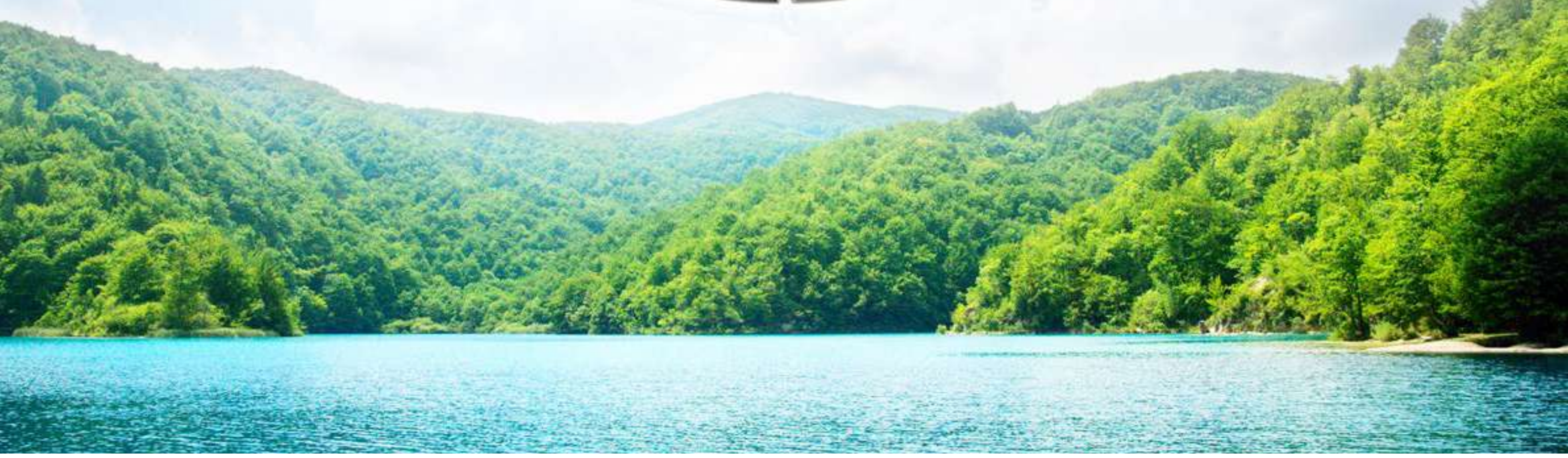
ASEAN'S JOURNEY TOWARDS SUSTAINABLE SANITATION:

A Practical Guide to Decentralised Wastewater Management



IGES Institute for Global Environmental Strategies

National Water Resources Board

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50th Year of ASEAN-Japan Friendship and Cooperation

JAIF Japan-ASEAN Cooperation

ASEAN'S JOURNEY TOWARDS SUSTAINABLE SANITATION: A PRACTICAL GUIDE TO DECENTRALISED WASTEWATER MANAGEMENT

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Foreword

Rapid urbanisation and population growth in ASEAN cities and provinces have brought to the fore one of the region's most pressing issues—the appropriate management of wastewater. This challenge is both an obstacle and the key to progress for rapidly developing ASEAN nations. The current state of wastewater management in many ASEAN cities and provinces is not only detrimental to the environment and public health, but it also hinders the collective progress of ASEAN countries towards ensuring access to clean and safely managed water, and sanitation services for all. This predicament is further complicated by the diverse geographical, climatic and socio-economic contexts across the ASEAN region. From sprawling metropolises to remote rural areas, the challenges facing wastewater management are as varied as the landscapes themselves. In many areas, outdated or non-existent wastewater treatment facilities, coupled with a lack of practical technical guidelines and financial resources, contribute to the problem. The impacts of these challenges are far-reaching and hinder the ASEAN region's efforts to achieve the targets of Sustainable Development Goals (SDGs) 6.2 and 6.3. Without adequate sanitation and hygiene, or any substantial improvements in water quality, ASEAN countries risk falling short of their commitment to ensure access to clean water and sanitation for all.

Hence, "**ASEAN's Journey Towards Sustainable Sanitation: A Practical Guide to Decentralised Wastewater Management**" emerges as a vital resource in this context. It provides a comprehensive toolkit for ASEAN municipalities to navigate decentralised wastewater management complexities. The decentralised wastewater management (DWM) approach has gradually received increasing attention from ASEAN countries as a promising solution that can overcome the limitations of centralised systems, leading to sustainable, efficient and cost-effective wastewater management.

This Guidebook offers practical insights, best practices and actionable steps tailored to the specific challenges of municipalities in the region. It provides technical guidance regarding DWM system design, treatment technologies and reuse options, thus empowering local authorities and technicians to implement projects or programmes that meet their unique needs.

The Guidebook does not merely provide technical guidance; it affirms the power of collective wisdom and collaboration. It presents best practices and case studies from ASEAN and beyond, serving as an inspiration for municipalities embarking on their DWM journey.

This Guidebook aligns with the commitment of ASEAN countries to SDG 6, providing a roadmap to help ASEAN countries achieve targets SDG 6.2 and 6.3. We commend the experts and practitioners who have developed this Guidebook and express our gratitude to all ASEAN countries for their prioritisation of sustainable wastewater management.

We urge all ASEAN municipalities, policymakers and stakeholders to embrace this Guidebook as a blueprint for building resilient, sustainable communities. Let us seize this opportunity to safeguard our water resources, enhance public health and create a better future for all. Together, we can transform wastewater management challenges into opportunities for progress and prosperity.

Mr. Yasuo Takahashi
Executive Director,
Institute for Global Environmental Strategies (IGES)

Acknowledgements

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Operating under the auspices of the ASEAN Working Group on Water Resources Management, this initiative, also known as the PoDiWM-2 Project, is funded by the Japan-ASEAN Integration Fund (JAIF). Its primary objective is to assist ASEAN cities and municipalities in achieving inclusive, sustainable, resilient and dynamic growth—aligning with the ASEAN Vision 2020; the ASEAN Framework of Action on Marine Debris; and, the ASEAN Strategic Plan on the Environment, with a particular focus on the third, fourth and fifth strategic priorities of this plan.

This publication was made possible by generous funding from the Government of Japan through the JAIF. The project team would also like to sincerely thank the ASEAN Secretariat for their tremendous support, coordination and guidance, which were essential in ensuring the smooth and successful implementation of this significant regional initiative.

The final design of this Guidebook was completed with the strong support and dedicated efforts of all relevant members from URBANWaters Consulting GmbH, led by Andreas Schmidt, with contributions from Ajith Edathoot, Rohini Pradeep and Aparna Unni. Additionally, we wish to express our appreciation to the reviewers of this Guidebook, including the national focal points of ASEAN Working Group on Water Resource Management (AWGWRM), project technical advisors led by Dr. Ebie Yoshitaka from the National Institute for Environmental Studies (NIES) - Japan and the ASEAN Secretariat for their reviews, insightful comments and feedback on this Guidebook.

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Necessity of a Practical Guidebook

Access to clean water and appropriate sanitation is not only a fundamental human right but also a crucial factor for the socio-economic development of a region. Regrettably, numerous ASEAN countries continue to grapple with significant challenges in this regard. According to the SDG 6 Progress Report released by the United Nations in 2021, several ASEAN countries are lagging in their efforts to achieve SDG 6 targets, which strive for the availability and sustainable management of water and sanitation for all. The public sewer services in many cities, provinces and municipalities in the ASEAN region cover only a limited area. Furthermore, ASEAN countries are witnessing rapid population and urban growth, which adds to the burden on the existing wastewater treatment infrastructure. Meanwhile, conventional centralised wastewater management approaches often struggle with high infrastructure development and maintenance costs, inefficient use of water resources and a high environmental footprint. This cost factor becomes especially critical in ASEAN countries that largely include resource-constrained municipalities. Consequently, the decentralised wastewater management (DWM) approach has been steadily gaining traction as a promising solution towards achieving sustainable sanitation in ASEAN countries, particularly in the rapidly urbanising countries such as Thailand, Philippines, Indonesia, and Vietnam. Decentralised systems alleviate the concerns caused by centralised solutions by breaking down the task of wastewater management into smaller, more manageable and economically feasible units, subsequently creating opportunities for incrementally increasing city-wide coverage of improved sanitation services.

The decentralised approach involves managing wastewater near its source, using smaller sewer networks, adapting treatment to local conditions and assessing potential resource recovery options. It can also help to lessen the vulnerability of wastewater infrastructure to climate change impacts such as floods and storms, thus enhancing climate resilience and guaranteeing uninterrupted service provision. Effective DWM curtails the pollution of water bodies, protects aquatic ecosystems, and conserves biodiversity. Decentralised wastewater treatment systems (DEWATS) can also play a crucial role in removing the currently increasing number of microplastic pollutants from domestic wastewater sources.

However, appropriate operation and maintenance (O&M) of these systems requires a certain degree of technical proficiency that may not be readily available in all ASEAN communities, particularly those in remote and underdeveloped areas. Hence, without practical technical guidelines and regulations, it can be difficult to enforce the responsible management of these systems in these areas.

Hence, this Guidebook provides guidelines for developing and effectively implementing DWM programmes/projects that would prove instrumental in assisting ASEAN municipalities to tackle these challenges. Importantly, it aligns with the Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation), SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action), adopted by ASEAN countries.

This Guidebook provides valuable insights, best practices and a step-by-step technical guide for developing, implementing and managing decentralised wastewater projects. It covers various aspects, including establishing the enabling regulatory and institutional frameworks, site selection, technology selection, wastewater reuse options and monitoring strategies. The Guidebook also compiles best practices and case studies from ASEAN countries that highlight successful decentralised wastewater projects and their positive impacts. These experiences aim to inspire municipalities, promote knowledge exchange and expedite the adoption of decentralised systems. To ensure sustainability, decentralised systems require efficient management and a well-developed enabling environment at the municipal level. Hence, this Guidebook delineates the necessary policy and regulatory frameworks required to support decentralised wastewater projects. It also underscores the importance of stakeholder engagement, institutional arrangements, legal considerations and financial mechanisms.

Sustainability of decentralised wastewater treatment and management systems

The sustainability of wastewater treatment and management systems is essential for protecting the environment, safeguarding human health, conserving resources and contributing to economic and social well-being. Infrastructure and service investments, whether public or private, should also align with sustainability principles. However, investments in decentralised wastewater treatment projects frequently face numerous sustainability challenges related to technical, environmental, financial and societal factors; The five major sustainability challenges are highlighted below:

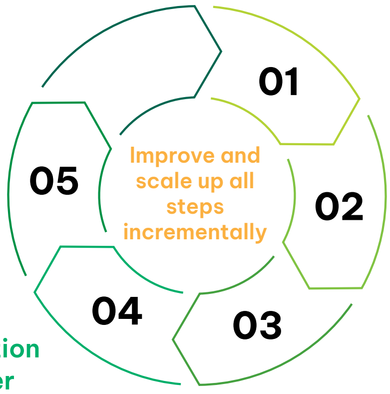
Figure a. Five major sustainability challenges for decentralised wastewater projects *(Source: Author)*

This Guidebook seeks to address these issues in a fundamental and universal manner. Legally or administratively, DWM can be divided into two categories: on-site and off-site infrastructure and services. The majority of on-site systems, including those serving institutions, commercial properties and individual parcels of land, are privately owned and operated.

Conversely, off-site systems are primarily publicly owned and operated, typically involving public sewer networks and treatment plants.

From the municipality's perspective, managing on-site sanitation and wastewater systems necessitates establishing an effective regulatory framework to ensure that individual plot owners adhere to overarching environmental policies. The municipality is primarily responsible for regulating and monitoring these systems. In the figure below, the primary responsibilities of a municipality are depicted via a Sustainability Compass.

On-site sanitation
Privately owned & managed



1. Set regulatory framework
- Septage management
- Installation & operation standards
- Discharge requirements
- Non-compliance system

2. Create mode for financing the regulatory framework
- Registration fees
- Pemalty system
- Public tax

3. Conduct inhouse capacity development
- Approval processes
- Inspection of implementation
- Project management

4. Facilitate training & certification for service & technology provider
- Training & certification body

5. Conduct public awareness campaign
- Regulatory framework
- Service provider
- Technical installation & operation standards

Figure b. Sustainability Compass for privately owned and managed on-site wastewater infrastructure
(Source: Authors)

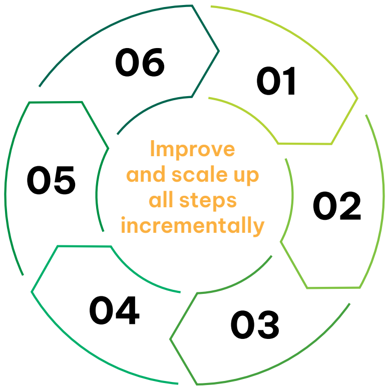
Once a municipality decides to provide public sewer-based wastewater services to residential and commercial areas, the system transitions into off-site wastewater management and publicly owned and operated infrastructure and services. Consequently, the primary responsibilities of the municipality shift from regulation and monitoring to operation. The municipality is tasked with implementing and operating the infrastructure and services, while ensuring compliance with overarching environmental policies. This transition, particularly for secondary or smaller cities/municipalities in ASEAN countries, frequently presents underestimated difficulties in terms of the municipality's capacity to finance, operate and manage wastewater systems. Hence, by using the Sustainability Compass as a guide, we can effectively address these challenges.

Off-site sanitation Publicly owned & managed

6. Conduct public awareness campaign
- Regulatory framework
- Operation service

5. Integrate DWW projects into urban planning
- Water & climate sensitive design
- Resource recovery (water, nutrients, energy)

4. Conduct inhouse capacity development
- Asset & operation management
- Operator training



1. Set model for financing O&M expenses fully for 10-20 years projection
- Project lifecycle cost analysis
- Assessment of tariffs or tax incomes

2. Set regulatory framework
- Plot/ sewer connection
- Fee collection
- Institutional setup for operation
- Ringfence of incomes

3. Set technical standards for design, construction and operation

Figure c. Sustainability Compass for publicly owned and managed sewered off-site wastewater services
(Source: Authors)

Establishing both on-site and off-site systems for wastewater management is a gradual process, which needs a substantial period to reach completion. The steps outlined in the Sustainability Compass for the on-site and off-site systems should be continuously enhanced and expanded to increase the scale, impact and longevity of the systems.

Thus, this Guidebook provides information and direction for the implementation and ongoing improvement of decentralised wastewater treatment and management systems.

Objectives and Structure of the Practical Guidebook

This Guidebook, titled "ASEAN's Journey Towards Sustainable Sanitation: A Practical Guide to Decentralised Wastewater", aims to provide ASEAN municipalities with a comprehensive resource for effectively designing, implementing and managing decentralised wastewater projects. The specific objectives of the Guidebook are as follows:

1. Offering technical guidance: This Guidebook provides step-by-step technical guidance on designing decentralised wastewater projects, including the conceptualisation and treatment selection, wastewater reuse options and monitoring strategies. This Guidebook will empower municipalities to make informed decisions and implement sustainable and appropriate decentralised wastewater solutions.
2. Presenting best practices and case studies: This Guidebook shares best practices and case studies from ASEAN countries and beyond. It also provides an overview of the existing manuals and addresses specific areas of decentralised wastewater management.
3. Addressing policy and regulatory considerations: This Guidebook outlines the policy and regulatory frameworks required to support decentralised wastewater projects. This includes considerations for stakeholder engagement, institutional arrangements, legal frameworks and financial mechanisms. By addressing these aspects, this Guidebook assists municipalities in navigating the policy landscape and implementing projects within the existing framework.
4. Fostering capacity building: This Guidebook provides instructions to facilitate capacity building at the municipal level by equipping local authorities, engineers and technicians with the knowledge and skills necessary for planning, implementing and managing decentralised wastewater projects. The Guidebook will empower municipalities to take ownership of these initiatives and ensure their long-term sustainability.

Overall, this Guidebook aims to serve as a practical and comprehensive resource that empowers municipalities in ASEAN countries to design and implement decentralised wastewater projects that address their specific challenges, foster sustainable development and contribute to the achievement of SDGs.

To facilitate the aforementioned objective, the Guidebook is organised as follows: Chapter 1 includes an introductory overview of the regional context pertaining to wastewater management (WWM). Subsequently, Chapters 2–7 offer an in-depth and universally applicable knowledge block, particularly focused on DWM. Chapters 8 and 9 provide practitioners with practical methodologies and detailed implementation procedures, which are closely aligned with the knowledge modules outlined in the knowledge block from Chapters 2–7.

