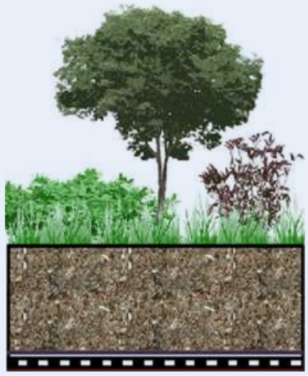
Figure 4.2.4: Floating treatment wetland at Neknampur Lake, Hyderabad

4.2.3 Green roofs and living walls

Green roofs and Living walls represent "effective systems for urban reconciliation ecology" (Francis & Lorimer, 2011) and have become integrated features 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, and 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 categorised 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. Since the surface area of a building's walls is always more than the area of the roof, and in high-rise buildings, this can be up to 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.

For Living walls, there is a supporting framework, and different types of plant attachment techniques are available (Fig. 4.2.5a). Growing media for living walls can be either soil-based or hydroponic. A waterproof membrane separates the living wall from the building wall, preventing moisture concerns. Because the system is vertical, the water storage capacity is limited, and the only way for the plants to get water is through the growth media. An irrigation system, often situated at the structure's top, is critical for such systems, assuring the growing media's constant wetness for plant development. In general, the plants used for green walls should be chosen with the site location, climatic circumstances, and design goal in mind. Climbers are the most widely utilised plants for living walls. Climbers can be self-supporting (e.g., root climbers and sticky suckers) or supported by a structure that they can grip (e.g., twinning climbers/creepers or scrambling plants).

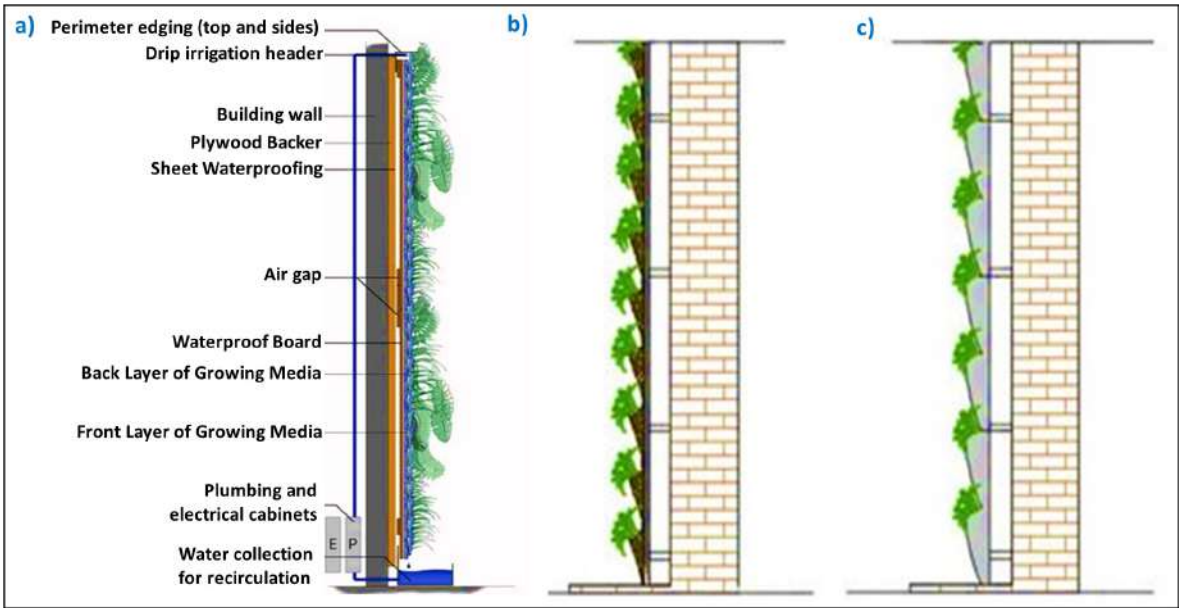


Figure 4.2.5 : Living walls structure and type a) Schematic representation of a living wall b) continuous living wall c) modular living wall

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

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 such as trays, planter tiles vessels, flexible bags or panels, carrying substrate inserted into a supporting structure, one above the other (Fig. 4.2.5c). The growth medium is made up of a light substrate mixed with granular material to provide a high water retention capacity. As per the supporting structure, 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 stabilisation ponds (WSPs) are impoundments into which wastewater flows in and out after a predetermined retention period. WSPs are better suited to tropical and subtropical areas since sunshine, and ambient temperatures play an important role in their process performance. Treatment is primarily based on the natural biological purification processes that occur in every natural water body. Their operation requires no other energy other than that received from sunlight. Compared to other technologies, WSPs appear simple; however, they contain a complex ecological system of microorganisms, insects, and often chordate animals. Treatment is optimised by selecting appropriate pond depths, retention time and organic loadings to aid in the maximum growth of organisms crucial 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.

- Anaerobic pond – removes TSS and some soluble organic matter
- Facultative pond–eliminates residual organic matter by algae and heterotrophic bacteria activity
- Maturation pond – removes pathogens and nutrients

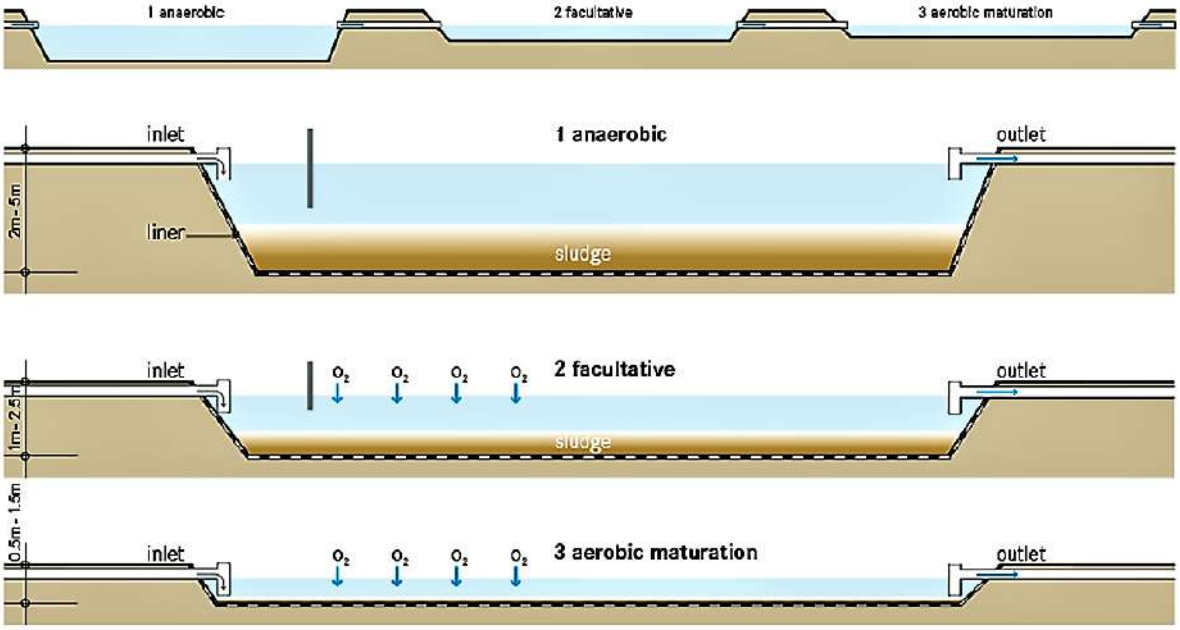
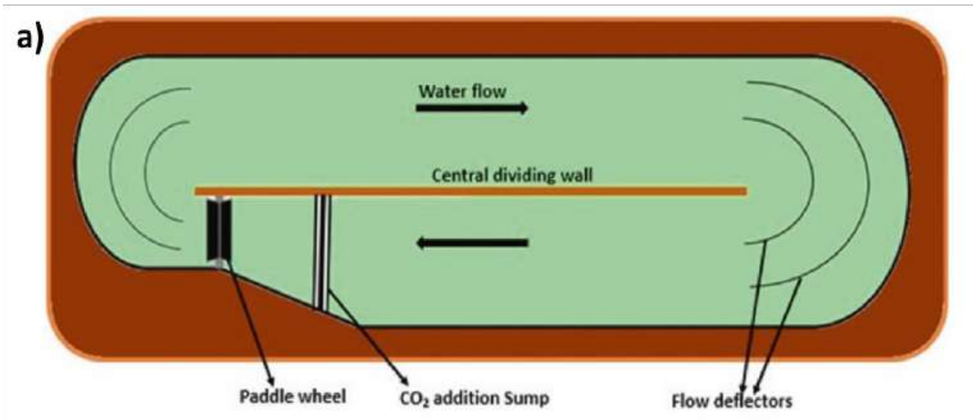


Figure 4.2.7 : Schematic diagram of a waste stabilization system (Source: Tilley et al., 2014)

4.2.5 High-rate algal ponds

High-rate algal ponds (HRAP) are shallow, paddlewheel-mixed open raceway ponds that employ algae species to treat wastewater (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 the settling of the sludge in the bottom and promote algal circulation culture (Craggs et al., 2014). The HRAP performance is based on a symbiotic interaction between bacteria and microalgae in which algae photosynthesis provides the oxygen necessary for bacterial organic matter decomposition, and bacterial organic matter decomposition provides the food for algal growth. The algal biomass generated during the process may be used for producing biofuels.



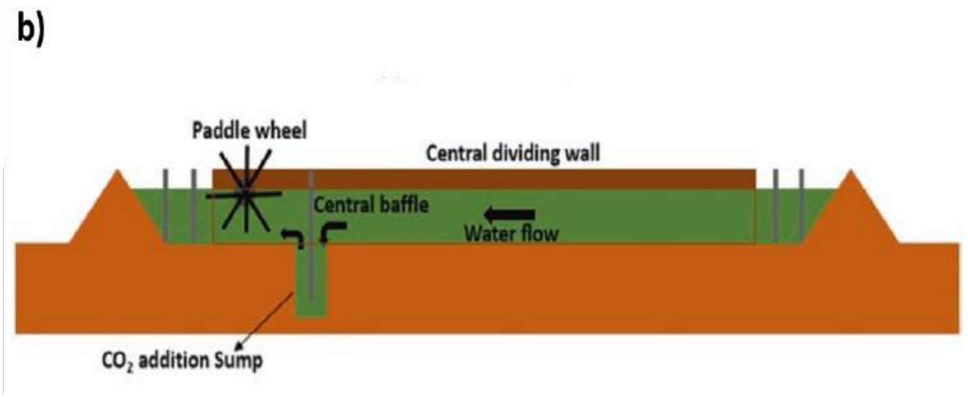


Figure 4.2.8: Schematic diagram of high rate algal ponds a) Paddle wheel in HRAP b) Side elevation view of HRAP (Source: Ranjan et al., 2019)

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 is a novel method that uses the combined activity of earthworms and microbes to treat wastewater. Vermibed and earthworms are the two main components of the vermifiltration system (Fig. 4.2.9). The porous vermibed material aids in the screening of wastewater and the trapping of solids. Vermibed is also a source of food for earthworms which aids in the growth and reproduction of microorganisms owing to earthworm ingestion. 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 utilise fresh human faeces with high moisture conditions and remove hazardous pathogens efficiently.

Through ingestion, biodegradation, and absorption through the body walls, earthworms and microorganisms both remove BOD, COD, TSS, and TDS from wastewater. Earthworms also release sticky fluids from their bodies called 'mucus,' which contain various enzymes that aid in the mineralisation of contaminants found in wastewater. Furthermore, the earthworm activity in the filter bed enhances oxygen penetration, generates favourable circumstances for microorganism aerobic activity, and reduces the production of odour and sludge.

Treatment systems such as vermifilters meet a variety of needs, including simple design and equipment, increased treatment potential, reduced sludge formation, and cheaper operational and capital expenses. Vermifiltration is an odourless process, and the resulting water is of good quality that can be utilised for agricultural irrigation and watering in gardens and parks.