Intro

1. Introduction & profiling WWM in ASEAN countries

2. Framing DWM

Knowledge block

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4. Technology selection
5. Operation & maintenance
6. Resource recovery
7. Manging emerging contaminates in wastewate
8. Design parameter guide

Application at city level

9. Guidance to formulate the enabling framework at city level for DWM

Application at project level

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11. Conclusion and recommendations

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- Guidebook chapters
- Existing documents
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List of Abbreviations

ABR	Anaerobic Baffled Reactor
AF	Anaerobic Filter
AFBR	Anaerobic Fixed-Bed Reactor
ARB	Antibiotic-Resistant Bacteria
ARGs	Antibiotic Resistance Genes
ASEAN	Association of Southeast Asian Nations
ASP	Activated Sludge Process
BOD	Biochemical Oxygen Demand
CAPEX	Capital Expenditure
CBA	Cost-Benefit Analysis
CG	Central Government
CWIS	City-Wide Inclusive Sanitation
CWs	Constructed Wetlands
COD	Chemical Oxygen Demand
DCF	Discounted Cash Flow
DEWATS	Decentralised Wastewater Treatment Systems
DWM	Decentralised Wastewater Management
EI	Educational Institutions
ECs	Emerging Contaminants
EIA	Environmental Impact Assessment
EPs	Emerging Pollutants
EO	Electro-Osmosis
FS	Faecal Sludge
FSM	Faecal Sludge Management
FSTPs	Faecal Sludge Treatment Plants
HRT	Hydraulic Retention Time

LCCA	Life Cycle Cost Analysis
LG	Local Government
MBBR	Moving Bed Biofilm Reactor
MBR	Membrane Bioreactor
MLD	Million Litres per Day
MPs	Microplastics
NGO	Non-Governmental Organisation
O&M	Operation and Maintenance
OD	Oxidation Ditch
ODA	Official Development Agency
OPEX	Operational Expenditure
R&M	Repair and Maintenance
RDC	Rotating Disc Contactor
RO	Reverse Osmosis
SBR	Sequencing Batch Reactor
SDGs	Sustainable Development Goals
SP	Private Service Provider (consultant, contractor, supplier, operator)
TF	Trickling Filter
USER	End User (residents, industry, institutions)
UT	Public Utility owned by LG or CG or legal community- or NGO-based entity
WWM	Wastewater Management
WWTPs	Wastewater Treatment Plants

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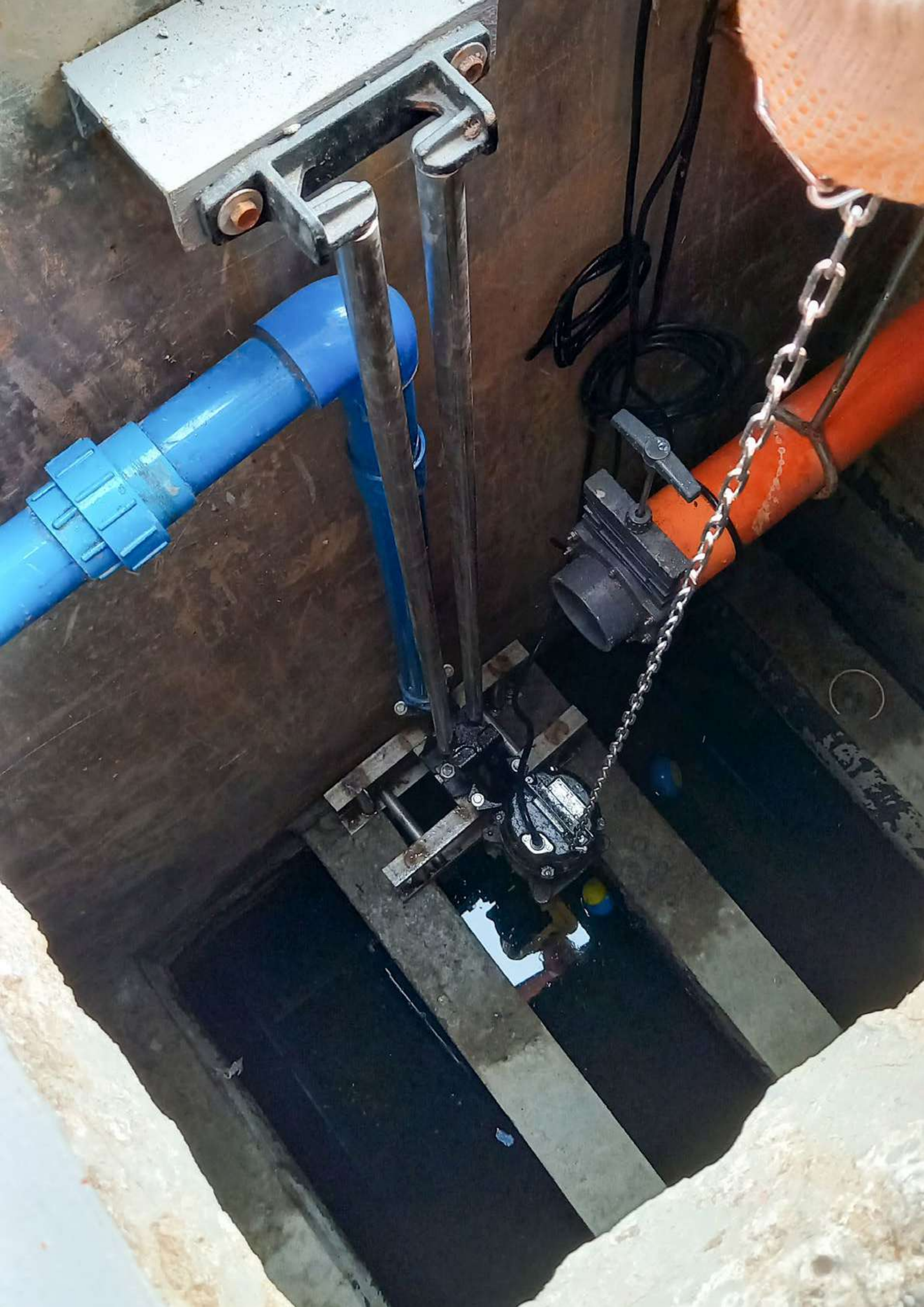


Chapter 1
Municipal wastewater management in ASEAN countries

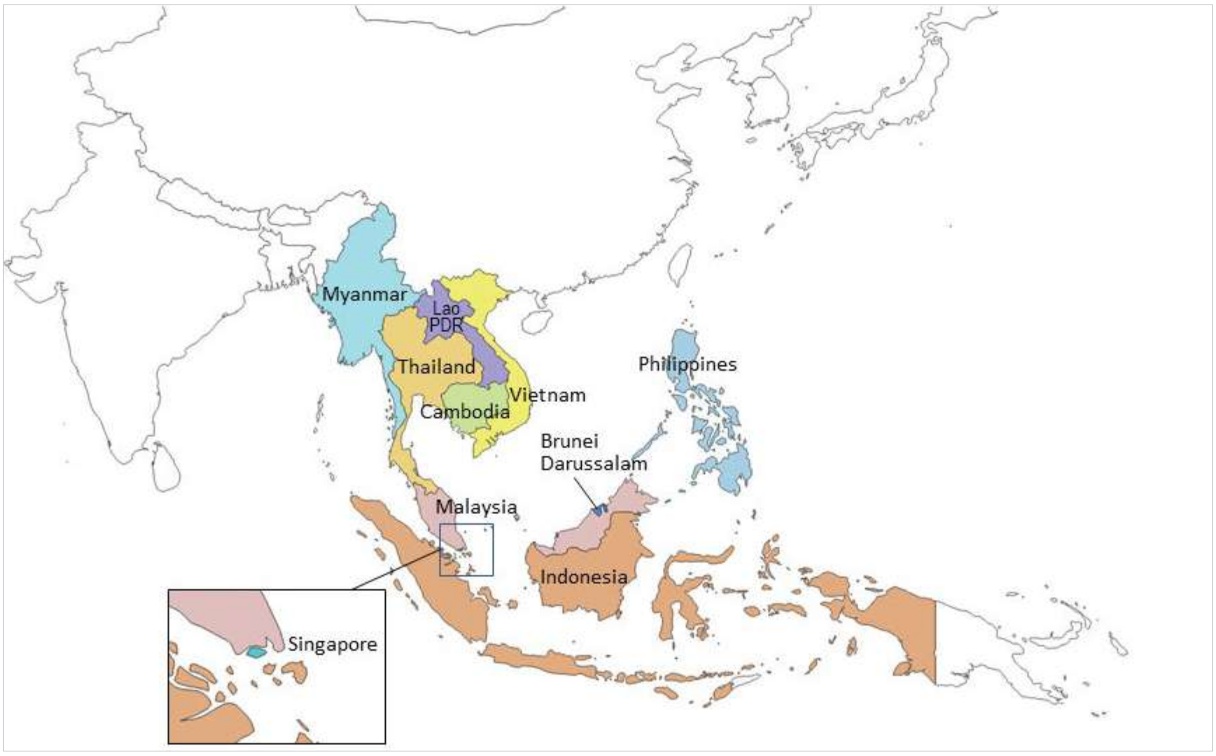


Figure 1.1. Countries in the ASEAN region
(Source: Authors)

1.1. Existing water supply and sanitation conditions in 10 ASEAN countries

The ASEAN region, comprising 10 nations, has made significant progress towards achieving universal access to safe water and sanitation. In 1990, 44% of the population of the ASEAN region did not have access to improved drinking water sources and 63% lacked improved sanitation. However, by 2015, the percentage of people without sustainable access to safe drinking water and basic sanitation had been reduced to less than 20%, in line with the Millennium Development Goals (MDGs).

Despite regional disparities, with countries such as Brunei Darussalam, the Republic of Singapore (hereinafter referred to as "Singapore") and Malaysia scoring high on these indicators and other countries such as the Kingdom of Cambodia (hereinafter referred to as "Cambodia"), Lao People's Democratic Republic (hereinafter referred to as "Laos") and the Socialist Republic of Vietnam (hereinafter referred to as "Vietnam") scoring low, there has been substantial progress regarding access to improved drinking water and sanitation across the ASEAN region, as indicated by MDG reports.

This positive trend continues in the era of Sustainable Development Goals (SDGs). The Joint Monitoring Programme (JMP) of UNICEF and the World Health Organization (WHO) provides data regarding the drinking water and sanitation service level across ASEAN countries, as depicted in Figures 1.2, 1.3 and 1.4.

Figure 1.2 shows that most ASEAN countries provide at least a basic level of drinking water services. Over 60% of urban areas in countries such as Singapore, the Republic of the Philippines (hereinafter referred to as "the Phillipines") and the Republic of the Union of Myanmar (hereinafter referred to as "Myanmar") provide safely managed drinking water services that are accessible on-premises, available and free from contamination. However, countries such as the Kingdom of Thailand (hereinafter referred to as "Thailand"), Vietnam and the Republic of Indonesia (hereinafter referred to as 'Indonesia') continue to primarily provide basic service levels; these include improved drinking water sources that may not necessarily be available on household premises (hereinafter referred to as "on-premises").

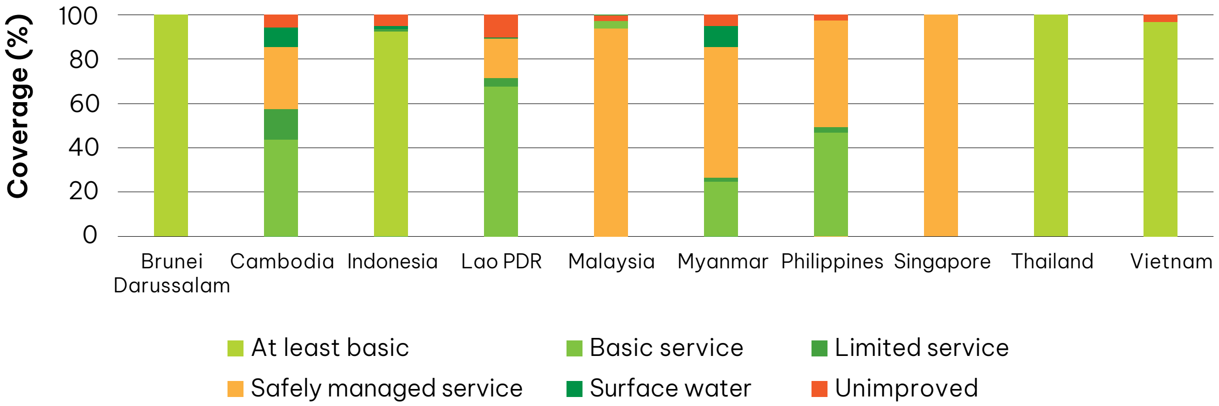


Figure 1.2. Access to drinking water in ASEAN
(Source: WHO & UNICEF 2020)

JMP definitions for Improved Drinking Water:
SAFELY MANAGED - Drinking water from an improved water source which is accessible on-premises, available when needed and free from faecal and priority chemical contamination;
BASIC - Drinking water from an improved water source, which fulfils the condition that the collection time is ≤ 30 min for a round trip including queueing;
LIMITED - Drinking water from an improved source, which fulfils the condition that the collection time exceeds 30 min for a round trip including queueing;
UNIMPROVED - Drinking water from an unprotected dug well or unprotected spring; SURFACE WATER – Drinking water directly to rivers, dams, lakes, ponds, etc.
(Source: Joint Monitoring Programme (2020 data) country dashboard)

Similar trends are observed regarding the access to improved sanitation in these countries, as shown in Figure 1.3 and Figure 1.4.

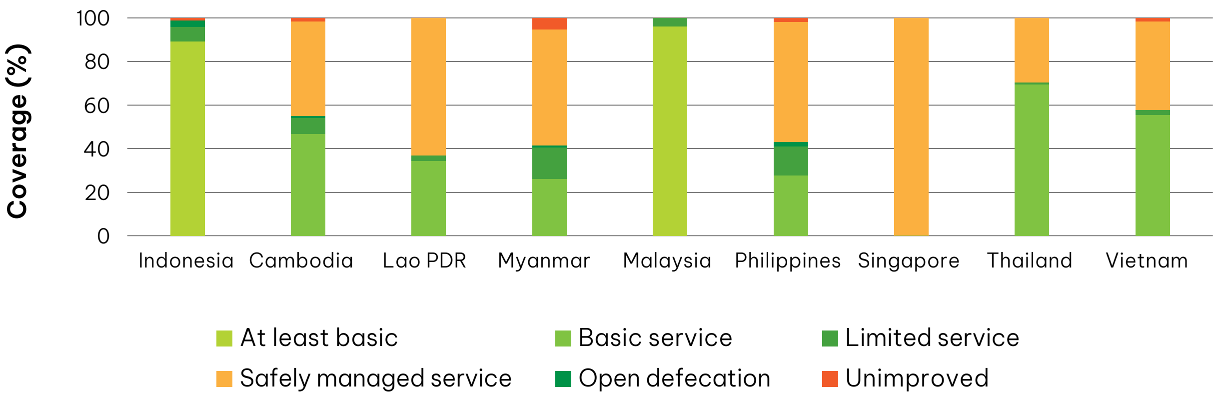


Figure 1.3. Access to improved sanitation in urban areas in ASEAN region
(Source: WHO & UNICEF 2020)

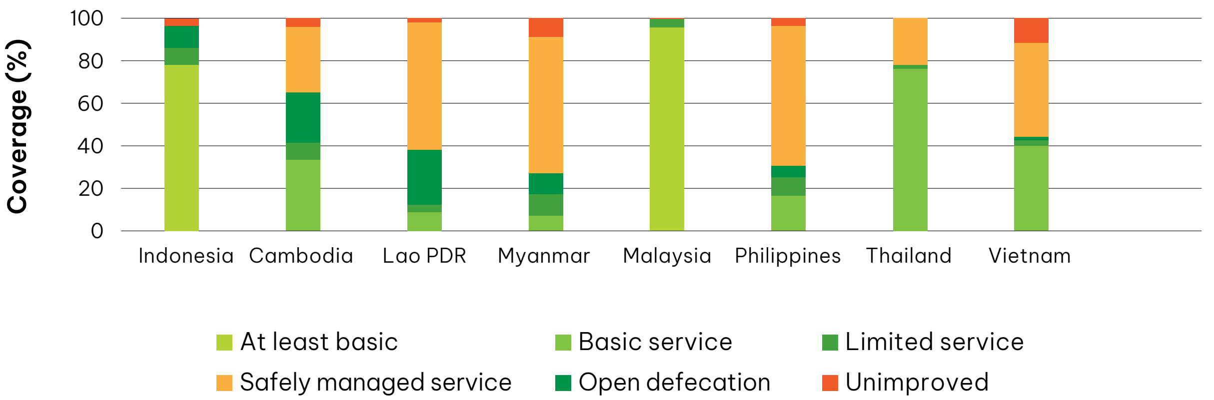


Figure 1.4. Access to improved sanitation in rural areas in ASEAN region
(Source: WHO & UNICEF 2020)

JMP definitions of Improved Sanitation:

SAFELY MANAGED- Use of improved sanitation facilities that are not shared with other households and where excreta are safely disposed of in situ or removed and treated off-site;

BASIC- Use of improved sanitation facilities which are not shared with other households;

LIMITED- Use of improved sanitation facilities shared between two or more households;

UNIMPROVED- Use of pit latrines without a slab or platform, hanging latrines or bucket latrines;

OPEN DEFECATION- Disposal of human faeces in fields, forests, bushes, open bodies of water, beaches and other open spaces or with solid waste

(Source: WHO & UNICEF 2020).

While most countries have achieved basic sanitation, only Singapore, Myanmar and the Philippines provide safely managed urban sanitation services. **The safe provision of these basic services depends on a critical factor: the safe treatment and reuse/disposal of generated wastewater.** This is also an important indicator of the gap to be bridged in meeting one of the global targets under Sustainable Development Goals that is, Target 6.3 under SDG 6, which aims to "*improve water quality by reducing pollution, eliminating dumping and minimizing the release of hazardous chemicals and materials, halving the proportion of untreated wastewater (-50%) and substantially increasing recycling and safe reuse globally*".

The UN Water Progress Report 2021 presents the following data (Table 1.1) regarding the proportion of household wastewater generated, collected and treated. It is important to note that the pertinent data were only available for five of the 10 ASEAN countries—namely Laos, Malaysia, the Philippines, Singapore and Thailand.

Table 1.1. Country-wise data regarding household wastewater

Country	Household Wastewater Generated				Household Wastewater Collected				Household WW Safely Treated			Proportion of Household WW safely treated (%)
	Total (m^3)	Proportion - sewers (%)	Proportion - septic tanks (%)	Proportion - all other (%)	Total (m^3)	Proportion - sewers (%)	Proportion - septic tanks (%)	Proportion collected (%)	Total (m^3)	Proportion - sewers (%)	Proportion - septic tanks (%)	
Brunei	47.2	95.4	0	4.6	-	-	-	-	-	-	-	-
Cambodia	333.8	29	64.2	6.8	-	-	-	-	-	-	-	-
Indonesia	6,903.3	15.6	81.4	3	-	-	-	-	-	-	-	-
Lao PDR	221.3	1.3	23.8	74.9	28.3	100	48.5	12.8	22.3	50	39.8	**10.1**
Malaysia	1,864.9	83.8	16.2	0	1,713.0	100	50	91.9	1,637.7	95.4	48.8	**87.8**
Myanmar	1,329.2	1.4	31.3	67.3	-	-	-	-	-	-	-	-
Philippines	3,193.1	8.4	84.3	7.4	1,564.2	100	48.2	49	1,371.3	50	46	**42.9**
Singapore	240.9	100	0	0	240.8	100	NA	100	240.8	100	NA	**100**
Thailand	3,540.5	13.7	83.1	3.2	1,812.1	100	23.7	33.4	863.9	50	21.1	**24.4**
Vietnam	2,867.6	1.3	73.2	25.5	-	-	-	-	-	-	-	-

(Source: UN Habitat and WHO, 2021)

Table 1.1 provides information regarding how household wastewater is managed in terms of collection and treatment based on the management system employed in each country. The figures in the table were obtained from country-level data regarding the population connected to the sewer network. The listed information represents a combination of calculated, estimated, assumed and reported data from the UN Statistical Department in each country. It is important to note that the figures for safely collected and treated wastewater from septic tanks include both faecal sludge (FS) and septage emptied and transported to off-site treatment plants, as well as that held safely in on-site containment.

As of 2022, **approximately 58% of the world's domestic wastewater is safely treated as per UN Water data**. In ASEAN countries, the percentage of safely treated domestic wastewater varies widely from country to country; however, as of 2022, the capacity of many countries to safely treat wastewater continues to be below 50%. The UN Water dashboard below presents specific data regarding the percentage of safely treated domestic wastewater in each ASEAN country.

Table 1.2. Updated figures for safely treated domestic wastewater in ASEAN (2022)

Country	Brunei	Cambodia	Indonesia	Lao PDR	Malaysia	Myanmar	Philippines	Singapore	Thailand	Vietnam
% Domestic Wastewater Safely Treated (2022)	-	47	-	10	88	15	67	100	25	40

Source: UN Water Dashboard; Data for Eastern and South-Eastern Asia; Website: Indicator | SDG 6 Data

Once again, the uneven distribution of data regarding the percentage of safely treated wastewater between the reporting countries is apparent. Singapore and Malaysia reported 100% and 88% safe treatment of household wastewater flow, respectively. While the Philippines seems to have improved its treatment coverage (from 43 to 67%), for other ASEAN countries, it continues to remain below 50%. For Brunei Darussalam and Indonesia, the significant gap in their treatment coverage as compared to the remaining ASEAN countries precludes their inclusion in the analysis.

These statistics highlight a significant gap in achievement regarding the safe treatment of household wastewater for most countries, except Singapore and, to a great extent, Malaysia.