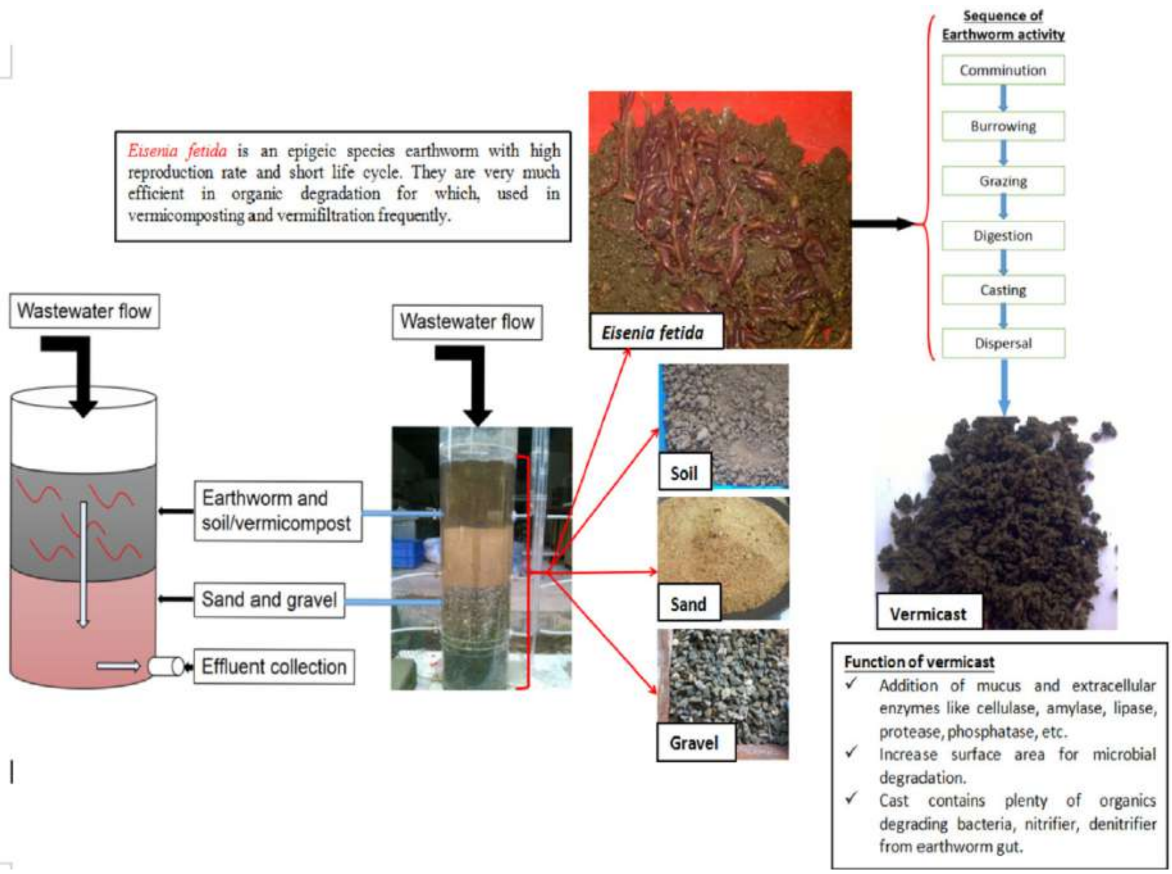


Figure 4.2.9: Schematic diagram of vermifilter (Source: Singh et al., 2019)

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) procedures for an STP entail collecting water samples manually at various sites and are taken to the laboratory for analysis of physical, chemical and biological agents. However, limited spatiotemporal coverage, labour-intensive, high operational cost, and lack of near-real-time water quality information limits to take important decisions with regard human and environmental health (Katsriku et al., 2015, Vijayakumar & Ramya, 2015). Thus, a reliable WQ management system is required to assess the performance of the STP as well as maintain a database for effective decision making. The use of IoTs can help in the monitoring of different processes and equipment in the wastewater treatment facility. IoT-controlled pipe valves can also be used to address flaws in the current sewage treatment systems. By establishing an IoT-based wastewater treatment system, it is possible to obtain real-time control in the entire process chain through pre-set configurations (Su et al., 2020). It may improve crisis reaction time, standardise management, save energy, and increase economic efficiency.

Currently, IoT, coupled with advanced technologies such as cloud computing, artificial intelligence and machine learning algorithms, and service-oriented architecture, has led to the development of smart water quality monitoring systems (SWQMSs) (Dong et al., 2015, Geetha & Gouthami, 2016). Using data collected through crowdsourcing, instruments, sensors, satellites, photographs, videos, news, and other sources under SWQMS offers near-real-time awareness and decision-making (Zhou, 2012)

Solinas, a deep tech start-up, is 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

For many environmental monitoring applications, Wireless Sensor Networks (WSNs) have shown promising results in the field 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. Because of the low cost of the sensor nodes, the usage of WSNs for WQM is preferred as it enables remote, near-real-time monitoring of processes with minimum human interaction. Thus, the use of WSNs to WQM has opened up a new research path toward developing decentralised SWQMSs that can fulfil the water needs of smart cities (König et al., 2015). Many studies have demonstrated the usage of such technology, and discussing one is beneficial

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 is made up of a nitrate and nitrite analyser that uses the ion chromatography detection technique. The analytical device is coupled with an IoT software platform which has been tested under the functioning wastewater plant facility, and a decentralised SWQMS was deployed for wastewater quality monitoring and management. This research is a component of the LIFE EcoSens Aquamonitrix research project that intends to evaluate and improve this technology in order to produce and market a cheaper and fully automated in situ analyser for water quality monitoring. This device is built using a portable ion chromatography system, as done by Murray et al. (2019).

This device uses a novel design of an ultraviolet light-emitting diode-based optical detector to detect nitrite and nitrate in natural waters at a low cost

The SWQMS is operated through five different processes: system initialization, data capture and storage, data modelling, data analysis and visualisation, and data management. The data gathered from the sensors is decoded, pre-processed, and modelled in the EcoSens Aquamonitrix System (Fig. 4.3.1) and further processed to provide analysis and interpret results. The operators of wastewater treatment facilities and government organisations in charge of environmental protection can make decisions with the use of this information.

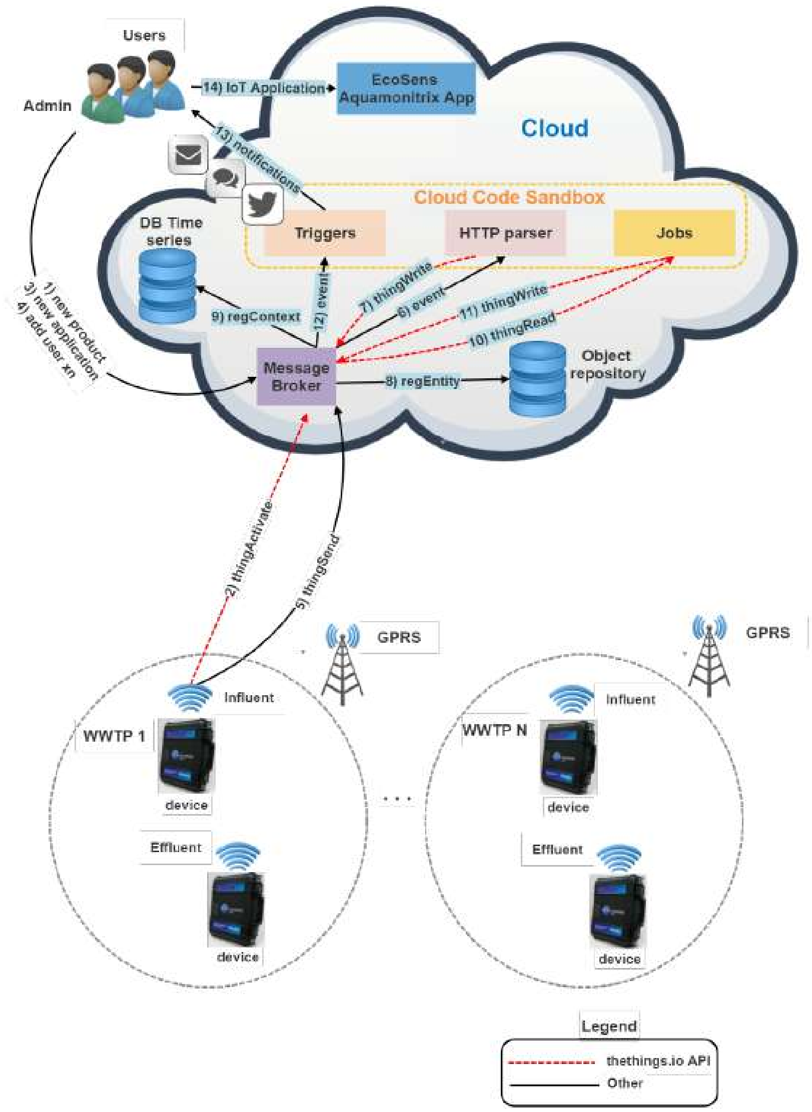


Figure 4.3.1: EcoSens Aquamonitrix Smart Wastewater Quality Monitoring System (Source: Martínez et al., 2020)

The initial test showcased the features and functionalities of the IoT. For this, eight devices (one for influent and one for effluent) have been installed at four WWTPs in the Murcia Region (Spain): Alcantarilla, Los Alcázares, Molina de Segura, and San Pedro del Pinatar. During the test period (i.e., May 2019), the data for nitrate and nitrite concentrations were collected twice a day which provided almost near-real-time monitoring.

The data collected is then analysed, and the results are displayed through the user interface using various customizations. Thus, the results of the experiments proved to be useful in appropriate for monitoring and management. These solutions need scaling up in order to be deployed in smart city distribution networks. This will enable the end-users and the water manager, and technical staff to act more quickly and effectively to deal with pollution problems.

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

GIS-based approach

Problems related to domestic wastewater management are difficult to monitor and manage due to the limited availability of quality observation data. Especially in developing countries like India, observation infrastructure is comparatively weak. In the lack of widespread vital information, the regional scale studies fail to provide dependable results. Remote sensing and GIS-based (RS and GIS) approach to minimize this data gap and support capturing, handling, 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, to highlight the areas of interest (or the areas which may satisfy the relevant criteria). The sizing and performance methods in GIS aid in computing 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 the 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) is a multi-criteria decision-making model that employs weighting criteria and helps to build an evaluation model). It was used to apply weights to each of the criteria used in order to get a better 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 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. Availability of water for irrigation, distance from the wastewater treatment plant, and suitability of agricultural land for crop cultivation are considered as the techno-economic sub-criteria, while the quality of irrigation, crop, water, soil, and aquifer vulnerability is considered as the environmental sub-criteria in the decision-making process. Additionally, the limiting factors of wastewater reuse are considered to be topography, land use, depth of soil, 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 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(SDSS) in various sectors, 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).