Collectively, the data presented in Figures 1.2, 1.3 and 1.4 and Tables 1.1 and 1.2 indicate the following:

- Access to improved sources of water and sanitation has been achieved nearly universally across ASEAN nations. However, access to 'safely managed services', which represents the highest level of drinking water and sanitation services, continues to be a long way off for countries apart from Singapore and Malaysia.
- Safely managed services for drinking water are characterised by sources that are available on- premises, with adequate availability of water that is free from contamination. In the case of sanitation, the safe treatment and disposal of excreta, whether on-site or off-site, is a critical defining feature of safely managed services.
- On average, the proportion of safely treated wastewater in ASEAN countries is less than 50% of the collected wastewater. There is a significant disparity between individual nations, ranging from as low as 10% for Laos to as high as 100% for Singapore; the latter has also made significant strides in the safe reuse of treated wastewater. This disparity can be attributed to various factors, including historical and cultural factors, socio-economic factors, governance and political factors, infrastructure and technology factors and demographic factors. Additionally, geographic and climatic factors may have also played a role in creating this disparity.

1.2. Diversity within the ASEAN countries

This section provides an overview of ASEAN countries and highlights several factors that demonstrate the diversity within these neighbouring nations. These factors are significant because they serve as either drivers or barriers to the provision of drinking water and sanitation services.

Table 1.3. Demographic details of ASEAN countries

Name of the Country	Area (km²)	Population* (in millions)	Population Density (per km²)
Brunei Darussalam	5,8	0.43	74.6
Cambodia	181	16.59	91.7
Indonesia	1,919	272.25	141.8
Lao PDR	237	7.34	31.0
Malaysia	330,2	32.58	98.7
Myanmar	676,6	55.29	81.7
Philippines	300	110.19	367.3
Singapore	729	5.45	7.49
Thailand	513,140	65.21	127.1
Vietnam	331,344	98.50	297.3

** 2021 Population (Source: ASEAN Statistical Yearbook 2022)*

Regarding population density, there is a wide variation among the countries, even excluding the city state of Singapore. Laos has the lowest average population density of 31 persons per sq. km, while the Philippines has an average population density of over 10 times that number (367). Additionally, there exist intra-country variations in population density. All ASEAN countries include regions where the population density varies from 25–50 persons per sq. km to 500–1000 persons per sq. km.

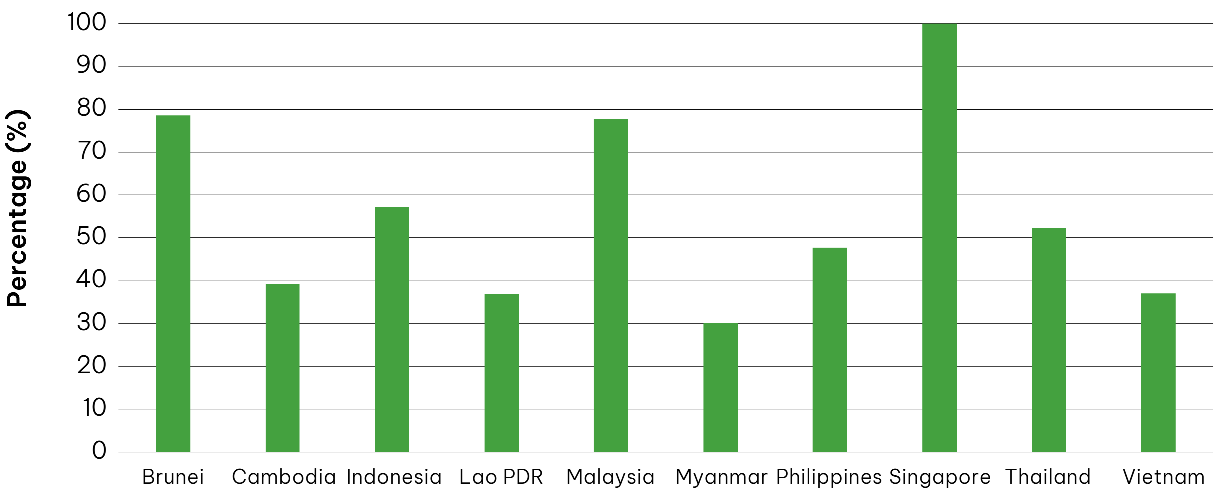


Figure 1.5. Proportion of the urban population in each ASEAN country
(Source: ASEAN Statistical Yearbook 2022)

Excepting Myanmar, ASEAN countries have experienced steady growth in their urban population over the last decade. Currently, in 5 out of the 10 ASEAN countries, over half of their population lives in urban areas. According to the United Nations Department of Economic and Social Affairs' World Urbanization Prospects, it is projected that by 2050, the majority of the population of all ASEAN countries will be living in urban areas. Even in countries where rural populations dominate, such as Myanmar and Cambodia, urban growth is expected to be between 10 % and 15 % till 2050, which would result in the doubling of the current urban population in these countries.

This rapid urbanisation is likely to increase the burden on natural resources and increase the demand for infrastructure and services. The responsibility of providing these services falls on various local bodies. It should be noted that planning infrastructure services in ASEAN countries, particularly wastewater management, will be a significant challenge due to variations in natural factors such as geography, hydrogeology and climate. These factors differ not only between nations but also within nations. For instance, Vietnam's climate varies regionally based on its topography. The northern parts of the country have a subtropical climate and are occasionally subjected to cold waves. In contrast, southern Vietnam remains hot throughout the year. The temperature ranges from 3–37°C in the mountainous regions and from 21–35°C in the southern plains.

Similarly, some countries, such as those part of the Indo-China peninsula, experience distinct dry and wet seasons, while island nations such as Malaysia and Indonesia face high temperatures and rainfall throughout the year. Table 1.4 provides some variations between the nations. When undertaking the planning for infrastructure services, local bodies must consider these variations to ensure that the services are effective and sustainable.

Table 1.4. Climatic and geographic variation across the ASEAN region

Country	Climate	Geography
Brunei	Tropical equatorial.	Comprises two unconnected parts: the western part (where most of the population resides) and the mountainous eastern part. The Borneo lowland rainforest comprises a major area of this country.
Cambodia	Tropical monsoon climate: Temperature ranges from 21–35°C; Extreme climate risk arising from water shortage, extreme flooding, mudslides, higher sea levels and potentially destructive storms.	The prominent landscape is a low-lying central plain surrounded by uplands and low mountains and includes the upper reaches of the Mekong Delta. Thinly forested transitional plains extend outwards from the central region and rise to elevations of approximately 650 feet.
Indonesia	Tropical rainforest climate: The dry season falls between May and October, and the wet season falls between November and April.	Lies along the equator; It is the world's largest archipelagic state.
Laos	Tropical savannah: Rainy season from May to October.	Landlocked; forested and mountainous landscape; it includes the Mekong River western boundary.
Malaysia	Equatorial climate; High temperature (23–32°C) and humidity; Mean annual rainfall for the peninsular region is 2,540 mm and that for east Malaysia is 2,030–3,560 mm.	Two regions separated by the South China Sea: Peninsular Malaysia and East Malaysia; Coastal plains rise to hills in the Peninsular region.
Myanmar	Monsoon climate; Annual rainfall range < 1000 mm in central parts to 5000 mm in coastal regions; Temperature ranges from 21–32°C.	Mountain ranges run north to south from the Himalayas; It includes three major river systems including Irrawaddy, Salween and Sittaung.

Country	Climate	Geography
Philippines	Tropical maritime climate with three distinct seasons; Annual temperature ranges from 21–32°C; Experiences 15–20 typhoons annually from July to October.	It is an archipelago consisting of more than 7,000 islands and islets. As it is on the western fringes of the Pacific Ring of Fire, the country experiences frequent seismic and volcanic activity.
Singapore	Tropical rainforest climate; No distinct seasons; Temperature ranges from 23–32°C.	Comprises 63 islands; Land reclamation has increased the land area by over 200 km^2 in the last five decades.
Thailand	Predominantly tropical savannah climate (i.e. this is partly tropical monsoon climate and tropical rainforest climate).	Located in the centre of the Indo-China peninsula.
Vietnam	Subtropical climate in northern Vietnam, tropical climate in southern Vietnam; and, variable temperature ranges in different parts (3–37°C in mountains and plateaus; 21–35°C in southern plains); Average rainfall is 1,500 - 2,000 mm; Prone to tropical depressions, storms and typhoons	Located on the Indo-China peninsula; The land is mostly hilly (40%) and forested (42%); The Red River Delta and Mekong River Delta are significant features of the landscape.

Based on the figures below, it is observed that there is some diversity in the hydrogeological setting of these countries. Figure 1.6 shows the hydrogeology of the countries in the Mekong River Basin and Figure 1.7 depicts the island countries Indonesia and the Philippines, along with Malaysia. For example, regions with strong pore water indicate alluvial areas, whereas strong karst water indicates soluble rocks such as limestone which subsequently holds large amounts of water. The presence of water in fissures or fractures indicates hard rocks. The region is also known for the scattered presence of volcanic rock.

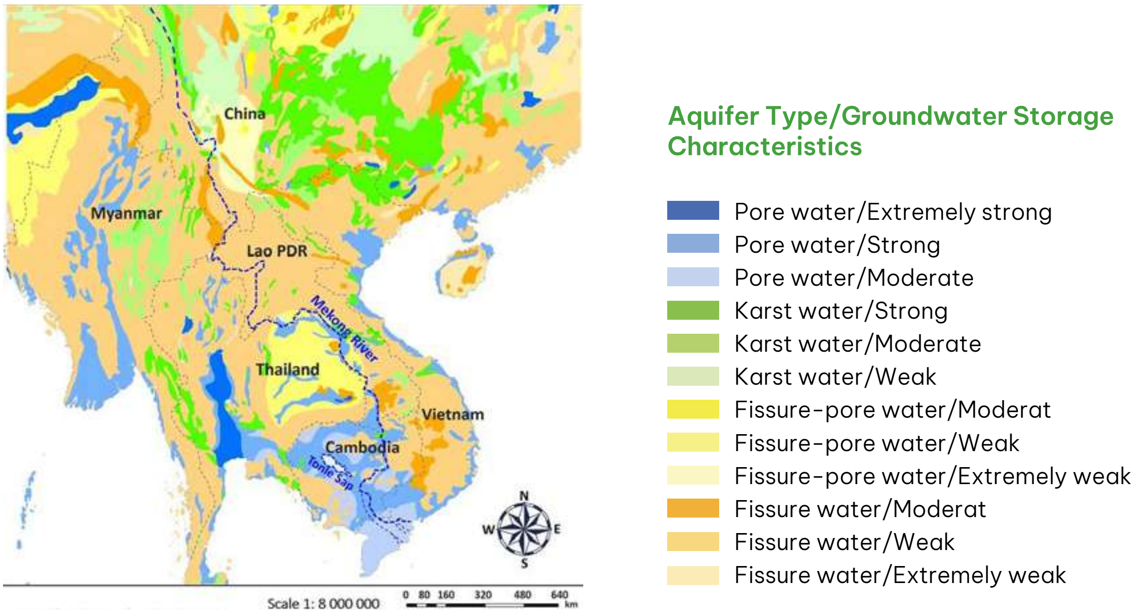


Figure 1.6. Hydrogeological setting of the Mekong River Basin
(Source: E. Lee et. al., 2018)

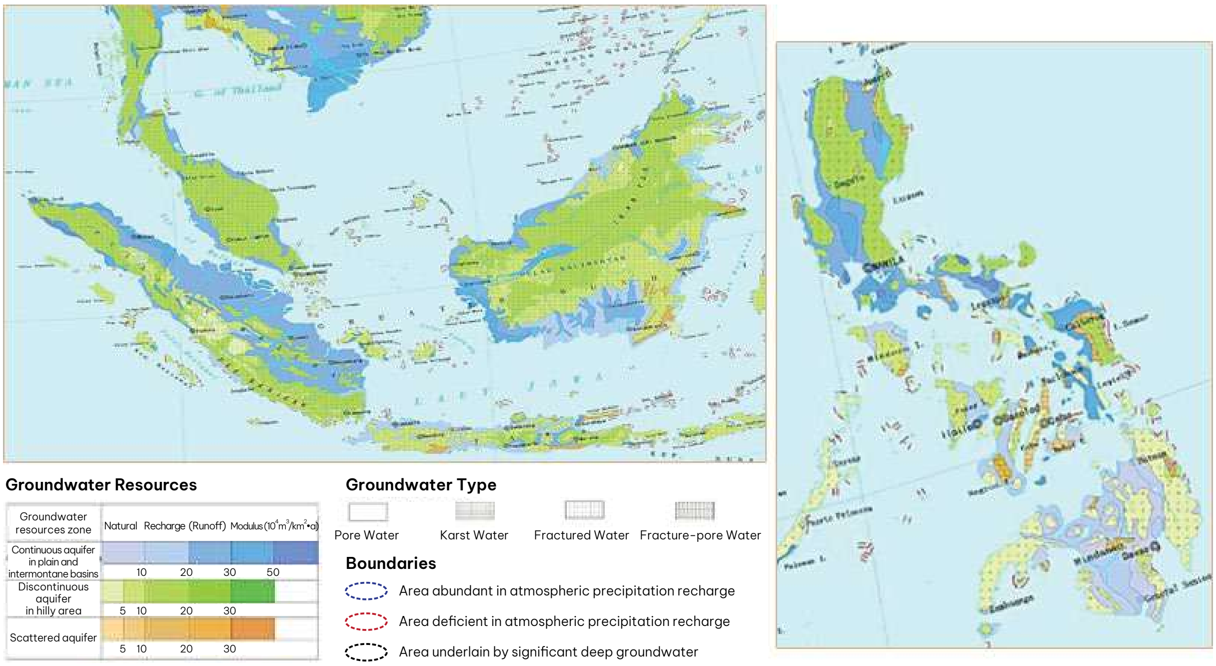


Figure 1.7. Hydrogeological setting: Indonesia, Malaysia and the Philippines
(Source: China Geological Survey, 2012)

However, this is only a broad regional overview. The geological diversity within each country is likely to be even more extensive; therefore, more colourful maps will emerge. This is important to note because it indicates the litho-diversity, soil setting and groundwater behaviour in different regions. These factors directly influence the design and implementation of infrastructure such as wastewater treatment facilities in these regions.

Towards improved governance regarding DWM in ASEAN

All of the factors mentioned so far—the gap in terms of safely managed water and sanitation services (especially wastewater treatment); the steadily growing urban population; and the diversity with respect to topography, climate, hydrogeology, etc. both between and within ASEAN countries—are all significant points in favour of adopting a decentralised approach to wastewater management in these countries.

This approach provides flexibility in terms of designing wastewater treatment systems which suit local needs and realities. Often, it is more cost-effective as compared to the centralised approach as well. Moreover, despite climate-related disasters, decentralised systems provide a better chance for building resilient systems as the risks are distributed. Typically, being on a smaller scale, they are also more manageable.

In the case of ASEAN countries, the responsibility of planning, implementing, maintaining and monitoring decentralised wastewater systems falls on various local authorities. These include town councils, municipal committees, village authorities, people's committees and local administrative organisations. These depend on the governance structure of different nations.

Given the diverse local governance structures across ASEAN countries, it is difficult to pinpoint a single body responsible for wastewater management. At the national level, different ministries or departments may be responsible for water and sanitation, whereas municipal administration regarding the service provision falls under another ministry or department. All these governance structures become important stakeholders in wastewater management at different levels.

Similarly, the roles and responsibilities of local government bodies can also vary. However, in general, local government bodies have the following responsibilities:

- Planning and implementing wastewater treatment and management systems within their respective jurisdictions;
- Regulating and monitoring the discharge of wastewater into the environment to ensure compliance with environmental standards and regulations;

- Collecting fees or taxes for wastewater management services provided to residents or businesses;
- Ensuring appropriate O&M activities regarding wastewater treatment facilities and infrastructure;
- Complaint redressal or attending to emergencies related to wastewater management, such as sewer overflows or blockages;
- Conducting public awareness and education campaigns to promote appropriate wastewater disposal practices and reducing the contamination of water bodies;
- Collaborating with other local government bodies and national and international organizations to share knowledge, resources and best practices regarding wastewater management.

There exist many barriers to wastewater management, especially at the local level. This is true for most ASEAN countries. In general, these barriers or challenges include the following:

- Lack of enforcement and regulation of standards;
- Poor O&M of the treatment plants;
- Low connection and collection efficiency;
- Weak cooperation among relevant stakeholders;
- Limited funds available from local bodies;
- Inadequate capacities and skills of the local workforce;
- Low public awareness regarding safe wastewater management.

It is within this larger context that this particular Guidebook is being prepared. It is primarily intended for municipal officials and other local decision-makers to plan and implement decentralised wastewater management (DWM) systems in their respective areas. The Guidebook is intended to provide local authorities with practical ways to plan, execute, maintain and monitor DWM systems. This includes not only solutions to questions such as how to select the appropriate technology, but also non-technical aspects such as regulations and financial sustainability.

Chapter 2
Framing decentralised wastewater management in the ASEAN context

2.1. Practical decentralised wastewater management concepts: An orientation through key terms

Figure 2.1. Frequently used terms in the context of decentralised wastewater systems

The above terms are often used in the context of decentralised wastewater systems. Some refer to specific technologies, whereas others are technical terms or conceptual ideas. The purpose of this chapter is to provide the definition of each term and guidance regarding the practical applications of these concepts in ASEAN countries. It is possible that other sources may provide slightly different definitions; however, they should not differ significantly from the definitions presented in this Guidebook. The conceptual ideas represented by certain terms are discussed in further detail in subsequent sub-chapters.

Decentral vs. central is a common distinction made in wastewater management discussions. However, providing a clear definition for these terms can be a complex task and the definition can vary depending on one's perspective.

For instance, in large metropolises such as Metro Manila, where 12 or more wastewater treatment plants (WWTPs) operate, the wastewater management system may be considered as decentralised. Nevertheless, each of these plants serves hundreds of thousands to millions of people. In contrast, for a private landowner, there are predominantly only two options to consider: establishing a wastewater system on their property or connecting it to a central public sewer system. Whether this system serves a 1,000 or 1 million people may not be their primary concern.

Chapter 2.1 of the Guidebook aims to clarify the approach to decentralised wastewater management addressed in this document.

Biogas, primarily comprising methane, is a natural by-product of anaerobic wastewater treatment. The concept of biogas production from anaerobic wastewater treatment is a well-researched topic. Many decentralised wastewater projects have attempted to generate biogas, subsequently promoting its use as an energy source for users of wastewater systems, thus creating a potential revenue stream. However, because of the low biogas generation potential of domestic wastewater and the increased technical complexity of the systems due to the addition of a biogas production unit, this concept is often not viable. However, treatment systems that combine biogas generation with source separation, where biogas is produced only from blackwater or faecal matter or is mixed with other organic waste, have proven to be both technically and economically feasible in DWM.

The cluster approach, also known as a 'decentralised wastewater cluster', is a technical term that refers to a city-wide wastewater system that comprises multiple independent sewer networks with treatment infrastructure. These clusters are designed to serve areas with similar characteristics. The boundaries of each cluster are mainly defined either by a hydraulic catchment area served exclusively by a gravity sewer system or by administrative boundaries. This system allows for a progressive and incremental approach to city-wide sewerage coverage, being especially useful for local bodies with limited resources.

Useful reference:

While the concept of decentralised clusters can be implemented in various ways, the 2022 publication titled 'Cluster Approach for Scaling up Decentralised Sanitation' reviews three examples of the cluster approach implemented in Phnom Penh, Cambodia; Mazar-e-Sharif, Afghanistan; and, Dar-es-Salaam, Tanzania; planning exercises for clustering were conducted in these cities. These examples

detail methodologies for ensuring city-wide coverage of sanitation services by using centralised, decentralised and on-site sanitation systems through the cluster approach.
(Source: Schmidt et al., 2022)

Community-based sanitation is a management approach in which a community forms a task force to actively plan and implement sanitation infrastructure and services for their own area. These projects often involve community members in their operations and are typically implemented with the help of development partners and municipalities in areas where public services are underdeveloped or cannot be provided by the designated water utility in the short to medium term. Consequently, community-based projects tend to be stopgap solutions that require a high level of capacity building. Since they are initiated and run by the community, these projects tend to have a high impact and foster a sense of ownership. However, challenges arise when such projects transition to mid- to long-term operations, committee or task force membership changes or when operational costs increase. When these projects are implemented top-down with insufficient capacity building, they often lack ownership and result in unsustainable service provision.

Useful reference:
Indonesia's SANIMAS programme, launched in 2006, is a well-known example of a community-based approach to sanitation. The SANIMAS programme trains local communities to operate and maintain sanitation facilities, including toilets, septic tanks and wastewater treatment systems. The programme also provides financial assistance to low-income households to help them access sanitation services. There are many examples of community-managed decentralised wastewater treatment systems (DEWATSs) built under this initiative in Indonesia. Typically, between 20 and 100 households are served by each DEWATS, with a community committee responsible for its maintenance (WSP, 2013).

The constructed wetland is a nature-based water and wastewater treatment technology, which will be further explained in Chapter 3.

Useful reference: *UN-HABITAT, 2008. Constructed Wetlands Manual.*

DEWATS refers to 'Decentralised Wastewater Treatment System'. Over the past decades, DEWATS has been promoted by the German NGO BORDA e. V. However, DEWATS is often mistakenly perceived as a BORDA technology or as an umbrella term for decentralised wastewater technologies. DEWATS is primarily a concept that aims to provide the most sustainable wastewater treatment solution for specific local conditions. It has been developed for applications in areas where the wastewater sector is underdeveloped and where there is no sufficient power supply. This objective resulted in a simple multi-stage, gravity flow-only technology concept consisting mainly of a sedimentation tank followed by an anaerobic baffled reactor and anaerobic filter and, in a few cases, a simple horizontal flow gravel filter. Further information on this topic is provided in Chapter 3.

Useful reference:

Ludwig Sasse, 1998. Decentralised Wastewater Treatment in Developing Countries

FSM stands for faecal sludge management and is a term used to describe the safe management of sludge and wastewater from non-sewered or on-site sanitation systems. It is an operational service that includes the following components of the sanitation value chain: containment, collection, transportation, treatment and disposal/reuse.

Useful reference:

Strande et al. 2014. Faecal Sludge Management: Systems Approach for Implementation and Operation

CASE STUDY 2.1. **FSM in Odisha, India**

The state of Odisha in eastern India has become the model for adopting state-wide FSM in the absence of large-scale sewerage networks and centralised treatment. The Odisha Water Supply and Sewerage Board leads FSM initiatives in the state and provides technical sanctions for establishing treatment plants in areas governed by smaller local bodies. Beyond the creation of infrastructure, the state streamlines the entire service through sustained tracking and management and establishes online systems to ensure compliance. In several instances, the entire O&M tasks of the faecal sludge treatment plants (FSTPs) are performed by women's self-help groups.

Greywater treatment is a technical concept that can be applied in two ways. First, along with wastewater source separation, low-pollutant wastewater from bathing, laundry and handwashing is treated separately, mainly for local reuse as irrigation water or to recycle water for other purposes, such as toilet flushing. Second, greywater is often considered as the effluent (supernatant) from septic tanks. Hence, the second option is to collect septic tank effluent from individual households and treat it in a centralised or semi-centralised wastewater treatment plant.

Useful references:

1. *Oteng-Peprah et al. 2018. Greywater Characteristics, Treatment Systems, Reuse Strategies and User Perception: A Review*
2. *Imhof & Muhlemann, 2005. Greywater Treatment at the Household Level in Developing Countries: A State-of-the-Art Review*

Interceptor wastewater treatment is a technical concept in which a wastewater treatment plant is installed either in or adjacent to a storm drain. The basic idea behind this concept is that many urban stormwater drains carry a high volume of wastewater from areas that are not sewered or are difficult to sewer in the short to medium term. In such cases, a treatment plant is installed in or adjacent to the storm drain to treat all or part of the flow (mainly dry weather flow) before it is discharged into a protected receiving water body such as a lake or river. This approach is highly common in India.

CASE STUDY 2.2. **Rejuvenation of Mahadevapura Lake through interception and diversion, followed by treatment.**

Mahadevapura is a 26-acre lake in the city of Bengaluru, India. It is part of the city's unique system of cascading lakes. Untreated sewage flowing into the lake through its outfalls was a major threat to the lake. A multi-stakeholder effort was undertaken to rejuvenate the lake.

These stakeholders were as follows:

- Bruhat Bengaluru Mahanagara Palika (BBMP), the city government;
- United Way of Bengaluru, which consolidated Corporate Social Responsibility (CSR) funds to implement interventions;
- Consortium for DEWATS Dissemination Society (CDD India, which designed and implemented wastewater treatment and lake replenishment solutions.

CDD developed a nature-based solution for this purpose. The effluent diverted from the lake inlet carrying sewage is treated by a 1 million litter per day (MLD) DEWATS, followed by floating wetlands. The treated water is subsequently released into the lake, greatly improving its water quality and preventing eutrophication.

Source: CDD India

"Johkasou" is a Japanese term for prefabricated or packaged WWTPs. These plants use activated sludge bed systems, moving bed bioreactors, trickling filters, and/or membrane bioreactors. National policies and regulations have resulted in setting standards for the technical design and operation of small to medium wastewater treatment systems used for on-site or privately owned and managed wastewater treatment systems in Japan. The effectiveness of such systems has been demonstrated in Japan through manufacturing efficiency, provision of systematic training and certification of operators. Consequently, the term 'Johkasou' has become well-known in the decentralised wastewater sector outside Japan.

Useful reference:
Hiroshi Ogawa. Domestic Wastewater Treatment by Johkasou Systems in Japan

Nature-based solutions are a term used in wastewater treatment to refer to an approach that uses natural processes and systems to address the challenges associated with wastewater treatment and management. It involves the implementation of techniques and strategies that mimic or harness the power of natural ecosystems to improve the treatment efficiency and overall sustainability of wastewater treatment processes. Nature-based solutions to wastewater treatment often involve the use of constructed wetlands (CWs), natural or engineered wetland systems and land-based treatment methods. These systems use the natural processes of filtration, biological degradation and nutrient cycling to treat and purify wastewater.

Non-sewered and sewered sanitation are terms used to describe the level of service provided to a particular community or service area. In sewered sanitation, wastewater is collected from individual properties or buildings through a network of wastewater pipes (sewers). This does not necessarily indicate that there is a treatment system at the end of the pipe. In unsewered areas, sanitation is provided by on-site systems such as pit latrines, septic tanks, cesspits or small-scale treatment plants.

CASE STUDY 2.3. **DEWATS in Alappuzha municipality, Kerala**

The following figure shows a small-scale DEWATS located within 15 m^2 in a low-income settlement. The system treats all wastewater from more than 50 households in the colony before discharging it into a nearby canal. The coastal city is famous for its intricate network of canals and is known as the Venice of the East. This treatment system was installed to prevent the canal from being polluted by untreated wastewater.

Source: CDD India

Low cost and low maintenance are terms often associated with decentralised wastewater systems, whereas centralised wastewater systems are perceived as costly. However, this perception is not entirely accurate from a technical standpoint and can often lead to poorly designed projects. While the specific per capita investment and operational costs of centralised systems are often lower, they require significantly higher initial investment and effort, as well as a developed enabling environment. In contrast, decentralised approaches have lower initial investment costs, less complexity and can be more easily adapted to the local context. This flexibility can prove to be advantageous in terms of cost-effectiveness and maintenance. However, it is crucial to recognise the importance of the high need for soft components and capacity-building efforts, which can account for 20–40% of the infrastructure budget. The goal of achieving 'low cost and low maintenance' sanitation should not lead to low quality and no maintenance sanitation, which has been a common problem in the past.

On-site and off-site sanitation are terms used to describe the location of a sanitation system and the bodies responsible for the running of these systems, as discussed in Chapter 2.4.

Package plants is a term used to describe a type of wastewater treatment system design. These plants are prefabricated systems made of materials such as polyethylene or fibreglass and are designed for sizes ranging from 6–50 PE (person equivalents). Container-based packaged systems can also accommodate wastewater of a volume of 500 PE. They incorporate various advanced wastewater treatment technologies. The manufacturing process ensures the production of high-quality wastewater treatment systems with a relatively low cost. However, transportation costs are often underestimated; further, these plants may have limited flexibility in terms of treatment capacity. Additionally, the cost of creating foundations for installing packaged plants should be considered. Note that Johkasou systems are essentially packaged systems. Please refer to Chapter 3 for further information.

Reuse is a term used to describe an activity and is part of the concept of 'resource recovery'. Wastewater contains components that can be recovered and reused with the appropriate technology; some examples include organic matter that can be used for generating energy or as compost, phosphate and nitrogen that can be used as fertiliser and recycled water that can be used for irrigation. See Chapter 7 for further information.

Simplified sewer is a term that expresses both a desire and technical concept. This desire stems from the inaccurate perception that conventional sewer designs (developed over the last century) are often excessively costly and complex in nature. However, it is important to approach this desire with caution, as it can lead to incorrect and poorly designed sewers that result in high operational effort and costs. As a technical concept, 'simplified sewer' aims to find the most optimal sewer design and layout based on local conditions through dedicated on-site engineering. Simplified sewer systems are gravity-based and include sub-concepts such as solids-free sewers or condominial sewers. Further detailed information can be found in Chapter 3.

Source separation is a technical concept that answers the question 'Is it right to combine all wastewater streams and treat them at the end of the pipe at a high cost or can certain waste streams be separated at the source for separate treatment and reuse?' In this context, the source refers to the indoor sanitation system itself, where blackwater can be separated from greywater or urine can be separated. Source separation in sanitation represents a revolutionary shift in wastewater management, both on-site and off-site. This is a key approach that enables effective resource recovery and reuse. Further detailed information can be found in Chapter 5.

Zero-discharge is a technical concept which aims to eliminate the generation of wastewater or to ensure that all wastewater generated is treated and reused on-site, thereby avoiding any discharge of wastewater into the public domain (off-plot). This often involves source separation and reuse, such as treating greywater separately from blackwater for different purposes, such as toilet flushing or gardening. The Indian government's promotion of the zero-discharge concept has several benefits. First, it helps conserve fresh water at its source through reuse, thereby reducing the pressure on water resources. Second, it helps reduce environmental pollution. It also relieves the government of the burden of providing sewerage services. Further detailed information can be found in Chapter 5.

2.2. Characterization of the on-site, decentralised and centralised wastewater management approaches

Municipal wastewater management can be broadly divided into three approaches, which are commonly practiced in cities, provinces and municipalities worldwide.

2.2.1. On-site Sanitation with Faecal Sludge Management (non-sewered)

The on-site approach divides the responsibility of wastewater management between private individuals and the city administration. In the on-site system, excreta and wastewater are collected, stored, and/or treated on the plot where they are generated (see Chapter 3). These plots can be used for residential (households), commercial and industrial activities, as well as for institutions such as hospitals, universities, and military camps. Technically, this on-site sanitation system can include latrines, sewer pipes, septic tanks, soak pits and even small- or medium-sized WWTPs, with or without effluent reuse. From an administrative viewpoint, what they all have in common is that the overall responsibility for managing the on-site sanitation system remains with the plot owner. Most on-site systems generate effluent and sludge that are stored in a containment. FSM is an external private or public operational service for the on-site system that collects and disposes of the sludge. To protect public health and the environment, the sludge needs to be treated and safely disposed of or reused.

This approach is characterized by a high degree of decentralization and fragmentation of responsibilities. In several cities of low - and middle-income countries, including the ASEAN region, on-site sanitation is practiced without a complete FSM system and sufficient treatment of the effluent. Changing this situation requires a strong enabling environment to ensure the sufficient construction and operation quality of on-site sanitation systems, professional and affordable emptying services and safe FSM. Most ASEAN countries face significant challenges in managing highly fragmented on-site systems; some of these challenges are: insufficient FSM, limited capacity for service delivery, low levels of investment and a lack of appropriate regulations and standards. Figures 2.2, 2.3 and 2.4 illustrate the degree of fragmentation associated with the on-site system and off-site decentralised and centralised treatment infrastructures.

Key features

- It is a non-sewered system in which the effluent wastewater from containment systems is discharged into stormwater drains, water bodies or infiltrated into the ground (open system)
- The FS from containment systems is emptied by a public or private service provider and transported to a sludge treatment plant either when the containment is filled up (on demand) or at fixed intervals organized by the utility (scheduled). This is referred to as FSM.

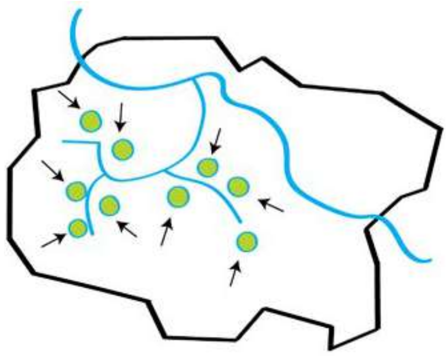


Figure 2.2. Visual conceptualisation of on-site sanitation

2.2.2. Decentralised Wastewater Management (DWM) Approach (sewered)

This approach involves a limited network of sewer systems that connect a few hundred plots or households to a small wastewater treatment plant located near the served areas. The management of such systems is mainly public and may be divided between the city administration and local stakeholders. The concept of having smaller service areas and networks reduces the total investment and operational costs, as well as the implementation period; it also increases the technical flexibility and adaptability to local conditions and supports local capacity development. DWM concepts are often applied in peri-urban areas, villages or small towns. However, there is also the option to connect individual DWM service areas or smaller clusters progressively to larger network clusters. A definition of DWM based on the number of people served is context-specific and is not uniform worldwide. However, commonly, decentralised systems serve up to 10,000 people, with most systems serving an area of 1,000–5,000 people; these systems can be hydraulically managed without/with minimal pumping of wastewater.

Technically, DWM system implementation includes a variety of technical options in the areas of source separation, collection, treatment and reuse/disposal (please see Chapter 5 for further information). While this variety in technical options proves to be particularly use for adapting wastewater concepts to the local context, it can also be challenging in terms of quality control of implementation and operation of systems due to their fragmentation. General challenges associated with DWM include finding land for installation and effluent discharge options, quality control of implementation and operation and managing a large number of individual installations. More ASEAN-specific challenges are outlined in Chapter 1.

The present Guidebook differentiates between:

- Privately owned and managed wastewater systems (these fall under on-site sanitation)
- Publicly owned and managed wastewater systems

Both are further explained in Section 2.4.

Key features

- Sewered system: This is a privately owned system that is operated on a specific plot (on-site) or publicly owned and either publicly or privately operated.
- A decentralised wastewater treatment system either discharges treated effluent into water bodies and stormwater drains or reuses it.
- Approximately 40-60% of the investment cost is used for constructing and maintaining the sewer network.

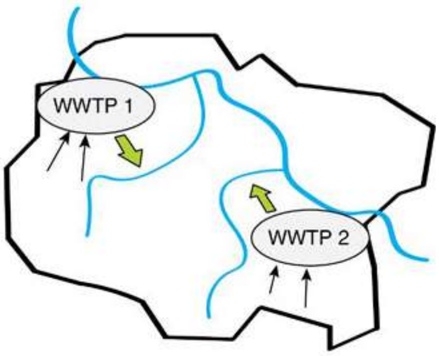


Figure 2.3. Visual conceptualisation of the DWM Approach

2.2.3. Centralised Wastewater Management Approach (sewered)

The centralised approach involves a large network of sewer pipes (often including pumping systems), connecting large areas of the city to one (or a few) central wastewater treatment plant(s). While the overall responsibility of operating this system lies with the government, its asset and operational management can be delegated to a designated utility or the city administration. Centralised systems typically serve highly populated urban areas.

In the context of ASEAN countries, the capital and other large cities operate centralised systems that mainly serve the city centres. The development of a centralised system to cover larger areas of a city is time (often requiring more than 20 years) and resource (costing millions of dollars) intensive. In ASEAN countries, only a small fraction of the population has access to centralized sewer systems. These systems typically treat less than 40% of the total wastewater generated in each country, with exceptions like Singapore and Malaysia..

Key features

- It is a sewered system in which the infrastructure is usually publicly owned and either publicly or privately operated.
- It has a large coverage area; however, it has high investment and operational costs.
- It requires high technical construction and operation standards and highly skilled personnel.
- Approximately 70–80% of the investment cost is required for the construction and operation of the sewer network.

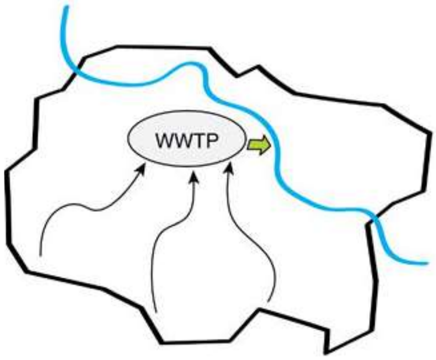


Figure 2.4. Visual conceptualisation of the centralised WWM approach

2.3. Drivers and barriers to DWM systems

One of the targets under SDG 6 is to improve water quality by reducing the proportion of untreated wastewater and increasing its reuse and recycling by 2030. However, in ASEAN countries, untreated wastewater, particularly from households, poses a significant barrier to achieving SDG 6. The UNDP estimates that over 80% of wastewater resulting from human activities is discharged into the environment without appropriate treatment. In the 10 ASEAN countries, 73.5% of the household wastewater remains untreated (UN Water 2021). To overcome this substantial challenge, the collection and treatment of wastewater near its source can play a pivotal role in the reduction of the amount of untreated wastewater released into the environment. Such decentralisation of wastewater management may also help address sustainability issues, as facilities can typically be constructed to meet current needs and expanded later as additional needs arise.

One advantage of decentralised systems is their ability to serve small portions (clusters) of an urban area according to local considerations of hydrogeology, landscape and ecology. A sustainable decentralised system is characterised by its focus on the on-site treatment of wastewater and the local recycling and reuse of the raw wastewater. The reusable treatment by-products include wastewater (for non-potable reuse), bioenergy (mostly from organic material transformation) and nutrients (mainly nitrogen and phosphorus).

Decentralisation also allows for the selection of the 'most appropriate technical and operation concept' in a given context. Ideally, the applied system should be economically affordable, environmentally safe, technically and institutionally consistent and socially acceptable for the specific application. Figure 2.5 illustrates the significant factors to consider when determining the sustainability of a technology.