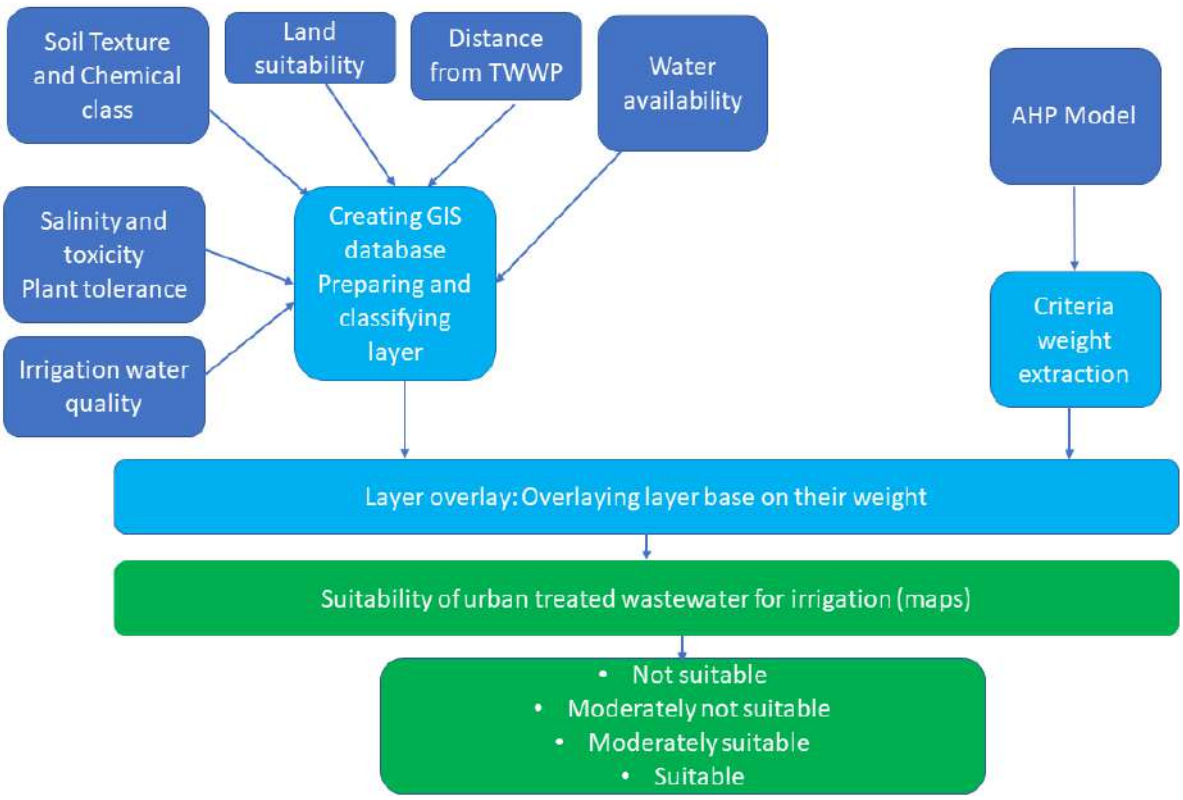


Figure 4.3.3: Methodological flow chart for site suitability analysis using multiple criteria decision making (MCDM) and Geographic Information System (GIS) (Source: Zolfaghary et al., 2021)

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 a major 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
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. Furthermore, septic tank effluent may leach into neighbouring soil, groundwater, or surface water. As a result, the pollution issues created by septic tank failure need the development of innovative approaches to increase blackwater treatment efficiency. These septic tanks are often poorly designed and tend to leak and overflow in the open environment, resulting in unsanitary conditions and the spread of illnesses. Tanks are often designed in a larger size to minimise frequent emptying. Soaking setups are seldom operated and managed. To guarantee that these septic tanks do not harm the environment, practical precautions should be taken.

The conventional septic tank with ABR improves sludge settling and contact (Fig. 4.3.4). Compared to a normal septic tank, a greater number of chambers and forced liquid movement through the collected sludge help in the removal of suspended solids and organic matter.

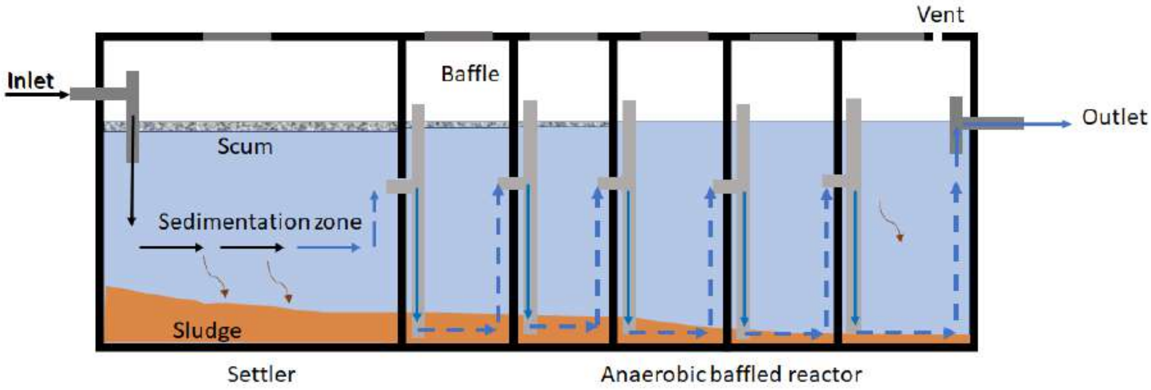


Figure 4.3.4. Schematic representation of ABR septic tank (Source: Tilley et al., 2014)

Another solution to improve effluent quality is using a modified septic tank-anaerobic filter unit, shown in Fig. 4.3.5. An anaerobic filter is an additional modification into a final chamber that includes a filter medium made up of either plastic or rocks. In the final stage, the wastewater from the first chamber is passed through the filter. Other associated processes, such as anaerobic digestion and disinfection chambers, can be included in modified septic systems. A vertical baffled septic tank with a filter and a disinfection chamber are one of the adaptations (Anil & Neera, 2016).

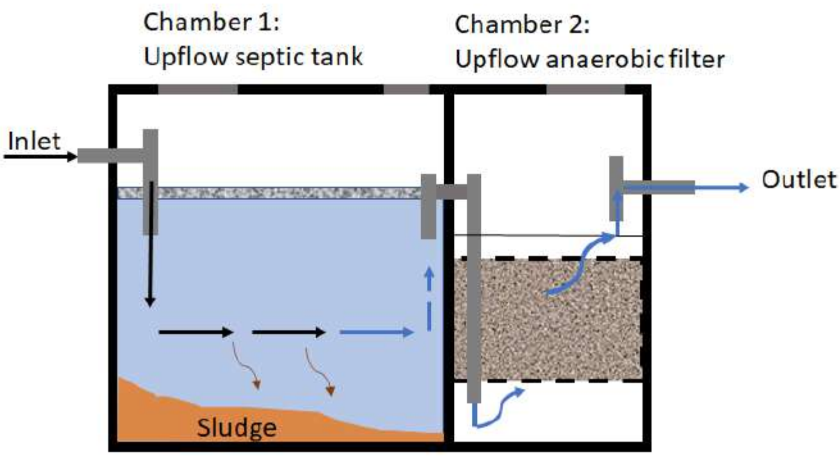


Figure 4.3.5: Modified septic tank-anaerobic filter unit as a two-stage on-site domestic wastewater treatment system

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

- Periodic audit of toilet facilities: ULBs must determine the kind of on-site sanitation systems are needed in order to guarantee appropriate containment and decrease pollution. If they have septic tanks, whether or not they are connected to soak pits
- Standardization of containment construction: People frequently build enormous tanks to avoid regular emptying owing to a lack of awareness, monitoring, and enforcement. As part of the building plan approval process, ULBs must strictly

enforce BIS containment system regulations in new/reconstructed houses. The ULBs can also appoint and train masons to build toilets, including containment systems that meet BIS requirements. ULBs can also educate residents about their existing septic tanks and soak pits and encourage them to renovate them in accordance with BIS guidelines.

- In the case where no sewerage system exists, and there is no space for soaking arrangements, as a temporary solution, excess effluent from a septic tank may be collected in well-lined roadside drains. By intercepting and diverting these drains, efforts should be made to transport this effluent to an appropriate location for off-site treatment through a decentralised wastewater treatment facility.
- Soak pits must be properly built and maintained. ULBs should also emphasize the importance 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, 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). Some practices lead to the 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, the 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 the utilization of scarce water resources in an optimal way.

Wastewater is a highly potential source of water for various purposes and is highly underutilized. For instance, 80% of the untreated wastewater from 110 cities, if utilized, can cater to 75% of the industrial water demand that can be met by 2025. Usage of sludge, which may get generated from the treatment process, could–serve the need for three million hectares of land on an annual basis, supplying essential nutrients for plant growth while reducing the dependency on fertilizers by 40% (Nikore & Mittal, 2021)

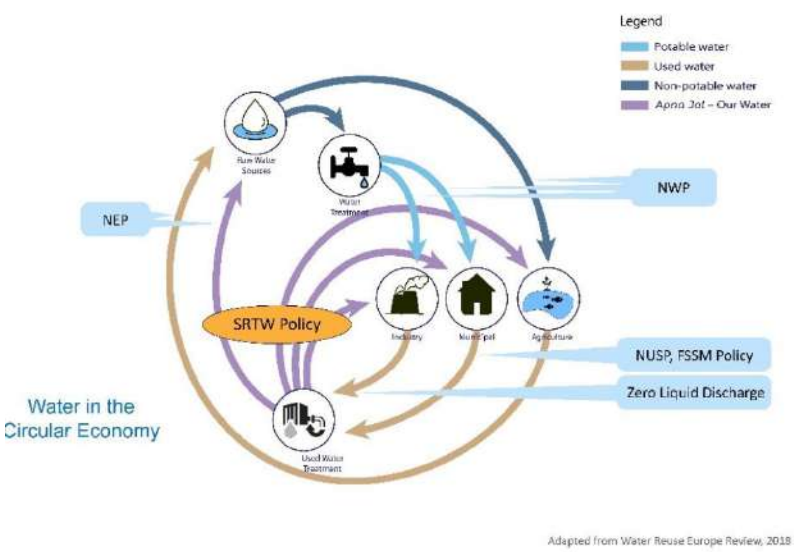
Safe Reuse of Treated Wastewater (SRTW) over untreated water is much beneficial. Firstly, on the water quality front, it curbs the issue of soil degradation and groundwater contamination. Secondly, it reduces human health hazards while dealing with contaminated water and consuming food items grown from untreated water. Thirdly, it could replace or supplement 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 at no cost.

At most, the treated wastewater is used in urban as well as 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 or state 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 the 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).



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, 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 treated wastewater for use 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 consisting of tree plantations around the cities in order to revive the ecological balance and improvement of the quality of the environment. It also facilitates the year-round utilization of wastewater. Similarly, treated wastewater can be used for the production of commercial non-food crops and flowers (Minhas et al., 2022).

In the direction to achieve SRTW, AgroMorph Technosolutions Private Limited, a DPIIT-recognised start-up and the winner of the 2021 AIM-ICDK Water challenge (Atal Innovation Mission – Innovation Centre of Denmark) is 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 strategy to improve 'cities' resilience and sustainability than conventional solutions and, thus, capable of effectively addressing urbanisation pressures and water and wastewater-related 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 (PPPs) or P3s are "schemes/initiatives/ programmes in which a government service or private business venture is sponsored and run through a collaboration between the government and one or more private sector enterprises". PPP attempts to boost cash flow and efficiency while improving service delivery quality by using private sector knowledge and increasing customer satisfaction. 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 out to bid on an Engineering Procurement and Construction (EPC) basis, with the EPC contractor playing a limited role in asset operation and maintenance (O&M). In many cases, the developed assets are of low quality, poorly managed, and do not meet the Pollution Control Boards' mandated effluent treatment standards. To guarantee the optimum utilisation of funds allocated and proper asset construction and maintenance, it is preferable to explore the possibility of PPP contracts, which would secure the private sector participants' long-term commitment through their continuing investments.

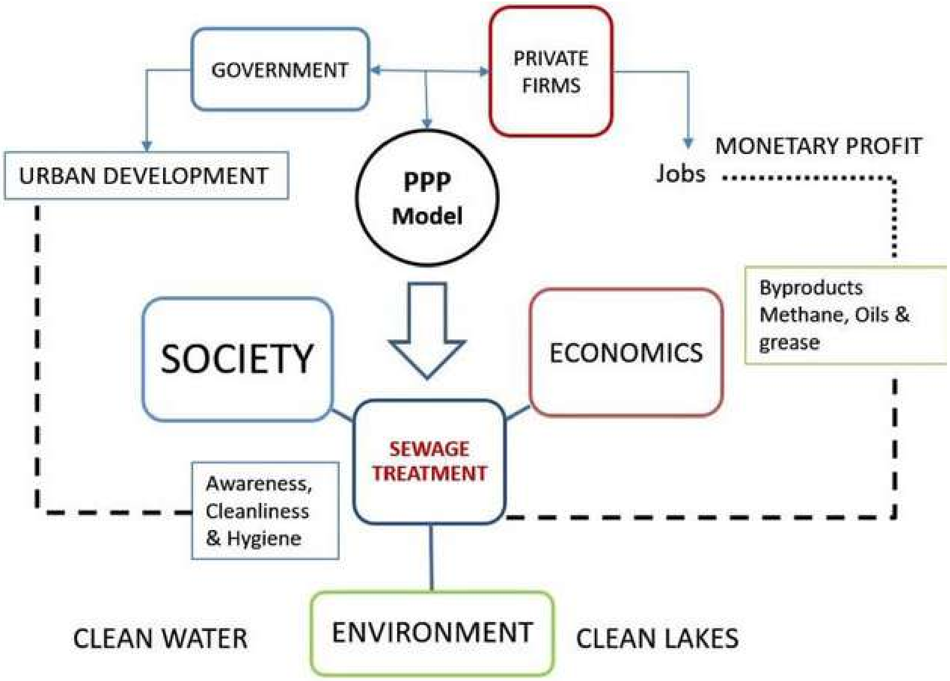


Figure 4.5.1: Public-Private Partnership (PPP) model for the sewage treatment business model (Source: Ashok et al., 2018)

Sewerage and sanitation services need large infrastructure investments, high operating and maintenance costs, and significant human resources; this service is getting increasingly expensive. Furthermore, the labour force hired by the urban local bodies (ULB) is far from efficient.