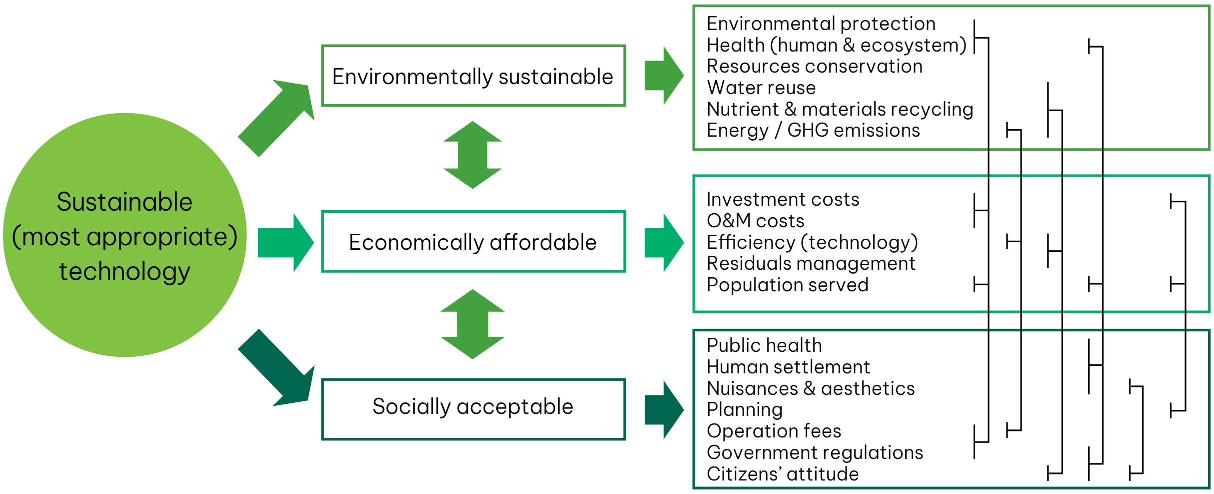


Figure 2.5. Sustainability criteria for the technologies
(Source: Capodaglio, Andrea G. 2017)

The different types of sustainability factors, that is, social, cultural, environmental and technical factors, must be considered in order to implement any wastewater treatment system; however, the financial resource aspect is often the most decisive factor in developing countries when choosing the type of wastewater treatment. This is the reason why decentralised systems are being increasingly considered as a viable alternative in developing countries because they are less intensive in terms of resource requirements and more ecologically sustainable than centralised systems (Tchobanoglous et al., 2003).

Centralised systems often require the construction of large WWTPs and extended conveyance pipes; the investments related to the latter may represent up to 70% of the total capital cost of the system. Developing countries cannot afford such high costs.

Another substantial difference between modern centralised and decentralised systems is the energy intensity required for their operation. Centralised systems are often associated with high energy consumption, mainly due to the use of wastewater pumping systems, although wastewater treatment systems themselves may benefit from some economies of scale and from the benefits of widely tested technology.

However, the decentralised approach is often impeded by the lack of appropriate policy frameworks and suitable institutional arrangements for managing such systems. Furthermore, there is an absence of technical assistance and capacity-building measures to support the effective implementation of decentralised systems (Parkinson and Tayler, 2003). Similarly, there is limited information on how sustainability can be ensured in regarding decentralised wastewater infrastructure; this concern is also applicable to the centralised treatment approach (Danyluk, 2008). Table 2.1 provides the drivers and constraints of the decentralisation of wastewater treatment.

Table 2.1. Drivers and constraints for implementing the DWM concepts

Drivers	Constraints	Impact of the constraints
Meeting the demand and goals for improved sanitation coverage	DWM is often considered a niche concept and is not yet fully integrated into the regulatory, institutional and financial framework (or enabling framework) of a city-wide sanitation strategy. Land requirements and land availability for the installation need to be determined. Effluent discharge options are often limited; less discharge into stormwater drains is a practical option.	The absence of enabling frame-works creates high transaction and capacity-building costs for individual DWM projects, affects their sustainability and hinders the potential of DMM projects to contribute to city sanitation goals.

Drivers	Constraints	Impact of the constraints
Lower investment cost and short realisation period	DWM infrastructures have a smaller capacity and coverage area; consequently, a lower total investment cost is required as opposed to that for centralised systems. However, the specific investment costs broken down to cost per capita can be similar or even higher than for larger, more centralised projects. DWM projects are often underfinanced and do not consider the effort required for local capacity development.	Often, DWM projects are considered and run as purely low cost and low-tech approaches, which often leads to low quality and unsustainable infrastructure and services.
Financial resource constraints		
Natural resource recovery demand	DWM projects can be adapted to the local context, demand and conditions, especially for the recovery and reuse of by-products such as treated water and biogas. Constraints often arise because DWM projects do not reach the economy of scale for the generation of by-products to be economically viable.	Idealistically planned projects may become highly complex, overloaded and lose their sustainability due to unplanned higher operational costs.
New ideas and design concepts	New ideas and innovations are needed to overcome constraints, unfold potential, recover resources and develop industries, including job creation, regarding DWM. DWM infrastructure and projects provide an ideal solution for developing countries; however, gaps in technical standards and evidence-based application of new concepts and technologies pose a sustainability threat to DWM projects.	Missing or weak technical standards demanded by the government can lead to an unsustainable price-driven business environment with ineffective incentives for the private sector to invest in quality products and services; this can also affect the procurement of human resources.
Business development and entrepreneurship		

(Source: The table was prepared by the authors)

2.4. Cost-benefit consideration of the DWM

There is a natural inclination among urban planners, central and local government representatives, and academia in municipal services to seek a universal method and criteria for making decisions about suitable wastewater management approaches and technical concepts.

To ensure adequate public health, environmental protection and public services in accordance with national policies, municipalities need to develop strategies, often in the form of a City-Wide Sanitation Masterplan and make critical decisions. These decisions are frequently tied to questions such as the following: Where and to what extent are on-site (non-sewered) or sewered wastewater management projects applicable? What are the feasibility and cost-effectiveness of centralised versus decentralised sewer projects?

In the water, sanitation and hygiene (WASH) sector, several attempts have been made to develop universal standards for criteria such as:

- Water consumption;
- Population density;
- Population income;
- Settlement characteristics and road accessibility;
- Geographical criteria;
- Specific costs per capita.

These criteria are essential for conducting area- or city -specific assessments. However, the outcomes derived from such assessments can only be deemed somewhat universal for areas or cities with similar characteristics.

This Guidebook focuses on the DWM approach. Chapter 2.3, especially Table 2.1, underscores the potential advantages and benefits of this approach. Furthermore, municipalities may raise the following critical questions: can the benefits of DWM be realised in their respective municipality areas? What are the costs for such a realisation?

Any cost-benefit analysis should be conducted on the basis of an area-or municipality-specific assessment. Concepts for design, implementation and operation may be cost-effective and beneficial in one project area but not in another if the underlying conditions differ.

Chapter 9 of this Guidebook introduces the topic of the City-Wide Sanitation Masterplan and the City-Wide Inclusive Sanitation (CWIS) approach and refers to useful reference and reading documents. Chapters 4 and 6 outline typical technical concepts for wastewater treatment and resource recovery in ASEAN countries, along with their O&M implications. Section 3.5 addresses the financial aspects, including the cost structure and lifecycle analysis for DWM projects; it also provides examples regarding the same.

Many municipalities in ASEAN countries are considering developing and applying more sewered wastewater systems. Conducting a project area-specific cost-benefit analysis of feasible technical concepts can help make informed decisions. However, undertaking a cost-benefit analysis regarding the available technical options without assessing the required capacity and capacity-building cost of the enabling frameworks may lead to sustainability and cost threats. The capacity of enabling frameworks refers to the legal, financial and institutional capacity to regulate, implement and operate any concept/approach at the municipality level. For on-site or non-sewered wastewater management concepts, municipalities need to have an appropriate regulatory framework, with an effective monitoring and non-compliance assessment system. For sewered and/or publicly owned wastewater management concepts, municipalities require an effective financial framework, project management and operational capacity. The costs of developing and maintaining such enabling frameworks are often underestimated and not sufficiently discussed in the sanitation sector.

Chapter 3 of this Guidebook provides a comprehensive overview of the regulatory, institutional and financial frameworks and the associated specific requirements for non-sewered and sewered wastewater management projects. It provides a comprehensive overview of the DWM-specific requirements and options that need to be assessed before a municipality commences infrastructure construction. The leading questions for conducting such an enabling framework assessment are outlined in Chapter 9.

Chapter 3
Regulatory, Institutional, and Financial frameworks

3.1. Introduction

Leading questions

Once the type and location of the DWM infrastructures and services have been determined, the following questions need to be answered:

- *What needs to be regulated?*
- *Who is responsible for implementing and operating the infrastructure and services?*
- *Who is responsible for financing them?*
- *Who is responsible for approving and monitoring their implementation?*

Centralised wastewater management systems primarily involve the establishment of one or a few large public sewer networks and treatment plants, which are run by a clearly defined overarching public authority. However, decentralised systems and services may present a different picture, wherein the responsibilities of running DWM systems are shared by stakeholders from various sectors. The scaling up of decentralised wastewater systems requires suitable mechanisms to enhance multi-sectoral coordination, cooperation and accountability among departments of various sectors.

In larger cities, all three approaches-site, decentralised and centralised—may co-exist independently or in integrated forms. All of these approaches may be necessary to achieve set mid- and long-term sanitation goals. Municipalities are increasingly working on enhancing their capacity to manage public wastewater infrastructure and services. Unfortunately, they often face the daunting challenge of effectively overseeing the numerous wastewater infrastructures and services. This leads to the following question:

How can these hundreds or thousands of installations owned and managed by private individuals or public entities be effectively controlled and regulated?

This Guidebook outlines the legal or administrative management options for two most common types of DWM:

- Privately owned and managed (on-site sanitation)
- Publicly owned and managed (off-site sewer-based sanitation)

Both options are defined through the legal or administrative responsibility for the DWM system or the *What* (i.e. the type of wastewater) and the *Where* (administrative boundaries).

3.2. Regulatory framework for privately owned and managed wastewater systems (on-site sanitation)

The term 'private' in this context refers to residences, commercial establishments, industries, real estate and institutions such as hospitals, universities or military camps. These entities operate their own wastewater systems within their administrative boundaries, which are defined by the plot of land owned by them.

Any sanitation or wastewater infrastructure installed on a specific plot or plots and servicing only that plot or plots, is considered *privately owned and managed*. This is often referred to as an on-site or on-plot sanitation system.

In summary, on-site sanitation refers to a *system in which excreta and wastewater are collected, stored, and/or treated on the plot where they are generated*. Technically, this system can encompass various components such as latrines, pipes, septic tanks, soak pits and even small- or medium-sized WWTPs, with or without effluent reuse.

For more information, please refer to the following link: https://sswm.info/content/onsite-sanitation.

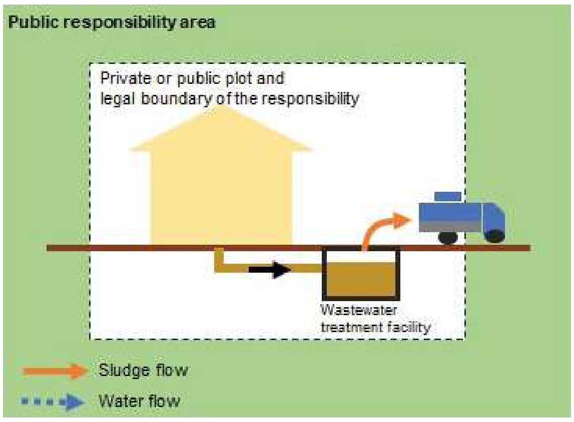
In ASEAN countries, it is common law for the plot owner to bear full responsibility for all activities on the plot, including ensuring compliance with overarching environmental regulations for activities such as wastewater management. This responsibility includes the installation and operation of any type of system that:

- Meets the objectives (treatment, resource recovery, etc.) of the landowner;
- Complies with environmental and public health protection standards set by national law and municipal requirements, including construction standards.

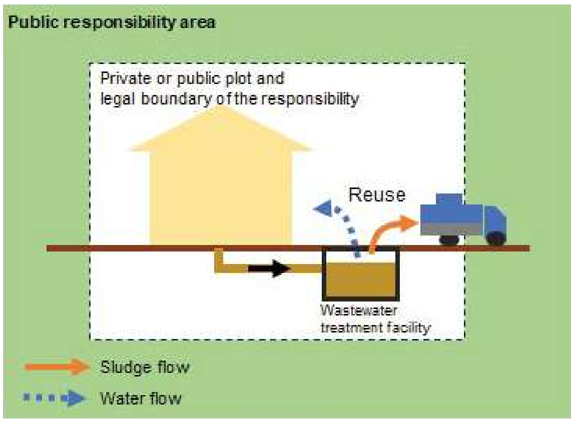
Most on-site systems generate two main types of waste streams: effluent (partly or fully treated) and sludge (including scum, grease, precipitation sludge, bio-solids, etc.). The sludge, which is usually the smaller mass stream, is stored in the sanitation system itself (on-site) and removed (desludged) on demand or as scheduled. However, the effluent stream, which is typically a continuous flow and a relatively high-volume stream, usually leaves the plot boundaries. This can occur either as a horizontal overflow into the neighbouring plot/drain or vertically by infiltration into the ground.

There are three main options by which these waste streams can be managed on the plot itself, as shown in Figure 3.1:

Option A:
Holding tank



Option B:
Partially or full treatment with reuse



Option C:
Partially or full treatment, no reuse

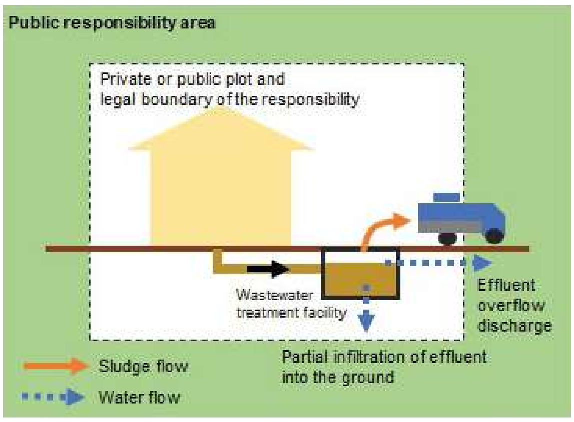


Figure 3.1. Universal visualisation of managing wastewater streams during on-site sanitation

Considering the three main options of managing the two main wastewater streams, the different environmental and legal impacts of these options as follows:

Option A – Holding tank: This option involves the use of a holding tank, which stores the entire wastewater sludge and liquid, with no overflow. Regular emptying is performed by a vacuum truck, which transports it to a place for disposal. While this option is commonly adopted in Middle East Asian countries, it is being increasing adopted in ASEAN cities, especially for institutional or commercial plots with no public sewer connections and no other technical or legal options for wastewater effluent discharge outside their plots.

Option B - Reuse: In this option, the wastewater is treated on-site by adhering to a standard that results in the effluent being reused on the plot. The sludge is periodically removed by vacuum trucks or other means. In comparison to option A, this option saves the transportation and disposal costs of wastewater and can help reduce freshwater consumption. This concept is increasingly promoted and enforced by municipalities in countries such as Singapore, India and Australia.

While options A and B can be considered as a zero-wastewater discharge approach towards on-site sanitation infrastructure, option C continues to be the most common situation in ASEAN countries. Zero-discharge means that no wastewater is discharged through an overflow or underground infiltration into the public area (green area in the figures under 3.2).

Option C: This option represents the most common scenario in which on-site sanitation systems separate the sludge from a liquid effluent stream. In this set-up, the sludge is periodically removed, often using vacuum trucks and the liquid effluent is typically discharged into the nearby public environment, either as an overflow into public or natural stormwater drains, wetlands, and/or infiltration into the ground. The quality of the discharged effluent depends on the type and operational efficiency of the on-site wastewater system, which can range technically from a simple pit latrine to a septic tank or a complete WWTP.

While this is the most common sanitation option in ASEAN countries, from the perspective of environmental and public health protection, this option presents the most uncontrolled and challenging sanitation situation.

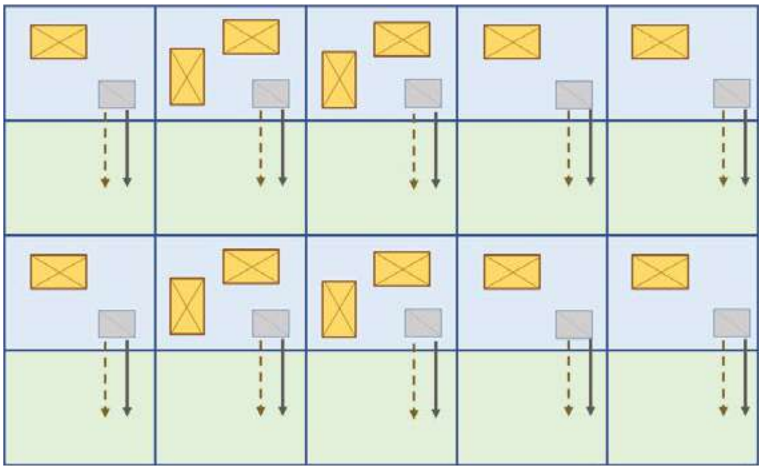


Figure 3.2. Universal visualisation of on-site sanitation in an urban context with numerous wastewater streams discharged into public land

In urban areas without existing public sewer systems, each household or plot may have its own on-site sanitation system. This results in a high number and concentration of potential polluters discharging untreated or treated wastewater into the ground or the environment. The local government is not directly responsible for treating these wastewater streams, and environment but it becomes their concern once any wastewater is discharged on public land (visualized in Figure 3.2 as green marked area). Hence, the local government is responsible for establishing an effective regulatory framework that controls pollution and requires private landowners to comply with government regulations and standards for their on-site systems.

Regarding the sludge stream, the local government has two options: it can operate a public sludge collection and safe disposal service. Alternatively, it can establish a regulatory framework that regulates the FSM service operated by private entities. Such regulatory frameworks cover technical standards for the installation and operation of WWTPs and government approval, monitoring and enforcement systems.

A regulatory framework should address the following basic components, as outlined in Figure 3.3. Institutional responsibility and their interaction to drive each component, and the level of implementation, vary depending on the country.

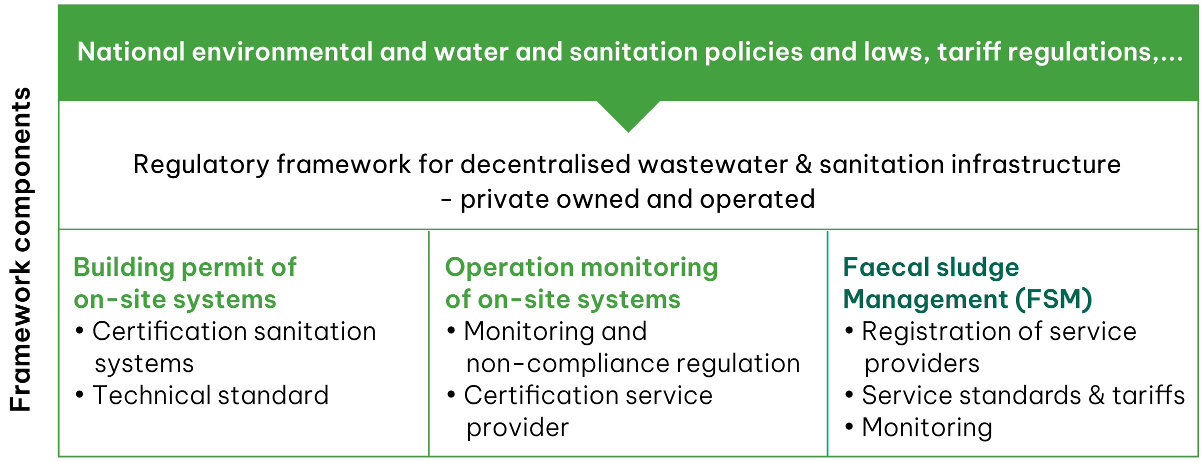


Figure 3.3. Universal visualisation of the regulatory framework for on-site sanitation

This Guidebook highlights the core components that must be addressed within a regulatory framework to control potential pollution from small on-site systems.