The high salary structure and inefficiency of the staff result in a significant increase in the cost of service, although the general public is dissatisfied with the quality of service given by ULBs. As a result, municipal governments should carefully examine private-sector engagement in sewage and sanitation services. With the state and central governments' previous issues in reach and budget, a joint approach has been relied on (Fig. 4.5.1).

Alandur, the first ULB in Tamil Nadu, attempted a PPP initiative in this area.

Between 2000 and 2005, about six PPP projects were undertaken, including Alandur, Tirupur, and four projects in Chennai. The availability of grant funding from the *"Jawaharlal Nehru National Urban Renewal Mission (JnNURM)"* and *"National River Conservation Directorate (NRCD)"* and the comprehensive policy thrust on PPPs in the infrastructure sector at the national level, which percolated down to the states, increased the number of PPP projects significantly between 2006 and 2011.

The Government of India is committed to raising the level and quality of economic and social infrastructure services throughout the country. In pursuit of this aim, the Government envisions PPP playing a significant role in leveraging private sector investment and operational savings in the supply 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 guarantee that the sewage system earns enough revenue to cover fixed and variable costs.
- Second, intergovernmental cooperation, alignment, and supervision are critical for the growth of PPPs and the management of political, regulatory, and financial risks.
- Thirdly, for PPP sustainability, a credible discretionary regulatory mechanism must be developed.

Recently, another P, People, was added to the PPP structure, and it is now referred to as Public, Private, People Partnership, with the new notion of PPPP or P4 being used. PPPP is a people-centred strategy in which all stakeholders, including Government, donor agencies, private enterprises, and civil society, collaborate. It involves the end user's view and role in PPP models. People are actively involved in investments and infrastructure development in order to build a sense of ownership and improve service sustainability

4.5.2 Community participation

Most wastewater treatment initiatives in India follow a top-down approach, with end-user communities having no influence on the sort of service they want or how much they are ready to pay for it. As noted in section 3.4, the extremely fragmented character of the institutional frameworks controlling the wastewater sector has resulted in poor levels of coordination among multiple agencies and little citizen engagement in the planning, design, and management of sewerage services. A deep understanding of the social dynamics of the community is essential for the successful use of relevant technology. This can only be accomplished by active public and community participation. Public engagement is best done by involving users in all stages of the project cycle, from planning and design through execution and decision-making, resulting in more efficient and sustainable projects/outcomes. Communities have a larger interest in the results and are more devoted to ensuring success when they have influence and control over choices that impact them.

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 addressed. Effective public participation begins with early contact with potential users and continues with the actual inclusion of all stakeholders by initiating the listed measures:

- Public meetings, campaigns and awareness programs to define the project's needs 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 update them on the project's progress and solicit input.
- Extensive discussions on pricing and benefits with stakeholders/end-user community.
- Form advisory committees to establish membership, responsibilities and resources of this committee
- Organising public workshops and training programmes to address the advantages and disadvantages of reuse.
- Creating entrepreneurial opportunities to attract local investments in terms of input materials

As a result, including all stakeholders equally in research and project execution can boost potential, flexibility, and creative innovation in responding to water insecurity issues.

In addition, unique incentives and reward programmes can be offered to the end-user community who want to employ natural solutions. These might include offering development incentives, property tax breaks, grant money, rebates, and installation finance directly to individual users, property owners, or community organisations in exchange for implementing solutions on their land. Awards and recognition schemes for successful instances will assist raise public awareness and encourage people to use these treatment methods.

Creating a web-based application for citizen science initiatives can boost public engagement in the chosen solution, aid in on-site monitoring, and provide large datasets with spatial and temporal coverage. The "Off the Roof Citizen Science Project" from Colorado State University (USA) is one such effort, with residents around the country analysing their roof runoff for pathogens to see how runoff might be best used. Another successful program is "Chronolog," in which Birmingham University (UK) installed chronolog stations across the Bartle Constructed Wetlands complex, and participants took selfies and uploaded them to their website. The purpose was to make a timelapse compilation using the submitted selfies to examine seasonal variations in ecological processes such as plant greening, water levels, and so on.

4.5.3 Performance evaluation of treatment plants

The treatment plant's performance effectiveness is dependent not only on sound design and construction but also on efficient operation and maintenance. A performance evaluation of a treatment plant employing any natural or conventional, or advanced technology is required to analyse compliance requirements current efficiency of existing treatment facilities and determine the current quality of treated sewage. According to the CPCB evaluation, out of 1093 operational STPs, the compliance status of 900

STPs is accessible, and only 578 STPs with a total capacity of 12,197 MLD are found to conform with the SPCBs' or Pollution Control Committees' approved requirements (PCCs). Another CPCB study assessed the performance of 152 STPs operating under NRCD in 15 states, with a total treatment capacity of 4,716 MLD. Following the assessment, the plant efficiency utilised was estimated at 66%. (3,126 MLD). Out of the 152 STPs, 9 are under construction, 30 are not operational, and the performance of 28 is unsatisfactory. In terms of treated effluent quality, 49 of the 152 STPs' treated effluent exceeds BOD limits, while 7 STPs violate COD general discharge criteria. According to the report, the primary variables affecting the effectiveness of treatment procedures are a lack of maintenance and poor plant design. As a result, to accomplish these capabilities, the present treatment plant must be improved, which necessitates a performance review to determine the potential for expansion or process change. In terms of treated effluent quality, 49 of the 152 STPs' treated effluent exceeds BOD limits, while 7 STPs violate COD general discharge criteria.

According to the report, the primary variables affecting the effectiveness of treatment procedures are lack of maintenance and improper plant design. As a result, to accomplish these capabilities, the present treatment plant must be improved, which necessitates a performance review to determine the potential for expansion or process change.

A proper monitoring plan, defining the testing schedules, locations, parameters of importance, testing methods and procedures, 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 simplify the flow of information from STPs to Urban Local Bodies, States, and the Central level, and it will connect 1600+ STPs. This mobile application is available for download from the Mobile App Store. Data on capacity and qualitative parameters such as pH, TSS, COD, BOD, and FC will be reported and updated weekly.

Citizen science programs can also enhance the monitoring of decentralised 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 the local, regional, and national level in managing wastewater. Through capacity-building activities, a 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 utilities, 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 the 17 Sustainable Development Goals (SDGs) under the 2030 Agenda that UN member states have adopted, Wastewater management is intimately related to 12 SDGs and relevant targets. Most Indian urban towns and cities have historically been able to plan some level of services for their residents. Many people have battled in recent years to keep up with the volume of waste produced. Due to record rates of rural-to-urban migration, economic growth, and shifting consumer habits, an ever-increasing urban population is the primary cause of this rise in wastewater quantities. (Rodić & Wilson, 2016). Participation and coordination of all stakeholders and agencies are crucial for urban wastewater management improvement (Fig. 5.2.1). Few points have been emphasized in relation to how to enhance institutional collaboration.

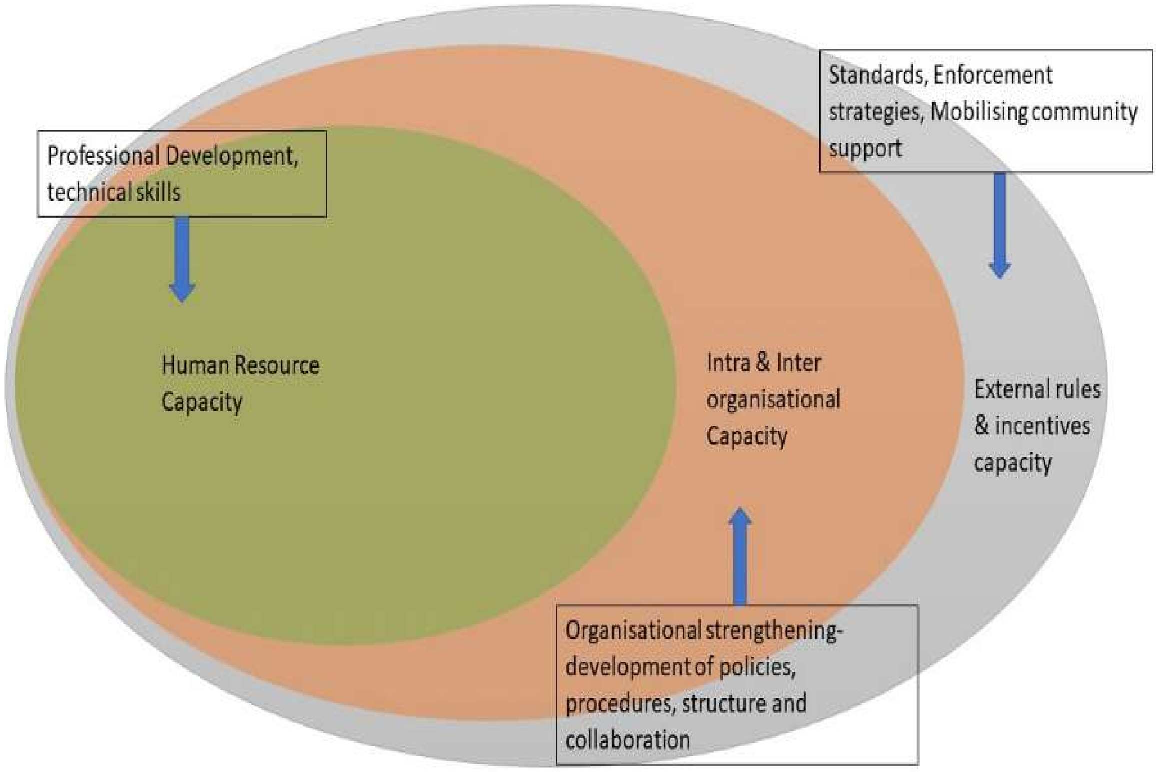


Figure 5.2.1: Institutional capacity-building framework (Source: Brown & Farrelly, 2009)

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

Increasing the number of decision-making actors or agencies, integrating urban planning, and comprehending trade-offs between many competing aims are all necessary for the implementation of UWM. 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 gathering and sanitary landfilling. It should also be formalized for those who already handle waste management in some way but are not yet a part of a formal waste management structure. It's important to acknowledge and progressively include this so-called informal sector keen on the established waste management system. To ensure that all parties engaged have a level playing field, clear and well-defined rules must be set. Introducing reforms gradually in the urban wastewater sector in the 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 its capacity become more critical in transforming to sustainable development.