In addition to establishing feasible environmental pollution control mechanisms, technical standards for on-site systems need to be determined to define the installation, operation and monitoring requirements. Such technical standards are usually subject to the Building Permit, which may include an Environmental and Social Impact Assessment and a Discharge Permit where applicable. Many municipalities in ASEAN countries have established septage management policies to fulfil this objective.

Effectively managing both components at the local government level requires adequate institutional capacity. Many municipalities face the following common challenges in handling on-site sanitation and wastewater systems:

(1) Building permit

- Lack of or insufficient technical standards.
- Insufficient in-house expertise in the local bodies to assess and approve technical designs.

(2) Operation monitoring

- Lack of human resources to conduct follow-up compliance monitoring for thousands of systems.
- Lack of a cost-recovery concept for regular compliance monitoring.
- Lack of locally available wastewater laboratories.

CASE STUDY 3.1. **Municipality of Bauang, the Philippines**

The Municipality of Bauang, located on the coastal area in La Union in the Philippines, with a total population of over 78,000 people (2020), is a remarkable case where government regulation and initiatives led to public and private investment in sanitation, which resulted into progressively improving the on-site sanitation situation in this area.

2010

- Coastal and river areas declared as Water quality Protection Area.
- Municipalities invested in improved stormwater drainage and the installation of anaerobic WWTPs at the public market, slaughterhouse and school.

2016

- New national environmental policies and wastewater effluent standards were issued and institutions and commercials were asked to conduct self-monitoring of discharged wastewater. Monitoring sheets with wastewater analysis reports were asked to be sent to the Environmental Management Bureau (EMB) on a quarterly basis.
- Private industries in Bauang started to invest for the first time in on-site wastewater treatment systems.

2019

- The Department for Environment and National Resources (DENR) revised the national wastewater effluent standards.
- The Department for Interior and Local Government (DILG) issued 'Policy and Guidelines on Sewerage Management'.
- The Department of Health (DoH) issued national technical standards for septic tanks and on-site wastewater treatment systems.
- The municipality of Bauang registered a private entrepreneur for investing in and operating FS collection and treatment services for on-site sanitation systems.

2022

- The municipality of Bauang is supporting a pilot project to upgrade an anaerobic WWTP installed at the public market.

As the government increasingly requires the private sector to invest in the installation and operation of advanced on-site wastewater systems, it is also obligated to have an adequate regulatory framework and institutional capacity for effective monitoring. Owing to rapid urbanisation in most primary and secondary cities in ASEAN countries, the private sector is installing thousands of on-site decentralised wastewater systems to meet the increasing demand. The private sector is not only installing a large number of systems but also a wide variety of technologies in these systems. This places a significant burden on local governments to assess, approve and monitor the performance of these different technologies. This often leads to the situation that many installations are mentioned only on paper for the sake of obtaining overall building permits or are installed but are not operation/show poor operation (See Case Study 3.2. in the box below).

(Source: 17_Decentralised Wastewater Systems in Bengaluru, India: Success or Failure? Available on: https://www.worldscientific.com/doi/10.1142/S2382624X16500430)

CASE STUDY 3.2. **The 4S Project**

Eawag/Sandec, Switzerland and its partners in India and Nepal conducted a systematic assessment of small-scale sanitation (SSS) in South Asia between 2016 and 2018. SSS refers to a sewer-based sanitation system that uses a small-scale sewage treatment plant (SSTP), which also allows for water reuse. Further, an SSS system is defined as one that serves 10–1,000 households (or 50–5,000 person equivalents, that is, treating approximately 5–700 m^3 of wastewater per day). A detailed evaluation of over 300 such sanitation units was conducted from multiple perspectives—technology, governance and financial sustainability. The study provided an in-depth understanding of the status, challenges and opportunities associated with small-scale treatment systems, as well as the way forward.

Reference link: *http://www.sandec.ch/4S*

Septic tanks, with or without soak pits, are the most commonly used decentralised wastewater treatment systems in ASEAN countries. Most local and central governments have developed designs adhering to technical standards to support building approval processes. While septic tanks are effective for small-scale applications (which process wastewater volumes of less than 10 m^3/day), they often do not meet the effluent standards parameters required by almost all ASEAN countries. Interestingly, the installation of septic tank systems continues to be permitted in most ASEAN countries. However, it is observed that local governments demand compliance with national standards when these systems need to be replaced with advanced wastewater treatment systems.

An increasing number of countries worldwide are establishing the following basic components to regulate the decentralised on-site wastewater sector:

Certification of on-site sanitation/wastewater products

Objectives/Description: An accredited body tests and certifies materials and technical systems against defined technical standards.

Table 3.1. Certification system for products

Short description	Requirements	References / Case studies
Certification of wastewater products such as: • Water and wastewater pipes • Prefabricated inspection chambers • Prefabricated WWTPs	• A regional or national accredited centre capable of conducting physical tests and issuing recognised certificates. • Providers of wastewater technologies are required to pay a fee for the certification of their systems. • Approving authorities should allow only certified wastewater systems to be installed.	Institutions such as National Sanitation Foundation (NSF) International, American Society for Testing and Materials (ASTM) International and the European Committee for Standardization (CEN) are accredited independent bodies that certify equipment used for water supply and wastewater management. The European standard EN 12566 is applicable to small wastewater treatment systems up to 50 PE. In the US, the Water Environment Federation (WEF) runs the Wastewater Treatment Plant Certification Program (WTCP) for the certification of WWTPs. In Thailand, the regulation and certification of wastewater systems fall under the jurisdiction of the Pollution Control Department (PCD) of the Ministry of Natural Resources and Environment. The Asian Institute of Technology (AIT) operates the 'AIT Small Scale Wastewater Treatment Testing and Training Centre' in cooperation with the PCD. In Japan, the Building Centre of Japan (BCJ) is the designated performance evaluation organisation for decentralised septic tank systems called 'Johkasou'. After undergoing performance evaluation testing by the BCJ, Johkasou is certified by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and is recognised as a 'performance evaluation type' Johkasou.

Technical design and construction standards

Objectives/description: Setting references (standards and specifications) for designing, approving, installing and monitoring the system.

Table 3.2. Technical design and construction standards

<table>
<tr><th>Short description</th><th>Requirements</th><th>References / Case studies</th></tr>
<tr><td>Design standards for small WWTPs: These standards encompass crucial parameters for process design and operation, which are particularly important for small systems because of their wide range of technical functions. It can often be challenging for wastewater experts to fully understand and evaluate the systems' performance. The design parameters include specific organic loading rates, hydraulic retention time, dimension ratios, C:N ratio and many others. Approval for the installation of a wastewater system should only be granted when accurate design calculations are provided in the application documents.</td><td rowspan="2">• Having such standards in place, which should be developed by authorised bodies or committees of practitioners.
• Implementing an approval process for issuing building and discharge permits in accordance with these standards.
• Having in-house wastewater expertise among the approving authority or reaching out to other independent expert bodies such as ministry departments for water, sanitation and public works or universities.</td><td rowspan="2">Organisations such as the German Water Association (DWA https://en.dwa.de/en/), the Environmental Protection Agency (EPA https://www.epa.gov/) in the US or the Central Public Health & Environmental Engineering Organisation (CPHEEO https://cpheeo.gov.in/) in India develop and update technical guidelines that are considered mandatory for obtaining the authority's approval, thus ensuring that practitioners design and document the design of the wastewater treatment system by considering these deadlines.

In Japan, the design, approval and installation of decentralised systems called Johkasou are regulated according to the Johkasou Act. Additionally, guidelines for their design and construction are issued by the Japan Conference of Building Administration.

IS 2470 (Part 1): 2002 - Design and Construction of Sewage and Drainage Systems - Part 1: Recommendations - This standard provides guidelines for the design and construction of sewage and drainage systems, including septic tanks.</td></tr>
<tr><td>Construction standards: These typically include specific or general technical specifications for construction. These specifications detail methods for tasks such as sewer pipe laying and verification of their water tightness, among other requirements. In many countries, including ASEAN countries, where the Ministry for Public Works and Transport (or an equivalent ministry) is involved, general specifications and standards for water and wastewater infrastructure are developed. Additionally, many municipalities often impose their own specific standards and specifications, considering their local implementation, operational experiences and conditions. These municipality-specific standards primarily apply to public infrastructure.</td></tr>
</table>

Certification of service providers and technicians

Objectives/description: This involves the certification of people, indicating that they have acquired specific skill sets after they have successfully completed training and passed a test in an accredited vocational training institution.

Table 3.3. Certification system for service providers and technicians

Short description	Requirements	References/case studies
For instance, the following roles may require certification: • Sewer plumbers (for example, they require a certificate in fusion welding to be employed as sewer plumbers). • WWTP operators. • Technicians or engineers certified to conduct external compliance monitoring (including site inspection and sampling).	• Having a nationally accredited training centre and a training certification system. • Regulation stating that certain activities in WWTPs should be performed only by trained and certified staff or experts.	German Water Association (DWA) www.dwa-nord.de/de/kl%C3%A4rw%C3%A4rter-grundkurs-online.html CePSTPO (Course for Certified Environmental Professionals in Sewage Treatment Plant Operation) www.eimas.doe.gov.my/course-for-certified-environmental-professional-in-sewage-treatment-plant-operation-cepstpo/ In Japan, managers of decentralised wastewater treatment systems are required to conduct maintenance checks and cleaning of the systems. However, it is generally difficult for Johkasou managers to perform these tasks by themselves. Therefore, O&M vendors registered by the prefecture governments or by nationally licenced Johkasou operators conduct these checks instead. Further information is available in 'Specification on the institutional system and technologies related to Johkasou operation and maintenance (draft)' operation_and_maintenance.pdf (env.go.jp)

Short description	Requirements	References/case studies
• Accreditation of environmental laboratories and technicians for wastewater sampling and analysis.	• Having locally available environmental laboratories. • Implementing a cost-recovery mechanism for covering monitoring costs.	International Laboratory Accreditation Cooperation (ILAC) https://ilac.org/
Registration process (with optional certification) for FS service providers.		
Operational standards for septic tanks: Cities in India are implementing these standards by establishing a comprehensive database of on-site sanitation systems. This database includes information regarding the location, size and recommended emptying intervals of the systems. The primary objective of this database is to ensure regular desludging of septic tanks, as this directly impacts the treatment performance. Furthermore, it ensures the safe disposal of the sludge at designated areas, such as FSTPs. By maintaining this database, the city can effectively monitor and manage the operation of septic tanks, promote appropriate sanitation practices and minimise environmental and health risks.		

Monitoring and non-compliance regulations

Objectives/Description: To ensure operational compliance with the requirements of building and/or discharge permits.

Table 3.4. External monitoring and non-compliance regulations

Short description	Requirements	References/case studies
Country-specific environmental laws establish specific requirements for discharge parameters, including analytical methods and monitoring intervals for both internal and external monitoring. Internal monitoring refers to the responsibility of the wastewater treatment system operator to conduct self-monitoring of the system, document the results and submit them to the relevant government department. For smaller decentralised wastewater treatment systems, effluent monitoring is typically required once a year. However, in many cases, the authenticity of the monitoring results that is, whether they are accurate or manipulated, remains unknown. In European countries such as Germany, private operators of decentralised on-site wastewater systems have additional obligations. They are required to maintain an O& M service contract with a professional service provider. Additionally, they must engage an independent accredited inspector who takes annual or random samples for testing. This ensures a higher level of scrutiny and accountability in maintaining water quality standards.	• Having an environmental law or municipal by-laws in place that regulate the monitoring of wastewater treatment systems and cover the following: • Parameter and monitoring intervals (usually, monitoring of larger treatment plants needs to be conducted more frequently and monitoring of small plants needs to be conducted once a year). • A system at the municipality level that reviews the monitoring reports and can follow-up in case of non-compliance. • Non-compliance regulation/procedures including enforcing the penalty system. • A mechanism for recovering external monitoring costs (usually paid by the owner of the WWTP).	**National Pollutant Discharge Elimination System (NPDES):** NPDES is the EPA's programme for regulating point sources of pollution, including wastewater treatment facilities. The NPDES programme outlines monitoring and reporting requirements for permitted facilities. Urban Wastewater Treatment Directive (91/271/EEC): This EU directive sets standards for urban wastewater treatment, including the monitoring of small wastewater treatment systems. It provides a framework for water quality protection and pollution prevention. Wastewater Charges Act (Abwasserabgabengesetz - AbwAG): AbwAG regulates charges and fees related to wastewater discharge. It includes provisions for monitoring and reporting about different components of a wastewater system.

Short description	Requirements	References/case studies
By implementing these measures, regulatory bodies aim to enhance environmental protection and ensure the appropriate functioning and compliance of wastewater treatment systems, particularly in the context of decentralised projects	• Having locally available accredited laboratories for wastewater analysis.	In Japan, Johkasou managers are required to undergo water quality inspections by inspection organisations designated by prefectural governors. There are two types of inspections: (i) the water quality test after installation and (ii) periodic inspections. Both consist of three types of inspection: visual inspection, water quality inspection and document inspection.
Accreditation of environmental laboratories and technicians for wastewater sampling and analysis.	• Locally available environmental laboratories. • Having a cost-recovery concept for covering monitoring costs.	The National Accreditation Board for Testing Calibration Laboratories (NABL - https://nabl-india.org/) provides accreditation to labs to perform sampling and analysis.

3.3. Regulatory framework for publicly owned and managed wastewater systems (off-site sewer-based sanitation)

Publicly owned and managed wastewater systems are tasked with collecting, treating and disposing of wastewater from residences, businesses and industries in a manner that protects public health and the environment.

This section focuses on the public sewer-based wastewater service. Truck-based services for the collection, treatment, and disposal of faecal sludge from on-site sanitation systems will be covered in other sections addressing faecal sludge management (see also Chapter 4.3.5).

This wastewater infrastructure, located on public land, caters to a specific urban area, with its overall management coming under the purview of the government. The responsibility of managing specific assets and operations is often outsourced to a dedicated public or private water/wastewater utility or private service provider. The most common management models are either publicly owned and operated or publicly owned and privately operated. Although models for privately owned wastewater infrastructure on public land do exist, their management structure is legally complex. Municipalities that have attempted this approach often revert to publicly owned and privately operated models. In some cases of decentralised wastewater projects, community-based entities take charge of planning, installing and operating wastewater systems for a particular community. These entities are established on community land (which is publicly owned) in scenarios where the local government is unable to provide adequate wastewater services; hence, the community takes the lead in providing services to itself.

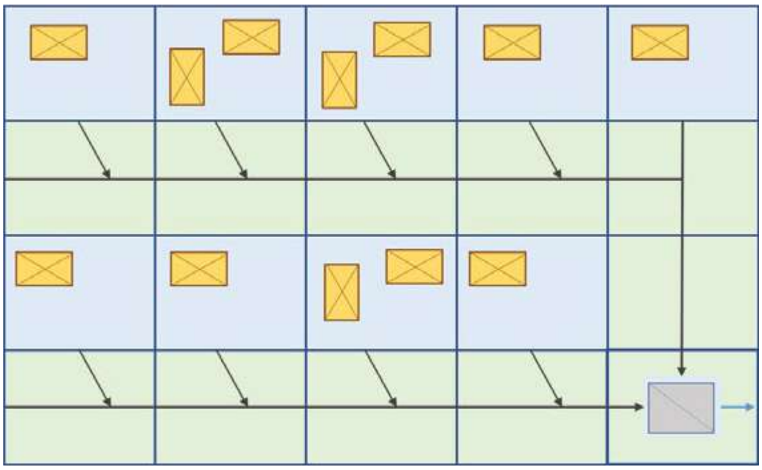


Figure 3.4. Universal visualisation of the publicly owned and managed wastewater concept (sewer-based)

Community-based wastewater projects have been implemented in the SANIMAS programme in Indonesia. Here, the government initiates and funds the installation of a wastewater system on public land and community-based entities are involved in—or even leading—its planning, installation and operation. However, such projects can face significant challenges, such as the limited institutional sustainability of community-based entities, unclear allocation and ring-fencing of funds for operation, major reinvestments for maintenance and an underestimation of local human resource capacity development.

Lessons from Indonesia's SANIMAS initiative suggest that community-managed decentralied wastewater management systems function best when an appropriate system is built in the right location, user numbers are optimized and sustained and there is shared responsibility with the government for O&M, also termed as co-management (WSP 2013-World Bank 2013, *Review of Community-Managed Decentralised Wastewater Treatment Systems in Indonesia*; Technical Paper of Water and Sanitation Program (WSP, 2013)

Technically decentralised wastewater systems consist of the following components:

- Interface between the private house connection and public plot connection;
- Sewer network for wastewater collection;
- Treatment plant;
- Effluent discharge point.

Other sub-options are outlined in Chapter 4.

In the case of publicly owned and managed concepts, the government holds overall responsibility for all system components. Accordingly, the regulatory framework differs from privately owned and managed on-site systems and can be outlined as follows:

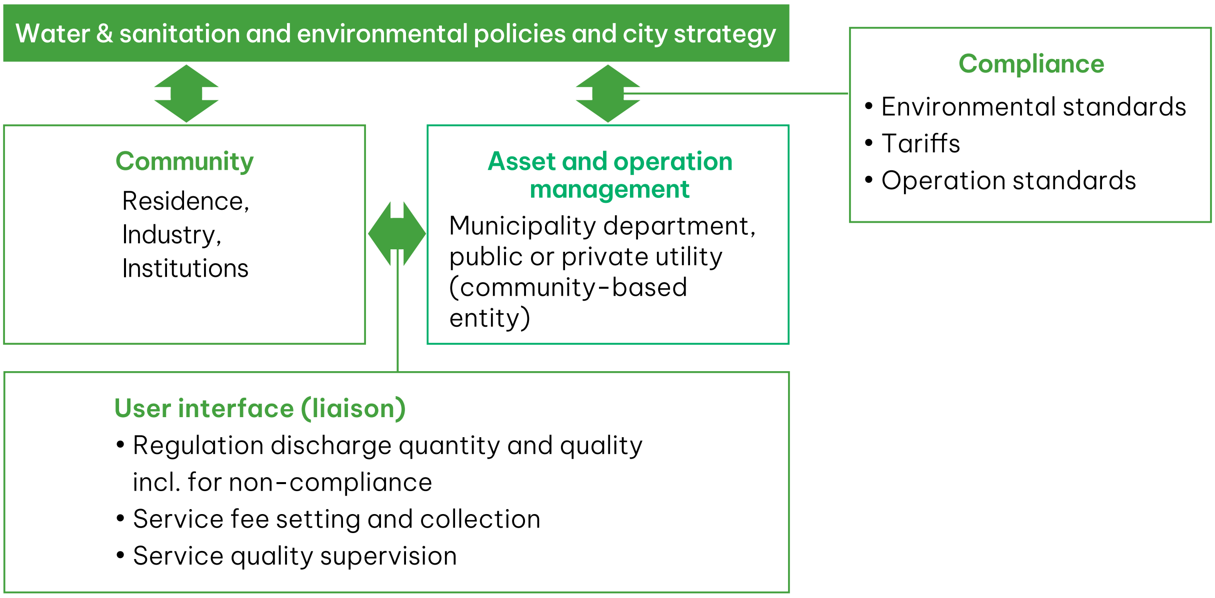


Figure 3.5. Universal visualisation of the publicly owned and managed wastewater approach

Figure 3.5 illustrates the basic universal framework and different interfaces of the publicly owned and managed wastewater concept. The public entity responsible for asset and operational management must comply with the overarching policy framework and standards and manage the wastewater-related service needs and activities of the user (community or municipal areas) to be served.