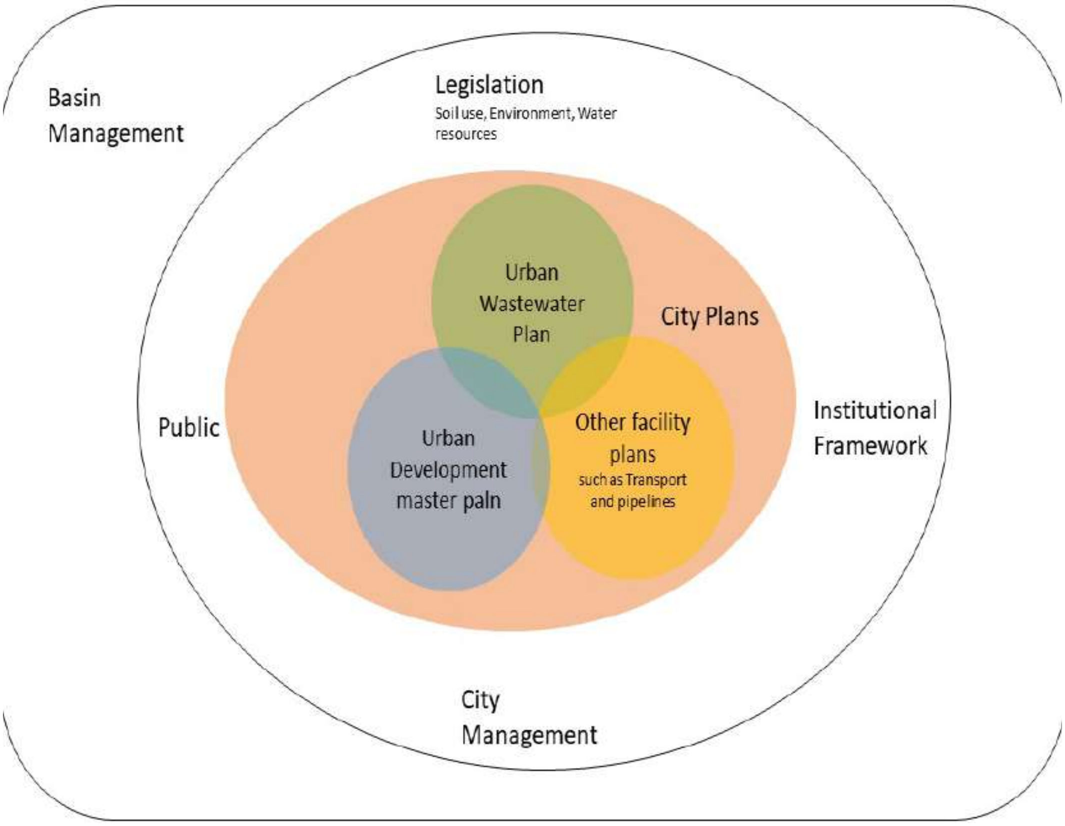


Figure 5.2.2: Institutional framework for UWM planning (Source: Tucci, 2010)

On this note, the following are key actions the Indian government has taken over the past 25 years to improve the country's solid waste management:

1. National waste management committee: The committee was established in 1990 with the primary goal of identifying recyclable materials in solid waste collected by rag-pickers
2. Strategy Paper: In August 1995, the MoUD and the NEERI worked together to prepare a manual on SWM.
3. Policy Paper: MoUD and the Central Public Health and Environmental Engineering Institute prepared have developed a strategy paper for wastewater treatment, good hygiene, SWM, and drainage system efficacy.
4. The master plan of Municipal Solid Waste: In March 1995, the MoEF, CPCB, and ULBs came up with a plan to create an SWM master plan with a focus on biomedical waste.
5. High-Powered Committee: In 1995, Dr Bajaj served as the chairman of a High-Powered Committee that was established to develop an acceptable long-term technical strategy for wastewater management.

The formulation of several environmental protection legislation and regulations that occasionally got into action was the result of the aforementioned efforts and some of the regulations that apply 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

The joint initiatives in India are still in their early stages, and UWM has not had any notable successes. However, a lot of businesses saw the UWM situation as a commercial opportunity. For the various parts of UWM in India (segregation at community bins, collection, transportation, including energy waste), about 40 projects are now under collaborative efforts.

"Thermax Ltd. (Incineration plants in collaboration with Danskrodzone, Denmark and Thermal Proces), Future Fuel Engineers (India) Pvt. Ltd. (bio digestion in collaboration with ECOTEC, Finland), Global Environmental Engineers Ltd. (biodigestion in collaboration with PAQUES Pvt., Netherlands), Hanzer Biotech (UWM), and Zen Global Finance Ltd. (RDF) are some Indian companies involved in UWM (Waste Management Services). Entec, Astria, Hitachi Zosen of Japan, Nellemen, Neilsen, and Rauscvenberger of Denmark, Lunde, TBW, and BTA of Germany", and other foreign companies are active in the UWM sector in the Indian market. Successful collaborations have traits like efficient implementation, improved services, risk sharing, cost reduction, and revenue generation. Power sharing, losing control of ULBs, cost hikes, a lack of responsibility, political dangers, and a lack of competitiveness are among the main issues on the opposing side.

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). By establishing the Clean Kerala Mission in 2002, Kerala became one of the few states in India to use successful rubbish management strategies. Later, in 2007, the Malinya Mukta Keralam campaign was launched, creating the perfect environment for a Mission Mode Action Plan to achieve the goal of Clean Kerala. The well-known slogan "Reduce, Reuse, Recycle and Recover" serves as the foundation for the Mission 2002 Strategy. In Phase-I, 26 Municipalities and 5 Corporations put their plans into action.

5.3 Sensitization of the public

An informed group of decision-makers is aware that waste management is a core public duty and is necessary for proper wastewater management. Therefore, waste management must be taken into account when making political decisions in each locality, along with other essential goals like the provision of safe drinking water, wastewater treatment, and all other public infrastructure components. 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).

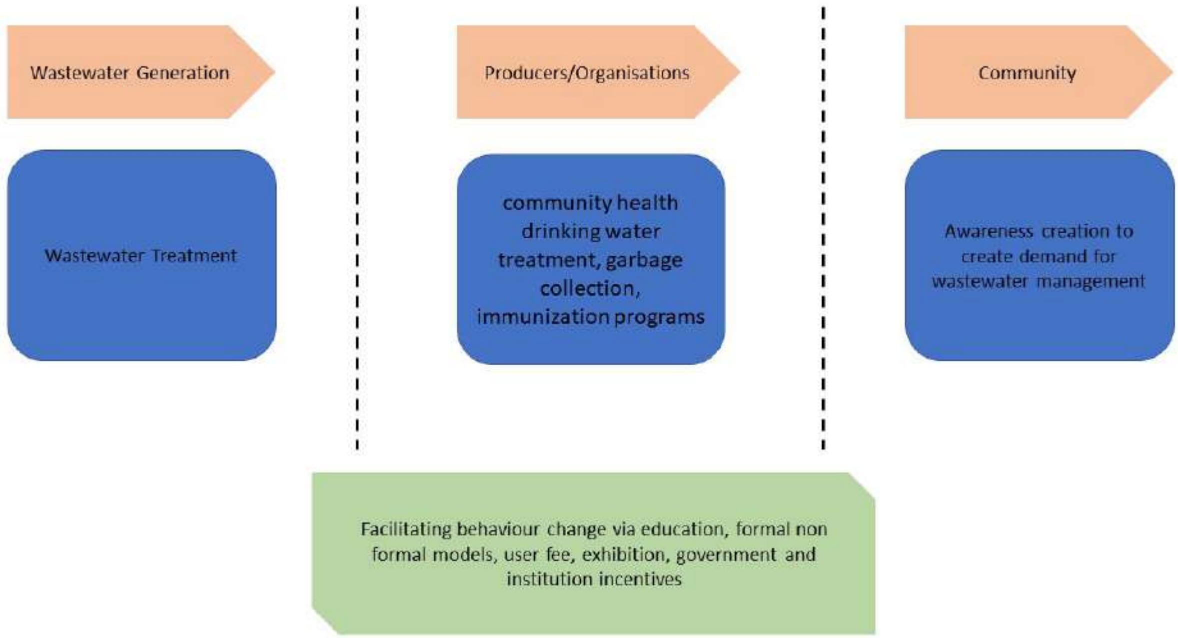


Figure 5.3.1: Sensitization framework for wastewater treatment and management (Source: Schellenberg et al., 2020)

5.3.1 Looking into the long-term benefits of wastewater treatment

Immunization programs are effective for wastewater treatment and disposal. The long-term advantages of wastewater treatment must be made clear. Untreated sewage can contaminate drinking water supplies and spread disease. The availability of safe, clean drinking water is sometimes taken for granted, and the majority of communities pay little attention to what happens to their wastewater. Most people consider cholera and other illnesses connected to sewage to be hazards to less developed nations. 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. A lack of community ownership and understanding of their duties and rights
2. Panchayats' inability, unwillingness, and ownership to maintain water supply systems
3. There are few avenues for residents to hold panchayats accountable for providing clean water.
4. A lack of tools and spare parts
5. Limited mechanic availability and a lack of incentives.

The following demands can be addressed to improve the user fee collection for better operation and management.In order to own and sustain these programs on urban water supply, the efforts need to be institutionalized while keeping in mind their sustainability. To achieve effective social mobilisation, community and development agents like NGOs, CBOs, etc., should be properly pushed for. In light of this, a community-based, demand-driven approach is strongly justified, with an emphasis on raising community understanding of the importance of urban wastewater management. Development workers and agencies now play a crucial role in assisting the government's strategy and initiatives to clear the way for the construction of wastewater treatment facilities that will ensure everyone has access to safe water.

5.2.3 National awareness fest/fair

Raising awareness is necessary to engage at least some degree of citizen 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.

5.2.4 Wastewater treatment courses at different levels of education

It has been noted in India that projects using treated wastewater suffer from a lack of social acceptance. For non-potable uses, very few people and the community are at ease using treated wastewater, but they are hesitant to utilize it for personal use. According to studies, this can be solved by raising people's awareness of the problem (Joshi & Ahmed, 2016). These challenges can be addressed by including wastewater treatment courses at various educational levels.

5.3.5 Formal, non-formal, and informal education modules

The idea behind education is to increase people's consciousness. The components of formal, non-formal, and informal education all contribute to effective awareness-raising. Although teaching styles and approaches vary, they all aim to educate various social groups (Fig. 5.3.2). The emphasis should be placed on developing an educational approach to identify and address the issue with wastewater management that we have.

Two stages might be used to increase awareness. The media and the internet would be used to raise awareness in the first phase. Adults are the target demographic for this phase. The need for proper wastewater management and the justification for the waste hierarchy will be emphasized. This idea is based on information showing the most common errors made, treatment-related myths, and the advantages of effective handling for increasing the amount of waste intended for energy use. A target group of educators, such as school teachers, waste management specialists, or company directors, are defined as the second phase of awareness.

Children are change agents who raise awareness of environmental issues and encourage neighbouring communities to value natural resources more. In order to raise awareness and affect behavioural and attitude changes regarding wastewater generation, treatment, and reuse, a formal education module that targets young minds might be designed. One example of a government that educates its inhabitants through informal education in Singapore. 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. Countries including the United States, Australia, the Netherlands, and China have all experienced similar initiatives (Filho et al., 2016).

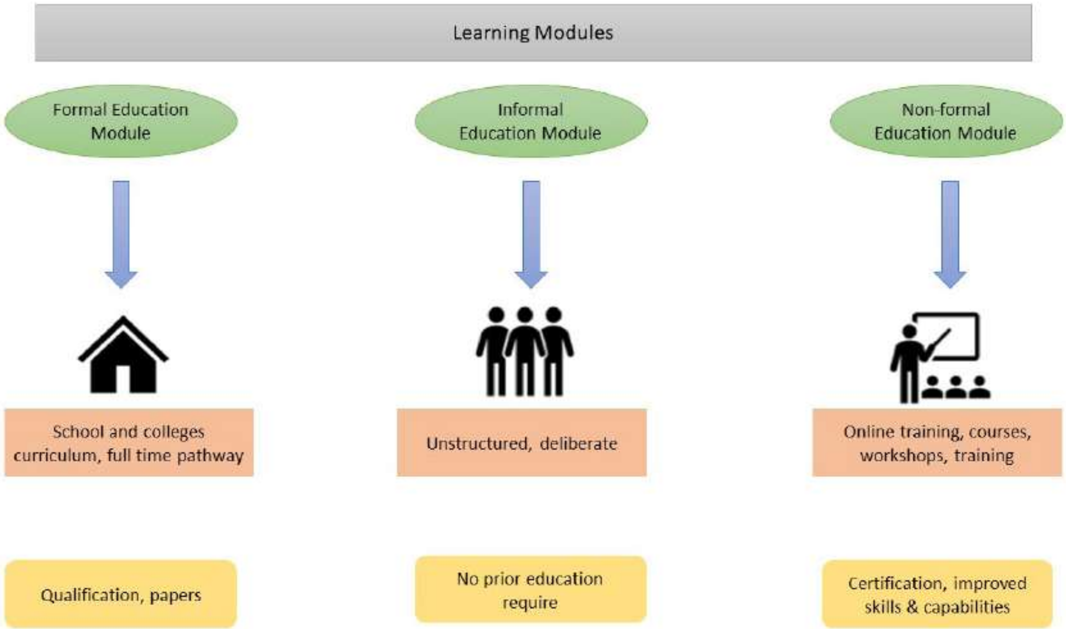


Figure 5.3.2: Formal, non-formal, and informal education modules

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. It's also interesting to note that these households' main information source came from their school-age children (TERI, 2020). Therefore, it is crucial to raise awareness among students so that this area's wastewater management can serve 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
स्वच्छता का संकल्प लें गंगा किनारे!
संकल्प रैली
गंगा स्वच्छता संकल्प दिवस
उ.प्र. राज्य गंगा नदी संरक्षण अभिकरण
जिला प्रशासन इलाहाबाद
अभिलाषा गुप्ता 'नन्दी'
महापौर
संजय कुमार
जिलाधिकारी

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 *"country's largest river basin",* accounting for 26% of the country's land mass, 28% of its water resources, and 43% of its population. The parent river, or main channel, runs through five major states: Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal, covering a total distance of 2,525 kilometres. In fact, the Ganga River basin, with all of its tributaries, spans about a million square kilometres across eleven Indian states. 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. The Namami Gange mission, which was launched with a budget of Rs 20,000 crores, is *"an umbrella programme that aims to merge prior and presently active projects as well as new initiatives planned as part of its component".* Under the Mission, a total of 378 projects have been sanctioned worth Rs 31,173 crores. The *"National Mission for Clean Ganga (NMCG)",* 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 faecal sludge and septage management.