User interface

Effective user interface management is crucial in public wastewater management, as the quality and quantity of wastewater being treated can affect the system's functionality and operational performance. While larger centralised systems can accommodate variations in wastewater quantity and quality more comfortably, smaller decentralised systems possess such capacity in a limited manner. Therefore, the practical solution regarding decentralised systems is to control the discharge of specific types of wastewater into the public system. Many municipalities enforce by-laws that mandate property owners to connect their plots to public sewers and pay the service fee. *To ensure sustainability, it is essential to sanction a comprehensive project development phase, involve users in the planning and development phases and implement practical by-laws with robust law enforcement mechanisms.*

Here, are some aspects (to be adapted to the local context) that should be addressed and regulated in the user interface:

Table 3.5. User interface aspects

Aspect	Impact	Selected aspects to be regulated
Quantity of wastewater	Excessive wastewater mainly results from: • Connecting the roof water or stormwater run off to the sewer • Uncontrolled stormwater intrusion through broken pipes or manholes • Urban development, which results in an increasing number of houses and plots. • All of these can cause malfunction and/or higher operational costs of the treatment system and/or reduction in the treatment performance. • While a WWTP can remain operational with small inflows of wastewater (due to a low number of user connections), this causes an adverse financial impact. This is because the operational costs remain the same regardless of the number of user connections.	• **Design engineers of the wastewater system define the hydraulic capacity, including growth protection and calculate the allowed and normal stormwater intrusion rates. • **The design engineer designs a sewer network that is protected against uncontrolled stormwater intrusion. • *User/plots are not allowed to connect the roof and/or outside ground drainages for stormwater to public sewers. • *New urban development connections within the service areas must be approved by the operator of the wastewater system. • *For users and/or plots within the service boundary, it is compulsory to connect to the public sewer and pay the service fee.
Quality of wastewater	Uncontrolled disposal of industrial wastewater, chemicals, solid waste and different types of domestic wastewater may cause malfunction, higher operational costs of the treatment system, reduction in the treatment performance, and/or adverse impact on water reuse.	• **Design engineers of the wastewater system define the characteristics of wastewater that can be allowed to discharge into the environment. • *Plots with commercial activities need approval from the wastewater operator before installing a sewer connection.

The aspects marked (*) are typically covered by wastewater by-laws or statutes that regulate the following:

- Rights and duties of the operator and user;
- The type of wastewater to be discharged;
- Service fees and the mode of fee collection;
- Actions undertaken in the case of non-compliance, including penalties.

Such wastewater by-laws or statutes are either specific to a service area or applicable to the entire municipality.

Meanwhile, the aspect marked (**) is usually addressed in municipal design standards for wastewater systems.

Asset and operation management

Under this category, *"Asset and Operation Management"* is understood as the management of the entire wastewater infrastructure and services. 'Asset Management' involves planning, financing (including refinancing) and physical installations, while 'Operation Management' encompasses the following:

- Regular technical operational tasks;
- Non-technical tasks such as user liaison;
- Commercial tasks such as service fee collection.

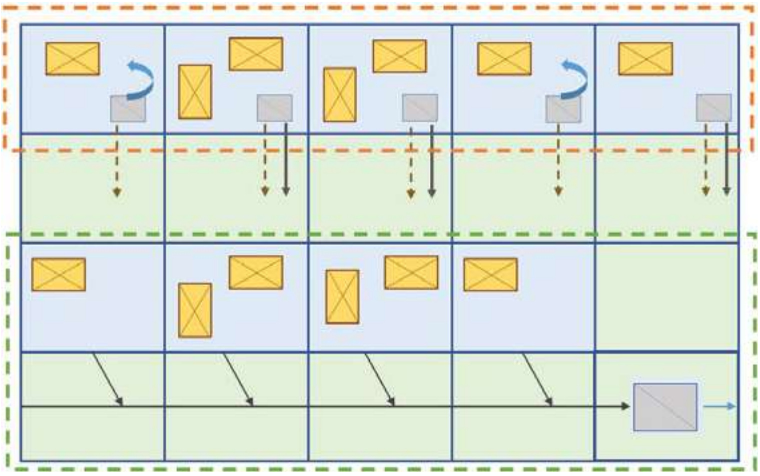


Figure 3.6. Universal visualisation of the co-existence of publicly owned and managed wastewater approach and on-site sanitation approach in the urban context

Assets refer to the complete wastewater treatment system, including the wastewater collection system (sewer), treatment plant and service equipment such as vacuum trucks. Ownership and management of these assets are not limited to the duration of the implementation project but extend throughout its entire lifespan.

In projects driven by international development partners, there is often a well-intentioned implementation of ambitious infrastructure projects, including assets such as water boreholes, pipes, treatment plants, recycling plants, trucks and buildings. However, these assets are often handed over to the municipality or community without ensuring their long-term sustainability. This situation raises the question of whether the local government possesses the necessary capacity in terms of human resources, finance and logistics to effectively manage these assets over a period of 10–20 years.

Determining the execution of tasks and responsibilities in such projects is guided by the institutional setting, which is based on national or local municipal policy frameworks. In the field of decentralised wastewater management, several institutional settings have been applied, but not all of them have proven sustainable in the long run.

During the development stage of any infrastructure project, the following institutional key questions should be addressed (see also Chapter 9):

- *Who owns the land for the sewer, treatment plant and discharge of treated wastewater?*
- *Who owns the assets and is responsible for asset management?*
- *Who operates the asset?*
- *How will the initial and repeat investment costs and operational costs be covered?*
- *How will the cash flow for the investment and operational funds/revenues be arranged?*
- *Who approves and supervises/monitors the respective steps/tasks?*

The answers to all these questions are crucial for ensuring sustainability of WWTPs, especially for decentralised wastewater projects and *it is important that all questions are resolved considering a long-term perspective of 10–20 years*.

To meet the rapid demand for safe sanitation solutions, municipalities or cities may need to implement the following three concepts:

- Private on-site sanitation systems;
- Public decentralised wastewater systems;
- Public centralised wastewater systems in larger cities.

Each of these concepts requires its own regulatory and institutional framework, whereas the frameworks for public decentralised and centralised systems are relatively similar.

3.4. Institutional frameworks

Establishing an institutional framework is crucial for addressing and resolving the aforementioned key institutional questions. Various institutional settings have been applied globally when implementing decentralised wastewater systems. The success and sustainability of these settings do not solely depend on the type of stakeholders, institutions or organisations involved, but rather on the robust resolution of the following key questions:

1) Are all key institutional questions adequately addressed with a long-term perspective of 10–20 years?
2) Do the assigned institutions possess the necessary capacity in terms of job descriptions, human resources, finance and logistics to effectively fulfil their respective tasks?

By ensuring that these key questions are satisfactorily answered, the institutional framework can support the long-term success and sustainability of decentralised wastewater management initiatives.

Public decentralised wastewater schemes are often implemented to bridge the gap between on-site sanitation and larger, centralised municipal wastewater systems, particularly in smaller municipalities or cities. In many ASEAN countries, the wastewater sector continues to be in a developing state and each country is at a distinct stage of development with respect to:

- Establishment of a wastewater industry capable of providing all necessary services, parts and technologies;
- Establishment of universities and vocational training centres that educate and certify wastewater project managers, social facilitators, engineers and technicians;
- Development of a regulatory framework that defines institutional responsibilities, establishes by-laws, sets technical standards and ensures effective law enforcement;
- Implementation of a self-sustaining financial framework to achieve cost recovery.

Decentralised wastewater projects serve as practical learning platforms and contribute to the progressive development of the local wastewater sector. However, it should be acknowledged that initial wastewater projects require significant accompanying capacity-building measures. The need for these measures is often underestimated in terms of time and budget allocation.

The following tables provide a universal overview of institutional stakeholders, their roles and their involvement in establishing and maintaining enabling frameworks for on-site and public decentralised wastewater projects. It is important to note that while the content in these tables generally aligns with the legal situations in ASEAN and other countries worldwide, adjustments may be necessary to accommodate specific country or city contexts.

Table 3.6. Institutional stakeholders in enabling frameworks

Stakeholder	Roles/Involvement
Government	• Develop and enforce regulations and policies related to wastewater • Establish institutional responsibilities and by-laws
	• Set technical standards and guidelines for wastewater management
	• Provide oversight and law enforcement
	• Establish self-sustaining financial frameworks for cost recovery
	• Coordinate with other stakeholders for integrated water resources management
Water Utility Provider	• Implement and manage public decentralised wastewater infrastructure
	• Provide wastewater collection, treatment and disposal services
	• Ensure compliance with regulatory requirements and standards
	• Invest in infrastructure development and maintenance
	• Establish tariffs and billing systems for cost recovery
Community	• Engage in public participation and awareness campaigns
	• Cooperate with the government and water utilities for sustainable wastewater management
	• Follow regulations and guidelines for on-site sanitation
Research Institutions	• Conduct research and development regarding wastewater treatment technologies
	• Provide technical expertise and support for policy development
	• Develop capacity-building programmes and training initiatives

Table 3.7. Institutional stakeholders for the implementation of wastewater treatment projects

Stakeholder	Roles/Involvement
Government	• Provide financial support and incentives for project implementation
	• Facilitate permits and approvals for construction and operation of the project
	• Ensure compliance of the generated effluent with environmental and health regulations
	• Monitor and evaluate project performance and impact
Water Utility Provider	• Plan, design and construct decentralised wastewater infrastructure
	• Manage project implementation and coordinate with contractors
	• Conduct feasibility studies and assess environmental impacts
	• Ensure appropriate O&M of the infrastructure
Private Service Provider	• Planning and consulting services
	• Construction and supply
	• Operation service
Community	• Participate in project planning and decision-making processes
	• Provide input regarding community needs and preferences
	• Collaborate with water utility providers and government agencies
NGOs and Civil Society	• Advocate for sustainable wastewater management practices
	• Support community engagement and empowerment
	• Provide technical assistance and capacity building
	• Monitor project implementation and advocate for accountability

Please note that the roles and involvement of these stakeholders may vary depending on the specific context and legal framework of each country or city.

Table 3.8. Abbreviations used to indicate different stakeholder groups and the types of involvement

Stakeholder group	Involvement
CG → Central government	R → Responsibility
LG → Local government	P → Providing services
USER → End user (residents, industry, institutions)	C → Consultation
UT → Public utility owned by LG or CG or legal community- or NGO-based entity.	S → Support
SP → Private service provider (consultant, contractor, supplier, operator)	O → Ownership
NGO → Non-governmental organisation	A → Approving
EI → Educational institutions (academia, vocational training centre)	M → Supervision/ monitoring
ODA → Official development agency	( ) → Optional or only for initial development purposes

Tables 3.9, 3.10 and 3.11 provide an overview of the most potential options which involve stakeholders; the respective involvements of the stakeholders are also indicated. For any project, the options may need to be adjusted to align with the local situation and policy frameworks.

Table 3.9. Potential institutional stakeholders for establishing and maintaining enabling frameworks for privately owned and managed wastewater/sanitation infrastructures (discussed in Chapter 3.2)

Responsibility	Overall task of establishing and maintaining	Institutional stakeholder groups and their involvement						
		LG	CG	USER	SP	NGO	EC	ODA
Sanitation targets	Selecting the service and priority areas	R	C	C	P	C	C/P	(S)
	City wastewater management strategy/approach	R	C	C	P	C	C/P	(S)
Regulatory framework	By-laws and law enforcement	R	C/S	C	P		C/P	(S)
	Non-compliance regulation	R	A/S	C	P		C/P	(S)
	Tariffs for FSM services	R	C	C	P		C/P	(S)
	FSM operation responsibility	R	C		P			
Financial framework	Asset management for the public FSM infrastructure	R	S					(S)
	Cash flow for funding and revenues for FSM services	R						
	Capacity-building funding	R	R					(S)
Capacity-building framework	City-specific requirements	R	C	C	P	C	C/P	(S)
	Technical standards	R	C/S		P	C/S	C/P	(S)
	Human resource development	R	R/S		P	P/S	P	(S)
	Research and development	R	R/S		P	P/S	P	(S)

Table 3.10. Potential institutional stakeholders for establishing and maintaining enabling frameworks for public decentralised sewer-based wastewater projects (discussed in Chapter 3.3)

Responsibility	Overall task of establishing and maintaining	Institutional stakeholder groups and their involvement						
		LG	CG	USER	SP	NGO	EC	ODA
Sanitation targets	Selecting the service and priority areas	R	C	C	P	C	C/P	(S)
	City wastewater management strategy/ approach	R	C	C	P	C	C/P	(S)
Regulatory framework	Establishing institutional responsibility along a sanitation value chain and project cycle	R	R	C		C	C	(S)
	Tariff and tax regulation	R	R	C	P	C	C	(S)
	By-laws and law enforcement	R		C	P	C	C	(S)
	Non-compliance regulation	R	C/S	C	P	C	S	
Financial framework	Project investment	R	R					(S)
	Cash flow for funding and revenues	R						
	Capacity-building funding	R	R					(S)
Capacity building framework	City-specific requirements	R	C	C	P	C	C/P	(S)
	Technical standards	R	C/S		P	C/S	C/P	(S)
	Human resource development	R	R/S		P	P/S	P	(S)
	Research and Development	R	R/S		P	P/S	P	(S)

Table 3.11. Potential institutional stakeholders for the implementation of public decentralised wastewater projects (explained in Chapter 3.3)

Responsibility	Overall task of establishing and maintaining	Institutional stakeholder groups and their involvement						
		LG	USER	UT	SP	NGO	EC	ODA
Land ownership	Land for collection system	O	(O)	O				
	Land for the treatment plant	O	(O)	O				
	Land for discharge/ reuse	O	O	O				
Asset ownership	Overall ownership and initiator	R		R				
	Financing the initial investment	R		R				(S)
	Refinancing infrastructure	R		R				(S)
	Planning and implementation	R	C	R	P	C	C	(S)
Operation	Overall operational management	R		R				
	Technical operational tasks	P		P	P			
	Non-technical tasks (user liaison)	P		P	P			
	Commercial tasks (fee collection)	P		P	P			
	Payment of the service fee	M	R	M				
Approval and monitoring	Project implementation	A	A/M			M		(S)
	Overall operational management	A		A				
	Technical operational tasks	M			P		M	
	Non-technical tasks	M	M			M		
	Commercial tasks	M	M			M		

3.5. Financial frameworks

3.5.1. Glossary

CAPEX Capital expenses: all costs related to initial and re-investment-related costs such as interest rates.	**Initial investment** All costs to establish a project including hardware, planning, non-technical costs, administration, capacity-building measures, etc.
OPEX Operational expenses: all costs related to operations, maintenance, breakdown, management, non-technical tasks and administration.	**Re-investment cost** All project costs are usually periodically repeated since there is a need to rebuild or upgrade hardware (new pump, truck, ...), build institutional capacity or conduct other maintenance activities within the project's lifecycle.
Lifecycle This describes the entire period of the wastewater infrastructure or service until it has fulfilled its purposes. For decentralised wastewater schemes, this lifecycle is usually 20–30 years.	**R&M** Funds or costs related to regulation and compliance monitoring.
Depreciation It is the estimated reduction in the value of the implemented sanitation/wastewater system.	**End user or user** A person who uses wastewater treatment services, such as residents of a community or staff/labourers of an institute or industries.
Service fee The amount of fee charged to the end user by a service provider or government to cover the cost of providing any type of sanitation/wastewater service, such as wastewater or sludge collection. Such service fees can partly or fully cover OPEX and in best cases, CAPEX as well and can be collected in different ways, such as through water bills and periodic or on-demand user fees.	**Ring-fenced funds** These funds are those which are specifically set aside for a designated purpose. They cannot be used for any other purpose.

Revolving funds A financial mechanism in which the interest from a principal amount invested is used to fund further projects. Therefore, it is a way of providing continued financing.	**Sanitation value chain** This describes all technical and operational components along the waste stream (wastewater and sludge) that are needed to handle the waste stream in a manner safe for public health and the environment. The sanitation value chain usually comprises a user interface (toilets), on-site containment (septic tank or any other container), collection (pipe or truck), treatment and disposal/reuse.
Sales revenue This is understood as revenues generated through selling of by-products such as recycled water, energy, solid fuels, compost, etc.	**ODA** An ODA provides financial and technical support.
Government budget These are the funds and budget allocated by the local and/or central government.	**Special taxes and charges** Taxes and charges are collected by the tax authority to partly or fully finance the cost of sanitation and wastewater through government budgets. Examples include a special tax, such as a tourist tax, allocated as part of the property tax.
Cross subsidy This includes the government or operator revenue streams other than from sanitation and wastewater such as water and electricity sales or a special tax or charge used to partly or fully finance the sanitation/wastewater costs. The cross subsidy can also be applied when the wastewater system helps to save water and reduce electricity consumption and related costs.	**Corporate Social Responsibility (CSR) funds** These are funds set aside by companies from their revenue/profit to support social and environmental causes that align with their CSR objectives.

3.5.2. General considerations

Typical leading questions that define the financial framework are as follows:

Leading questions

- *What are the costs of establishing and operating a DWM project?*
- *What are the sources of initial and re-investment costs?*
- *What are recovery options of operational costs?*
- *How is the cash flow for establishing and operating a DWM project established?*

One crucial yet often neglected question that is not easily answered is: *How much should the wastewater infrastructure and services cost?* Or, phrased in a different way: *what are the financial capacities of the end user and the government to establish and maintain infrastructures and services, including the required enabling regulatory and institutional framework?*

The following are the different approaches that a municipality may adopt to answer this question:

- Reviewing municipal or national guidelines/policies regarding water and sanitation tariffs and fees;
- Conducting an end user survey regarding the willingness or preferably, the ability of end users to pay a certain amount as service fee for improved sanitation/wastewater services. This survey can be conducted city - or municipality-wide or only for a specific service area.
- Gaining an understanding regarding the general global or regional figures.