The Mission comprises 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 the 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 the 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, the revival of cultural heritage and tourism and institutional building.

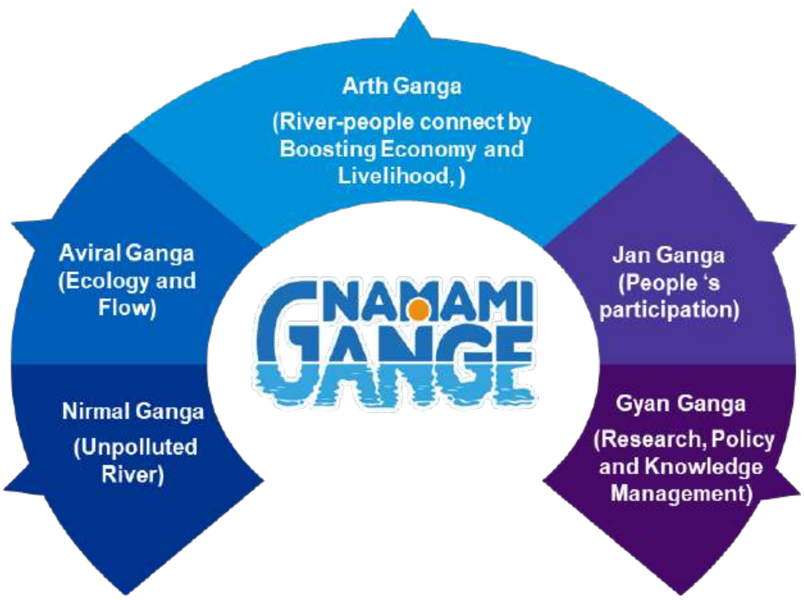


Figure 6.1: Five verticals under Namami Gange Mission

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

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

Addressing the challenges of rejuvenating a transboundary river and driving 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 the successful implementation of its goals. The roles and responsibilities of the five-tier institutional framework have been elucidated below:

- **"National Ganga Council"**: The *"National Council for Rejuvenation, Protection and Management of River Ganga"* or the *"National Ganga Council (NGC)"*, 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 Hon'ble Prime Minister presided over the NGC's first meeting, which took place on December 14 in Kanpur. Other attendees included members of the Union Council of Ministers and the chief and deputy chief ministers of the states that are covered in the Ganga Basin.
- **"Empowered Task Force":** Under the Chairmanship of the Union Minister for Water Resources, River Development, and Ganga Rejuvenation, the "Empowered Task Force" is represented by Chief Secretaries of States in the Ganga basin, as well as secretaries from related line agencies of Government of India. The Empowered Task Force coordinates and advises on the river Ganga rejuvenation, preservation, and management and requires different departments, ministries, and state governments to prepare an Action Plan with specified tasks, timelines, and methods for execution.
- "**National Mission for Clean Ganga (NMCG)":** At the national level, NMCG functions under the supervision and direction 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 is in charge of both levels of the organisation. He is supported by four Executive Directors, namely, Projects, Technical, Finance and Administration and a Deputy Director General. In 2016, NMCG was notified as an authority with statutory powers under the Environment Protection Act 1986, giving it regulatory, financial, and administrative competence.
- "**State Ganga Committees":** The *"State Ganga Rejuvenation, Protection and Management Committee"* or the *"State Ganga Committee"* were constituted to drive programme implementation in all the five main stem states through monitoring the execution of plans, programmes, and projects of all district-level agencies. The State Ganga Committee is chaired by the Chief Secretary of each State and includes Principal Secretaries of key State Departments as well as five experts from relevant disciplines appointed 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 a 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 the Convenor of the Committee. From April 2022 onwards, DGC-4M meetings (District Ganga Committee – Monthly Mandated Minuted Monitored meetings) will be regularly conducted in all districts of the basin. This has increased the people's participation in the implementation of the 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 to, and the end products are compliant with 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 the creation and rehabilitation of 5016 MLD of STP capacity and laying off 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 a 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 in various stages of completion.

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

In terms of decentralised solutions, in 2017, the Government of India formulated the *"National Faecal Sludge & Septage Management (FSSM) Policy"* to emphasize the need for 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, phytoremediation, bioremediation, bio-digesters etc. Successful implementation of FSSM projects has been achieved in States such as Andhra Pradesh, Maharashtra, Odisha and Telangana by adopting a combination of FSTP, co-treatment in STP, and 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 the 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 of independent household toilets to make 4,507 villages along the Ganga River Open Defecation Free (ODF).

Similarly, in urban areas, efforts are being made to make Ganga basin cities river and water sensitive. Some of the initiatives include the promotion of Zero Liquid Discharge in the context of Ganga Basin cities, setting up the Centre of Excellence on Water Reuse, organizing awareness campaigns for strengthening people's river connection and others. In collaboration with our partners, such as the "*Centre for Science and Environment*" and the "*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", and "Urban Wetland/ Water Bodies Management Guidelines".

Treatment of Industrial Effluents:

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

- Textile Cluster: Work for the upgradation of the existing 6.25 MLD CETP in Mathura is in progress. Tender preparation is in 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 cluster: On the main channel of the Ganga, there are three major tannery clusters: Jajmau, Banthar, and Unnao. having a 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 the upgradation of 2.15 MLD to 2.6 MLD CETP at the 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 the release of Charters for the implementation of cleaner technology, the upgradation of the treatment facility and the adoption of waste minimization practices in the major industrial sectors such as Pulp & Paper, Distilleries, Sugar and Textile. This has resulted in a 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",* and *"Charter for Sugar".*

NMCG also inspects Grossly Polluting Industries (GPIs) on a yearly basis through Third Party Institutes (TPI) like IITs, NITs, and CSIR Institutes. Since 2017, compliance verification of GPIs with the potential to discharge into the Ganga and its tributaries has also been carried out by TPIs. CPCB/SPCB/PCC takes stringent action against GPIs that discharge into the main channel of the Ganga River and its tributaries and fails to meet the statutory standards. During the 5th cycle of yearly inspection of GPIs 2021-22, an inventory of 1051 GPIs, including 9 CETPs functioning in five-river Ganga main channel states, was updated in cooperation with concerned SPCB/PCCs. The inventory of GPIs for the river Yamuna basin was carried out by 24 reputable TPIs and finalised at 1655 GPIs, including 33 CETPs.

Action is being taken by seven respective SPCBs/PCC, i.e., Uttarakhand, Uttar Pradesh, Haryana, Delhi, Jharkhand, Bihar & West Bengal. All 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 directions 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 (HAM-PPP) model"* and the *"One City One Operator (OCOP) model*" has been a game changer in the wastewater sector in the country and has given a need push to PPPs in the sector.

- HAM-PPP Model: Launched in 2017, the plan includes a 15-year, 100% central government financial commitment through NMCG for both the establishment and O&M of the STPs. An appropriate concessionaire for the development and operation of STPs is selected through competitive bidding under HAM-PPP, in line with the PPP procurement method used by the Government of India for infrastructure-related projects. During construction, 40% of the capital cost is paid, and the remaining 60% is paid over a 15-year period as annuities with interest on the unpaid amount and expenditures for O&M. The bidding is based on the 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 performance and accountability of the project for the entire life cycle. The model's uniqueness originates from the several benefits it provides, including guaranteed government financing, ongoing performance, specific accountability, and ownership for long-term success. So far, 30 HAM projects have been approved.
- OCOP Model: This model involves the creation of new STPs as well as the upgradation of existing treatment facilities in ULBs, with the goal of completely eliminating untreated sewage entering the Ganga. The projects, which are at various phases of completion, have been implemented in places such as Agra, Asansol, Bareilly, Burdwan, Durgapur, Farrukhabad, Ghazipur, Howrah-Bally-Kamarhati-Baranagar Bhagalpur, Kanpur, Kolkata, Mathura, Mirzapur, Patna, and Prayagraj.

Furthermore, NMCG, in partnership with CPCB, is closely monitoring emissions and effluents from industrial unit discharge locations via the Online Continuous Effluent Monitoring Stations. The analysers are mounted on stacks/chimneys and at ETP or STP outputs. The parameters being monitored include:

- for effluents- pH, BOD, COD, TSS, Flow, Chromium, Ammoniacal Nitrogen, Fluoride, Phenol, Cyanide, Temperature, AOx, and Arsenic
- for emissions – PM, Fluoride, NOx, SO2, Cl2, HCl, and NH3 emissions

6.4 Innovative applications and technological solutions for UWM

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

- **"Catch the Rain Campaign":** 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 an active part in the rejuvenation of small streams and rivulets restoration of lakes and water bodies in the Ganga basin.

- **"Bhuvan Ganga Portal":** In 2015, MoU was signed between National Remote Sensing Centre, Hyderabad and NMCG for Bhuvan Ganga Geoportal, which provides a platform to manage, access, visualize, share and analyse geospatial data as well as non-spatial data products and services. The platform supports NMCG in achieving its objectives of environmental and ecological improvement within the Ganga River basin. It is being widely used by NMCG in drain monitoring. In 2015, an MoU was signed between the National Remote Sensing Centre, Hyderabad, and the NMCG for the Bhuvan Ganga Geoportal, which provides a platform for managing, accessing, visualising, sharing, and analysing geospatial and non-spatial data products and services. The platform helps the NMCG achieve its goals of environmental and ecological improvement in the Ganga River basin. NMCG used it extensively in drain monitoring.
- The "**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 the Ganga basin in high resolution generating Digital Elevation Models (DEM). DEM, GIS-ready dataset, outlet/vent of sewerage and other discharge from all types of units industrial, commercial, and all other institutions, public drainage network, crematoria, ghats, RFD, solid waste disposal sites, STP/ETP/CETP, and so on are among the mapping deliverables. The models give useful information for developing urban river plans, establishing the baseline of river flood plains and controlling them for restoration and protection of major pollution hotspots, and assisting policymakers in making educated decisions based on the data provided. The mapping area is 43,084 km2 along the river's 10 km boundary.
- **"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*" employs drone technology to map all water bodies in 31 Ganga districts (3189 villages) in Bihar, Jharkhand, Uttar Pradesh, Uttarakhand, and West Bengal in order to rejuvenate water bodies that have dried up or are operating at less than full capacity.
- IIT Kanpur is working on "**reconstructing the Ganga of the Past using Corona archival photos".**
- "**Spring Rejuvenation using Remote Sensing, GIS & UAV technology"**
  - The Survey of India, along with CGWB, is conducting a pilot project on spring rejuvenation in the Tehri Garhwal area of Uttarakhand. The Tehri Garhwal district is being mapped schematically for the inventory of springs using LiDAR technology, hydrogeomorphic and lineament studies for the identification of the different types of springs and their recharge zones and spring rejuvenation through the construction of rainwater harvesting and artificial structures.

    - Rejuvenation of dying springs in Tokoli Gad catchment of Tehri Garhwal District using Geochemical & Geophysical techniques by IIT Roorkee. Under the project, the impact of land use, land cover change and natural or anthropogenic precipitation variability are being assessed. IIT Roorkee is using geochemical and geophysical approaches to rejuvenate dying springs in the Tokoli Gad watershed of Tehri Garhwal District. The research assesses the influence of land use, land cover change, and natural or anthropogenic precipitation variability.

- NEERI is doing "**GIS-based Mapping of Microbial Diversity"** to understand the water quality of the Ganga along the stretch, with a special focus on characteristics that show the interactions of a river with its diverse 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 the 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, and Survey by NIH, Roorkee
- IIT Roorkee is working on identifying critical soil erosion-prone areas and developing a catchment area treatment plan.
- A district-by-district list of small rivers is being added to a GIS-based inventory of small rivers as an additional part. Most of these small rivers are seasonal, and most of them have suffered hydrological degradation as a result of either poor water quality or a lack of flow during non-monsoon seasons. One of the goals of the initiative is the rejuvenation of these rivers since they have a direct influence on the quantity and quality of River Ganga flows.
- NMCG is employing GIS technology to map the cultural landscape of the main channel of the Ganga from its source to Ganga Sagar in collaboration with INTACH. The GIS Cell of NMCG has developed a prototype geoportal on the "Ganga Water Quality information system" with the 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 grass-root level to raise awareness, impart livelihood training and skill development, etc. For instance, it is closely working with the Himalayan Environmental Studies and Conservation Organization

- (HESCO) to support livelihood opportunities in the Ganga basin and employ environmentally sound techniques for the restoration of riverine ecosystems. Another example is the collaboration with Say Earth to share knowledge for rejuvenating, restoring and management of ponds and water bodies.
- 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 the Ministry of Environment, Government of Japan, for the promotion of the 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 for strengthening people's river connection 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 grass-root level communities. Some of the initiatives undertaken include:

- **"Ganga Utsav (Ganga Festival)":** Namami Gange has been holding Ganga Utsav (River Festival) since 2017 to mark the proclamation of River Ganga as the national river. From November 1st to 3rd, 2021, Ganga Utsav was held to commemorate not only the River Ganga but all other rivers in the country. Cultural performances, Ganga discussions, Kahani Junction, Live Paintings, Photo Exhibitions, and other events were part of the festivities.
- **"Ganga Quest"**: Ganga Quest, launched in 2019, is a bilingual international quiz tournament aimed at raising awareness of the national River Ganga, its significance, cultural and historical values, variety, and environment. The goal is to link individuals emotionally as well as intellectually by sensitising them to the current state of rivers and its historical significance. It had an amazing response, with over a million participants in the years 2020 and 2021. This year, over 7 lakh people enrolled for Ganga Quest 2022, with around 1.73 lakh people competing from India and 180 other countrie s.
- **"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's 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 of 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 Affairs, 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, Ganga and the 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 documented current trends and identified the 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 a "No-one-size-fits-all" solution, and the availability of land for such solutions is limited. Future infrastructures should aim to bridge the gap between wastewater generation and treatment by using sustainable solutions. Each urban centre (city/town/community/building/individual) has different requirements for land, capital and human resources and thus requires 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. The data-driven approach requires large volumes/frequency of data; however, currently, the data on wastewater is scarce. The development of affordable data monitoring tools can aid in these scenarios for effective monitoring and also sensitize stakeholders on load generation/reuse. There is tremendous support from the Government of India for Agriculture 4.0 and Industry 4.0 techniques that require the use of IoT, ICT, and 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 policymakers in taking scientifically validated best management plans. Public participation is necessary for managing natural resources and treating wastewater. Added local participation and involvement of the 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 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 the crowdsourcing 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 capacity-building efforts and improving the training capacity of locals through interactive media (e.g., guided multilingual tutorials). Training and awareness programs on promoting the reuse of wastewater are much needed to manage the water-related challenges in water-scarce areas across the globe.

There is a need to set up 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.

REFERENCES

Amerasinghe, P., Bhardwaj, R.M., Scott, C., Jella, K., & Marshall, F. (2013). *Urban wastewater and agricultural reuse challenges in India.* Colombo, Sri Lanka: International Water Management Institute (IWMI). 36p. (IWMI Research Report 147).

Anane, M., Bouziri, L., Limam, A., & Jellali, S. (2012). Ranking suitable sites for irrigation with reclaimed water in the Nabeul-Hammamet region (Tunisia) using GIS and AHP-multicriteria decision analysis. *Resources, Conservation and Recycling*, *65*, 36-46.

Anil, R., & Neera, A. L. (2016). Modified septic tank treatment system. *Procedia Technology*, 24, 240-247.

Ashok, S. S., Kumar, T., & Bhalla, K. (2018). Integrated greywater management systems: a design proposal for efficient and decentralized greywater sewage treatment.

Procedia CIRP, 69, 609-614.

Bozdağ, A. (2015). Combining AHP with GIS for assessment of irrigation water quality in Çumra irrigation district (Konya), Central Anatolia, Turkey. *Environmental earth sciences*, *73*(12), 8217-8236.

Brown, R. R., & Farrelly, M. A. (2009). Delivering sustainable urban water management: a review of the hurdles we face. *Water science and technology*, *59*(5), 839-846.

CAG. (2011). *Water pollution in India. Report no. 21 of 2011–12.* Indian Audit and Accounts Department, Government of India.

CAG. (2016). *Performance Audits (Urban Local Bodies)*. Indian Audit and Accounts Department, Government of India.

CAG. (2017). *Performance Audits (Urban Local Bodies)*. Indian Audit and Accounts Department, Government of India.

CAG. (2020). *The performance audit of the Management of stormwater in Bengaluru Urban area.* Indian Audit and Accounts Department, Government of India.

Cohen-Shacham, E., Walters, G., Janzen, C. & Maginnis, S. (eds.) (2016). Nature-based Solutions to address global societal challenges. Gland, Switzerland: IUCN. xiii + 97pp.

CPCB. (2013). *Performance Evaluation of Sewage Treatment Plants under NRCD*. Central Pollution Control Board, Ministry of Environment Forest and Climate Change (MoEFCC), New Delhi.

CPCB. (2015). *Inventorization of sewage treatment plants.* Central Pollution Control Board, Ministry of Environment Forest and Climate Change (MoEFCC), New Delhi.

CPCB. (2019). *Amended guidelines on the provision of buffer zones around waste processing and disposal facilities,* Central Pollution Control Board, Ministry of Environment Forest and Climate Change (MoEFCC), New Delhi.

CPCB. (2020). *Report of The Performance Audit of State Pollution Control Boards / Pollution Control Committees*. Central Pollution Control Board, Ministry of Environment Forest and Climate Change (MoEFCC), New Delhi.

CPCB. (2021a). Annual report. Central Pollution Control Board (MoWR), River Development and Ganga Rejuvenation, New Delhi, India.

CPCB. (2021b). National Inventory of Sewage Treatment Plants. Pollution Control Board, Ministry of Environment Forest and Climate Change (MoEFCC), New Delhi.

CPCB. (Mar, 2021c). Status of STPSs. Central Pollution Control Board, Ministry of Environment Forest and Climate Change, Government of India. https://cpcb.nic.in/status-of-stps/

CPCB. (2022). *National Water Quality Monitoring Network.* Central Pollution Control Board, Ministry of Environment Forest and Climate Change (MoEFCC), New Delhi.

CPHEEO. (2012). *Manual On Sewerage and Sewage Treatment*, Central Public Health and Environmental Engineering Organization (CPHEEO), Ministry of Urban Development, New Delhi, India.

Craggs, R., Park, J., Heubeck, S., & Sutherland, D. (2014). High rate algal pond systems for low-energy wastewater treatment, nutrient recovery and energy production. *New Zealand Journal of Botany*, *52*(1), 60-73.

CSE. (2017). *Decentralized* Wastewater *Treatment-Case Studies*. Centre for Science and Environment, India.

DECC. (2020). *Action Plan for Reuse of Treated Wastewater*. Directorate of Environment and Climate Change (DECC), Department of Science, Technology and Environment, Government of Punjab, India.

Dong, J., Wang, G., Yan, H., Xu, J., & Zhang, X. (2015). A survey of smart water quality monitoring system. *Environmental Science and Pollution Research*, 22(7), 4893-4906.

Dutta, V., Dubey, D., & Kumar, S. (2020). Cleaning the River Ganga: Impact of lockdown on water quality and future implications on river rejuvenation strategies. *Science of the Total Environment*, 743, 140756.

El Hamouri, B., Rami, A., & Vasel, J. L. (2003). The reasons behind the performance superiority of a high rate algal pond over three facultative ponds in series. *Water science and technology*, *48*(2), 269-276.

Environmental Financial Centre, (2017). Educating and Engaging the Public on Wastewater Treatment: Tools & Tips. Chapter-5, 727 E. *Washington Street*, Syracuse, NY 13210.

European Commission, (2015). *Towards an EU research and innovation policy agenda for nature-based solutions & re-naturing cities : final report of the Horizon 2020 expert group on 'Nature-based solutions and re-naturing cities' : (full version)*, Directorate-General for Research and Innovation, Publications Office.

Ferrero, G., Setty, K., Rickert, B., George, S., Rinehold, A., DeFrance, J., & Bartram, J. (2019). Capacity building and training approaches for water safety plans: A comprehensive literature review. *International journal of hygiene and environmental health*, *222*(4), 615-627.

FICCI Water Mission & 2030 WRG. (2016). *Urban Wastewater Public-Private Partnerships.* Federation of Indian Chambers of Commerce & Industry (FICCI) Water Mission and the 2030 Water Resources Group (2030) WRG.

Filho, W.L., Brandli, L., Moora, H., Kruopien□, J., & Stenmarck, Å. (2016). Benchmarking approaches and methods in the field of urban waste management. *Journal of Cleaner Production*, *112*, 4377-4386.

Francis, R. A., & Lorimer, J. (2011). Urban reconciliation ecology: the potential of living roofs and walls. *Journal of environmental management*, *92*(6), 1429-1437.

Fu, H., Niu, J., Wu, Z., Xue, P., Sun, M., Zhu, H., & Cheng, B. (2022). Influencing factors of stereotypes on wastewater treatment plants-Case study of 9 wastewater treatment plants in Xi'an, China. *Environmental Management*, 1-10.

Geetha, S., & Gouthami, S. J. S. W. (2016). Internet of things enabled real time water quality monitoring system. *Smart Water*, 2(1), 1-19.

Hasan, M. N., Khan, A. A., Ahmad, S., & Lew, B. (2019). Anaerobic and aerobic sewage treatment plants in Northern India: Two years intensive evaluation and perspectives. *Environmental Technology & Innovation*, 15, 100396.

Huh, S. Y., Shin, J., & Ryu, J. (2020). Expand, relocate, or underground? Social acceptance of upgrading wastewater treatment plants. *Environmental Science and Pollution Research*, *27*(36), 45618-45628.

India Water Portal, (2011). *Solution Exchange discussion–Ways to improve O&M of rural water supply schemes,* India Water Portal. https://www.indiawaterportal.org/questions/solution-exchange-discussion-ways-improve-om-rural-water-supply-schemes#Nm_Nripendra_Sarma

Iribarnegaray, M. A., Rodriguez-Alvarez, M. S., Moraña, L. B., Tejerina, W. A., & Seghezzo, L. (2018). Management challenges for a more decentralized treatment and reuse of domestic wastewater in metropolitan areas. Journal of Water, *Sanitation and Hygiene for Development*, 8(1), 113-122.

Jadhav, P. S., & Deshmukh, V. U. (2012). Forest fire monitoring system based on ZIG-BEE wireless sensor network. *International Journal of Emerging Technology and Advanced Engineering*, 2(12), 187-191.

Jamwal, P., Zuhail, T. M., Urs, P. R., Srinivasan, V., & Lele, S. (2015). Contribution of sewage treatment to pollution abatement of urban streams. *Current Science*, 677-685.

Jamwal, P., Nayak, D., Urs, P. R., Thatey, M. Z., Gopinath, M., Idris, M., & Lele, S. (2021). A multi-pronged approach to source attribution and apportionment of heavy metals in urban rivers. *Ambio*, 1-19.

Jassima, O., & dekan Abbasl, Z. (2019). Application of GIS and AHP Technologies to Support of Selecting a Suitable Site for Wastewater Sewage Plant in Al Kufa City. *Al-Qadisiyah Journal for Engineering Sciences*, *12*(1).

Jones, E. R., Van Vliet, M. T., Qadir, M., & Bierkens, M. F. (2021). Country-level and gridded estimates of wastewater production, collection, treatment and reuse. *Earth System Science Data*, *13*(2), 237-254.

Joshi, R., & Ahmed, S. (2016). Status and challenges of municipal solid waste management in India: A review. *Cogent Environmental Science*, *2*(1), 1139434.

Jung, Y. T., Narayanan, N. C., & Cheng, Y. L. (2018). Cost comparison of centralized and decentralized wastewater management systems using optimization model. *Journal of Environmental Management*, *213*, 90-97.

Kakwani, N. S., & Kalbar, P. P. (2020). Review of Circular Economy in urban water sector: Challenges and opportunities in India. *Journal of Environmental Management*, *271*, 111010.

Katsriku, F. A., Wilson, M., Yamoah, G. G., Abdulai, J. D., Rahman, B. M. A., & Grattan, K.

T. V. (2015). Framework for time relevant water monitoring system. *In Computing in Research and Development in Africa* (pp. 3-19). Springer, Cham.

Keshtgari, M., & Deljoo, A. (2011). A wireless sensor network solution for precision agriculture based on zigbee technology. *University of Embu*

Khalid, S., Shahid, M., Bibi, I., Sarwar, T., Shah, A. H., & Niazi, N. K. (2018). A review of environmental contamination and health risk assessment of wastewater use for crop irrigation with a focus on low and high-income countries. *International journal of environmental research and public health*, *15*(5), 895.

Kumar, M. D., & Tortajada, C. (2020). *Assessing wastewater management in India* (pp. 53-58). Singapore: Springer.

Lele, S., & Sengupta, M. B. (2018). From lakes as urban commons to integrated lake-water governance: The case of Bengaluru's urban water bodies. *South Asian Water Studies*, *8*(1), 5-26.

Lele, S., Jamwal, P., & Menon, M. (2021). Challenges in regulating water pollution in India.

Economic & Political Weekly, 56(52), 47.

Li, Y., Lin, C., Wang, Y., Gao, X., Xie, T., Hai, R., & Zhang, X. (2017). Multi-criteria evaluation method for site selection of industrial wastewater discharge in coastal regions.

Journal of Cleaner Production, *161*, 1143-1152.

Life ECOSENS Aquamonitrix, (n.d.). Enhanced Portable Sensor for Water Quality Monitoring, moving to genuinely integrated Water Resource Management–*ECOSENS AQUAMONITRIX–LIFE* Available online: https://www.ecosensaquamonitrix.eu/ (accessed on 19/08/2022)

Luthy, R. G., Sedlak, D. L., Plumlee, M. H., Austin, D., & Resh, V. H.: Wastewater-effluent-dominated streams as ecosystem-management tools in a drier climate, *Frontiers in Ecology and the Environment*, 13, 477-485

Masi, F., Bresciani, R., Rizzo, A., Edathoot, A., Patwardhan, N., Panse, D., & Langergraber,

G. (2016). Green walls for greywater treatment and recycling in dense urban areas: a case-study in Pune. *Journal of Water, Sanitation and Hygiene for Development*, *6*(2), 342-347.

Mateo-Sagasta, J., Raschid-Sally, L., & Thebo, A. (2015). Global wastewater and sludge production, treatment and use. In *Wastewater* (pp. 15-38). Springer, Dordrecht.

Minhas, P. S., Saha, J. K., Dotaniya, M. L., Sarkar, A., & Saha, M. (2022). Wastewater irrigation in India: Current status, impacts and response options. *Science of the Total Environment*, 808, 152001.

MoJS. (2020). *National Framework on the Safe Reuse of Treated Water*. Department of Water Resources, River Development & Ganga Rejuvenation, National Mission for Clean Ganga, Ministry of Jal Shakti, Government of India

MoUD, Ministry of Urban Development Government of India, (2010). *Review of current practices in determining user charges and incorporation of economic principles of pricing of urban water supply.* The Energy and Resources Institute, New Delhi.

MoWR. (2017). *STPs Under Ganga Action Plan.* Ministry of Water Resources (MoWR), River Development and Ganga Rejuvenation, New Delhi, India.

Murmu, S. K., Islam, N., & Sen, D. (2021). The heritage sewer networks of Kolkata (Calcutta) and ascertaining their coping potential under growing urban pressures. *ISH Journal of Hydraulic Engineering,* 1-11.

Murray, E., Roche, P., Harrington, K., McCaul, M., Moore, B., Morrin, A., Diamond. D., & Paull, B. (2019). Low cost 235 nm ultra-violet light-emitting diode-based absorbance detector for application in a portable ion chromatography system for nitrite and nitrate monitoring. *Journal of Chromatography A*, 1603, 8-14.

Neji, H. B. B., & Turki, S. Y. (2015). GIS-based multicriteria decision analysis for the delimitation of an agricultural perimeter irrigated with treated wastewater. *Agricultural Water Management*, *162*, 78-86.

Nikore, Mittali., & Mittal, Mahak. (2021). Arresting India's Water Crisis: The Economic Case for Wastewater Use. Issue Brief. *Observer Research Foundation.*

Noriega-Linares, J. E., & Navarro Ruiz, J. M. (2016). On the application of the raspberry Pi as an advanced acoustic sensor network for noise monitoring. *Electronics*, 5(4), 74.

Paul, M., Negahban-Azar, M., Shirmohammadi, A., & Montas, H. (2020). Assessment of agricultural land suitability for irrigation with reclaimed water using geospatial multi-criteria decision analysis. *Agricultural Water Management*, *231*, 105987.

Pérez, G., Coma, J., Martorell, I., & Cabeza, L. F. (2014). Vertical Greenery Systems (VGS) for energy saving in buildings: A review. *Renewable and sustainable energy reviews*, *39*, 139-165.

PIB. (2022, July 21). *Namami Gange Programme* {Press release]. https://pib.gov.in/PressReleasePage.aspx?PRID=1843386

Qadir, M., Drechsel, P., Jiménez Cisneros, B., Kim, Y., Pramanik, A., Mehta, P., & Olaniyan,

O. (2020, February). Global and regional potential of wastewater as a water, nutrient and energy source. In *Natural resources forum* (Vol. 44, No. 1, pp. 40-51). Oxford, UK: Blackwell Publishing Ltd

Ranjan, S., Gupta, P. K., & Gupta, S. K. (2019). Comprehensive evaluation of high-rate algal ponds: wastewater treatment and biomass production. In *Application of microalgae in wastewater treatment* (pp. 531-548). Springer, Cham.

Ravishankar, C., Nautiyal, S., & Seshaiah, M. (2018). Social acceptance for reclaimed water use: a case study in Bengaluru. *Recycling*, *3*(1), 4.

Rodić, L., & Wilson, D. C. (2017). Resolving governance issues to achieve priority sustainable development goals related to solid waste management in developing countries. *Sustainability*, *9*(3), 404.

Rodriguez, C., Van Buynder, P., Lugg, R., Blair, P., Devine, B., Cook, A., & Weinstein, P. (2009). Indirect potable reuse: a sustainable water supply alternative. *International journal of environmental research and public health*, *6*(3), 1174-1209.

Salgot, M., & Folch, M. (2018). Wastewater treatment and water reuse. *Current Opinion in Environmental Science & Health*, *2*, 64-74.

Saliba, R., Callieris, R., D'Agostino, D., Roma, R., & Scardigno, A. (2018). Stakeholders' attitude towards the reuse of treated wastewater for irrigation in Mediterranean agriculture. *Agricultural Water Management*, *204*, 60-68.

Sato, T., Qadir, M., Yamamoto, S., Endo, T., & Zahoor, A. (2013). Global, regional, and country level need for data on wastewater generation, treatment, and use.

Agricultural Water Management, 130, 1-13

Schellenberg, T., Subramanian, V., Ganeshan, G., Tompkins, D., & Pradeep, R. (2020).

Wastewater discharge standards in the evolving context of urban sustainability–The case of India. *Frontiers in Environmental Science*, 30.

Sharma, A. K., Tjandraatmadja, G., Cook, S., & Gardner, T. (2013). Decentralised systems–definition and drivers in the current context. *Water Science and Technology*, 67(9), 2091-2101.

Singh, A. (2019). Remote sensing and GIS applications for municipal waste management.

Journal of environmental management, *243*, 22-29.

Singh, A., Sawant, M., Kamble, S. J., Herlekar, M., Starkl, M., Aymerich, E., & Kazmi, A. (2019). Performance evaluation of a decentralized wastewater treatment system in India. *Environmental Science and Pollution Research,* 26(21), 21172-21188.

Singh, R., Samal, K., Dash, R. R., & Bhunia, P. (2019). Vermifiltration as a sustainable natural treatment technology for the treatment and reuse of wastewater: a review. *Journal of environmental management*, *247*, 140-151.

Smith, H. M., Brouwer, S., Jeffrey, P., & Frijns, J. (2018). Public responses to water reuse–Understanding the evidence. *Journal of Environmental Management*, *207*, 43-50.

Tilley, E. Ulrich, L., Lüthi, C., Reymond, P., & Zurbrügg, C. (2014). Compendium of Sanitation Systems and Technologies. 2nd revised edition. *Dübendorf : Swiss Federal Institute of Aquatic Science and Technology (Eawag).*

Timm, S. N., & Deal, B. M. (2018). Understanding the behavioral influences behind Singapore's water management strategies. *Journal of Environmental Planning and Management*

UNESCO. (2017). *Wastewater The Untapped Resource. The United Nations World Water Development Report-2017*, The United Nations Educational, Scientific and Cultural Organization.

United Nations. (2019*). World Urbanization Prospects: The 2018 Revision (ST/ESA/ SER.A/420)*. Department of Economic and Social Affairs, Population Division, New York: United Nations.

Vijayakumar, N., & Ramya, A. R. (2015, March). The real time monitoring of water quality in IoT environment. In 2015 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS) (pp. 1-5). *IEEE*. 3 January 2020).

Villarín, M. C., & Merel, S. (2020). Paradigm shifts and current challenges in wastewater management. *Journal of hazardous materials*, *390*, 122139.

Voulvoulis, N. (2018). Water reuse from a circular economy perspective and potential risks from an unregulated approach. *Current Opinion in Environmental Science & Health*, *2*, 32-45.

Wang, M., & Gong, H. (2018). Not-in-my-backyard: legislation requirements and economic analysis for developing underground wastewater treatment plant in China. *International Journal of Environmental Research and Public Health*, *15*(11), 2339.

WWAP (United Nations World Water Assessment Programme). (2017). *The United Nations World Water Development Report 2017.* Wastewater: The Untapped Resource. Paris, UNESCO.

Wei, F., Shahid, M. J., Alnusairi, G. S., Afzal, M., Khan, A., El-Esawi, M. A., Abbas, Z., Wei, K., Zaheer, I.E., Rizwan, M., & Ali, S. (2020). Implementation of floating treatment wetlands for textile wastewater management: a review. *Sustainability*, *12*(14), 5801.

Yi, W. Y., Lo, K. M., Mak, T., Leung, K. S., Leung, Y., & Meng, M. L. (2015). A survey of wireless sensor network-based air pollution monitoring systems*. Sensors,* 15(12), 31392-31427.

Zhou, H. (2012). The internet of things in the cloud. *Boca Raton*, FL: CRC press.

Zolfaghary, P., Zakerinia, M., & Kazemi, H. (2021). A model for the use of urban treated wastewater in agriculture using multiple criteria decision making (MCDM) and geographic information system (GIS). *Agricultural Water Management*, *243*, 106490.

Almost 80% of water supply ows 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.

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.

NITI Aayog

ATAL INNOVATION MISSION