For any implementation project, the municipal wastewater masterplan or strategy usually provides the direction and boundaries for setting the project-specific financial budget range for the initial investment and service fee (Chapter 9.1). Setting the budget range at the beginning of the project development phase (Chapter 10) brings essential orientation and efficiency into the entire implementation project. It guides decisions regarding technical approaches and technology selection and supports communication processes and acceptance by end users.

Examples of municipal or national guidelines/policies for water and sanitation tariffs and fees in ASEAN countries include the following:

- **The Philippines:** Water tariffs are set by the Metropolitan Waterworks and Sewerage System (MWSS) for Manila and its neighbouring cities. In other provinces, tariffs are set by the Local Water Utilities Administration (LWUA).

- **Thailand:** Water tariffs are set by the Provincial Waterworks Authority (PWA) and the Metropolitan Waterworks Authority (MWA) under the Waterworks Act. The tariffs are approved by the Ministry of Interior.
- **Indonesia:** Water tariffs are regulated by the Ministry of Public Works and Housing through the Directorate General of Housing Provision. Water tariffs are set by regional water supply companies and are approved by the regional government.
- **Singapore:** Water tariffs are set by the Public Utilities Board (PUB) under the Public Utilities Act. The PUB is responsible for the supply of water and treatment of wastewater.

Examples of general global or regional figures include the following:

- The United Nations '5% principle', which states that expenses for water and sanitation should not exceed 5% of the respective household income (UN, 2003).
- The Asian Development Bank (ADB) report from 2015 (ADB, 2015) titled 'Investment Needs in Urban Wastewater Management in Southeast Asia', which states that in ASEAN countries:
  (i) Specific investments for wastewater treatment range between 183–1,825 USD per capita, depending on the level of treatment; these range from 183 – 548 USD per capita for basic treatment technologies (pond and lagoon). The extent to which the cost of land, sewer or capacity-building measures is included in this calculation is not stated.
  (ii) Specific operational costs range from 91–730 USD per capita per year.
- 'Benchmarking of Operational Costs and Performance of Wastewater Treatment Plants in Southeast Asia' (Yoshitaka 2018). This report, published by the United Nations University Institute for the Advanced Study of Sustainability in 2018, provides an analysis of the operational costs and performance of WWTPs in several Southeast Asian countries.

While Sections 3.2 and 3.3 outline the regulatory and institutional settings, the next chapters outline the different financial frameworks needed for the following:

- Privately owned and managed on-site sanitation projects;
- Publicly owned and managed sewer-based wastewater projects.

3.5.3. Financial framework for privately owned and managed on-site wastewater systems

In this decentralised wastewater approach, the responsibility for installation, operation and financing of the on-site infrastructure and services lies with the plot owner. While the government can create financial incentives for on-site installations, its principal duty is to establish and maintain the regulatory framework, as depicted in Figure 3.3.

Table 3.12. Financial framework for regulatory functions

<table>
<tr><th rowspan="2">Primary function of the government and the cost position to be financed</th><th colspan="2">Common financial sources to cover the cost for</th></tr>
<tr><th>Creating institutional capacities</th><th>Keeping it operational</th></tr>
<tr><td>(1) Regulating and approving the technical standards of on-site installations (Building Permits) – R</td><td rowspan="2">LG/CG budget and optional ODA</td><td>LG/CG budget and administrative fee charged to apply for the project</td></tr>
<tr><td>(2) Monitoring the compliance of the technical standards (Operation Monitoring) - M</td><td>LG/CG budget and monitoring fee charged to plot/landowner or operator</td></tr>
<tr><td>(3) Regulating and/ or operating an operational service for on-site installation, also termed as FSM</td><td>LG/CG budget and optional ODA budget; in the best cases, CAPEX revenue from the service fee</td><td>LG/CG budget for the regulatory framework and operation from the service fee; in the same case, cross subsidy through water, electricity revenues or property taxes</td></tr>
</table>

(Source: Authors)

While this Guidebook does not go into the details of the FSM service, many practical references can be found in following links: https://fsm-alliance.org and https://www.eawag.ch.

In cases where the FSM service is provided by private entities, the government's is responsible for regulation and compliance monitoring. However, if the government acts as the service provider, the financial framework of this decentralised system mirrors that of publicly owned and managed sewer-based wastewater projects, as discussed in Chapter 3.3.

The table below outlines various funding sources, indicating where (on-site or FSM service) and for what (CAPEX, OPEX, R&M) they are typically applied. R&M, as referenced in Table 3.13, stands for government regulation and monitoring activity and related expenses.

Table 3.13. Funding sources and their application to on-site sanitation and FSM services for privately owned and operated wastewater projects
(Source: Authors)

Funding source	On-site sanitation		Public FSM service		
	User interface (toilet)	On-site containment (septic tank, WWTP)	Collection	Treatment	Disposal/reuse
Plot owner's private funds	CAPEX, OPEX	CAPEX, OPEX			
Government budget	(CAPEX)	(CAPEX), (OPEX), R&M	CAPEX, (OPEX), R&M	CAPEX, (OPEX), R&M	CAPEX, (OPEX), R&M
Special tax		(CAPEX), (OPEX), R&M	CAPEX, OPEX, R&M	CAPEX, OPEX, R&M	CAPEX, OPEX, R&M
User or service fee			CAPEX, OPEX,	CAPEX, OPEX, M	CAPEX, OPEX, M
National or internal grants	(CAPEX)	(CAPEX)	CAPEX	CAPEX	CAPEX
Revolving funds	(CAPEX)	(CAPEX)	CAPEX	CAPEX	CAPEX
Sales revenue			CAPEX, OPEX	CAPEX, OPEX	CAPEX, OPEX
Cross subsidy			CAPEX, OPEX	CAPEX, OPEX	CAPEX, OPEX
CSR funds/ grant	CAPEX	CAPEX	CAPEX	CAPEX	CAPEX

Note:

- The table excludes public–private partnership projects or private service providers who provide financial resources for CAPEX and OPEX. While these resources assist in prefinancing investments, they need to be recouped mainly through user/service fees, sales revenues or government budgets. Partial or full prefinancing of the initial investment by the private sector can alleviate the initial funding burden for the municipality.

- Bank loans, the most common prefinancing option, are also not included in the table. Repaying the bank loan and its interest rate falls under CAPEX and is typically covered by the outlined funding sources. The most sustainable approach is to repay bank loans by using funding sources such as user fees, sales revenue and special taxes and charges.
- () – These funding options, which are usually unsustainable, should be avoided or minimised. They are employed only as a last resort in low-income communities.

3.5.4. Financial framework for publicly owned and managed sewer-based wastewater projects

In the case of publicly owned and managed wastewater infrastructure and services, the municipality assumes the overall responsibility for executing all necessary operational and asset management tasks. It is also tasked with securing the required financial resources. As discussed in Chapter 3.3 of this Guidebook, municipalities can opt to outsource certain tasks to other entities. However, it remains the municipality's duty to ensure that all aspects of the sanitation value chain, including operational expenses (OPEX) and capital expenses (CAPEX), are appropriately covered throughout the infrastructure's entire lifecycle. This includes budgeting for routine maintenance, repairs, upgrades and potential future asset expansion or replacement.

The following table outlines the different funding sources and indicates where (on-site or FSM service) and for what (CAPEX, OPEX, R&M) they are typically applied.

Table 3.14. Funding sources and their application to publicly owned and operated sewer-based DWM *(Source: Authors)*

Funding source	On-site or on a private plot		Public sewer-based wastewater service		
	User interface (toilets)	House connection	Collection	Treatment	Disposal/ reuse
Plot owner's private funds	CAPEX, OPEX	CAPEX, OPEX			
Government budget	(CAPEX)	(CAPEX), (OPEX)	CAPEX, (OPEX), R&M	CAPEX, (OPEX), R&M	CAPEX, (OPEX), R&M
Special tax		(CAPEX), (OPEX)	CAPEX, OPEX, R&M	CAPEX, OPEX, R&M	CAPEX, OPEX, R&M

Funding source	On-site or on a private plot		Public sewer-based wastewater service		
	User interface (toilets)	House connection	Collection	Treatment	Disposal/ reuse
User or service fee			CAPEX, OPEX,	CAPEX, OPEX, M	CAPEX, OPEX, M
National or internal grants	(CAPEX)	(CAPEX)	CAPEX	CAPEX	CAPEX
Revolving funds	(CAPEX)	(CAPEX)	CAPEX	CAPEX	CAPEX
Sales revenue			CAPEX, OPEX	CAPEX, OPEX	CAPEX, OPEX
Cross subsidy			CAPEX, OPEX	CAPEX, OPEX	CAPEX, OPEX
CSR funds/ grant	CAPEX	CAPEX	CAPEX	CAPEX	CAPEX

Note:

- The table excludes public-private partnership (PPP) projects, where private service providers contribute financial resources for CAPEX and OPEX. These resources aid in prefinancing investments but need to be recouped primarily through user/ service fees, sales revenues or government budgets. Partial or full prefinancing of the initial investment by the private sector can ease the initial funding burden on the municipality.
- Bank loans, the most common prefinancing option, are also not included in the table. Repaying the bank loan and its interest rate falls under CAPEX and is typically covered by the outlined funding sources. The most sustainable approach is to repay bank loans by using sources such as user fees, sales revenue and special taxes and charges.
- () – These funding options are usually unsustainable and should be minimised or avoided, if possible. They are used, for instance, in low-income communities, but only as a last resort.

3.5.5. Cost structure of decentralised wastewater projects

The term "Cost Structure" refers to all hardware and software costs associated with establishing and operating a wastewater project. The following categorizations are suggested:

Sanitation Value Chain

The sanitation value chain for the decentralised wastewater project includes the following components:

- House connection: This connection on the private plot links the interface (e.g. toilets) of the respective buildings to the public collection sewer that is, the inspection chamber;
- Plot connection: This connection links the interface to the collection sewer;
- Wastewater collection system (sewer);
- Treatment plant;
- Discharge or reuse facility.

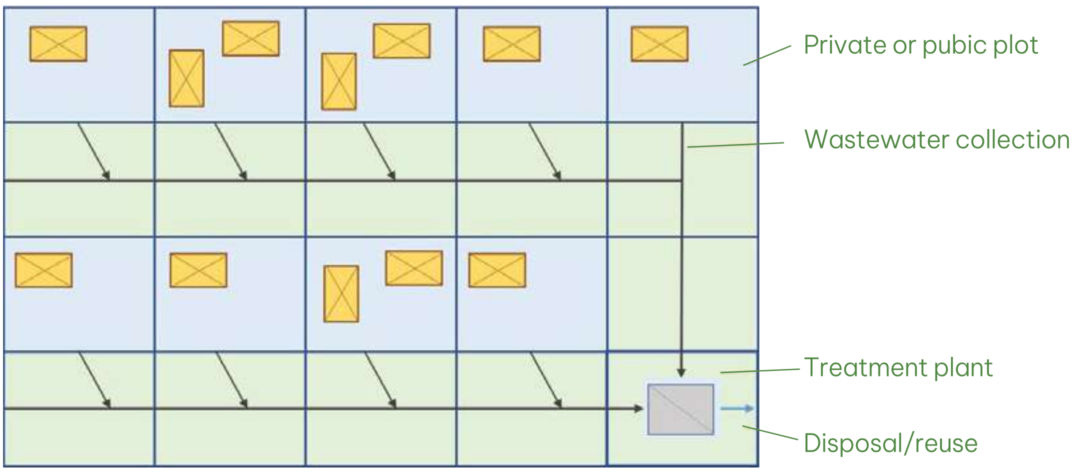


Figure 3.7. Universal visualisation of a publicly owned and managed wastewater system *(Source: Authors)*

Figure 3.7 shows a sample of a decentralised wastewater project using a DEWATS (status 2022). This example illustrates the distribution of the main project expenses, including the initial implementation costs, with specific figures broken down per capita or user. The initial investment cost does not include the cost of capacity development, which is accounted for under a different budget line.

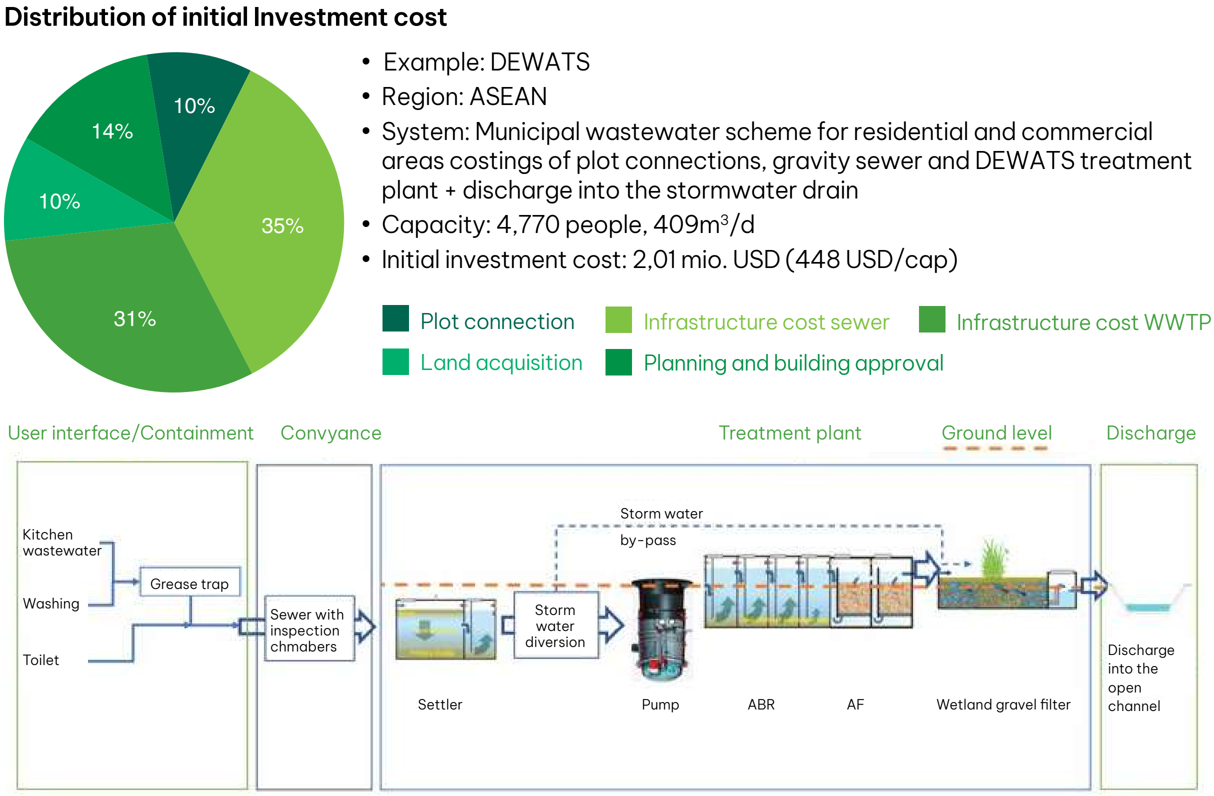


Figure 3.8. Example of the investment cost distribution for a municipal decentralised wastewater project
(Source: Authors)

Project Lifecycle

Breaking down the cost according to the project lifecycle offers a more comprehensive view of the project cost structure. This assists in identifying all cost positions throughout the project lifecycle.

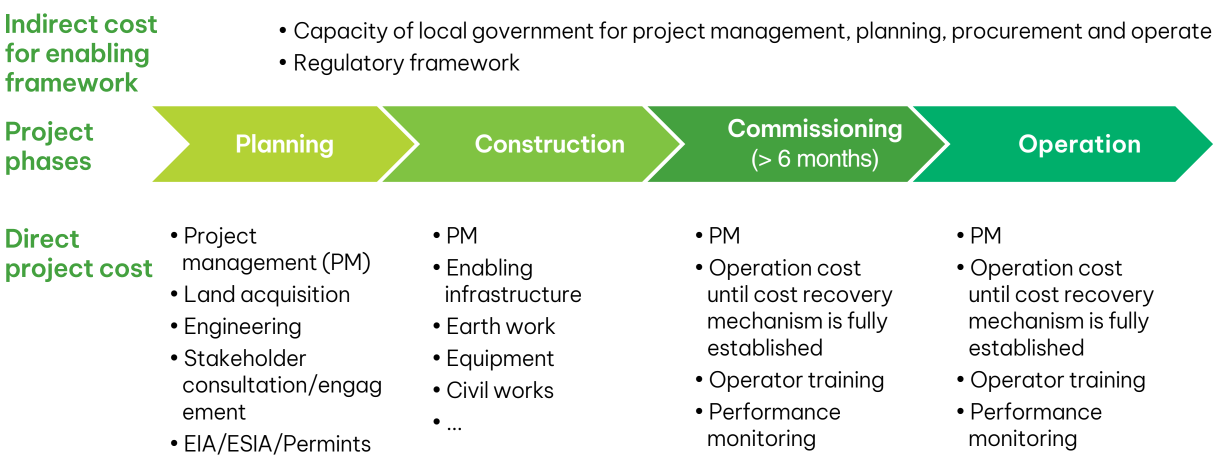


Figure 3.9. Indirect and direct project costs for a municipal decentralised wastewater project
(Source: Authors)

Figure 3.9 illustrates the typical cost components of a project (direct project cost). The choice of technology and local conditions significantly influence costs. For nature-based technologies such as constructed wetlands, the operational and technical costs are typically low, whereas land and earthwork costs can be high. In contrast, compact packaged WWTPs often incur higher equipment costs. Costs for earthwork and foundations are site-specific; often, these are underestimated, which adversely impact the projected investment cost. Thus, it is crucial to carefully consider and compare investment costs for different technologies by considering the local conditions and requirements. Relying solely on comparing information from the literature may not be prove to be sufficient in practical situations and could also be potentially misleading.

Project management (PM) costs in Figure 3.9 encompass expenses related to the municipality's oversight of the project, which may include staff resources or payments to external consultants. These costs cover activities such as facilitating meetings, stakeholder mobilisation transportation and procurement of services and goods. The time investment required for project management is often underestimated; hence, this should be considered from the outset and mitigated accordingly.

The cost group *engineering, stakeholder consultation and building permits* are common sub-categories within the planning cost component and typically account for 8%–14% of the investment cost.

Stakeholder consultation and engagement require particular attention, especially in projects involving community areas. These projects usually require substantial community processes that are time-consuming and costly. Roughly, an additional 10% of the investment cost can be allocated to the community process. If capacity-building measures are also necessary, an additional 5% of the investment cost should be considered for this purpose. Therefore, for wastewater projects in low-income communities, particularly in unplanned or peri-urban areas, the budget allocation for stakeholder consultation and engagement can reach up to 15% of the investment cost and in some cases, even up to 20%. For municipalities undertaking their first decentralised wastewater project, careful planning and budgeting are key. Neglecting effective community and stakeholder acceptance and ownership in such projects can lead to prolonged implementation periods and low sustainability, thus putting the entire investment at risk. The first project of this kind in a municipality should be approached as a learning project for all stakeholders and budgeted accordingly. This is a lesson often underestimated by many development partners, who are frequently driven by the desire to reach the maximum possible beneficiaries with the available funds.

Commissioning the operation: It is highly recommended to consider the first 6 to 12 months of operation as part of the investment project. The investment project should not conclude with the commissioning of construction and handing over of the asset but should end with the commissioning of the operation as well. This additional support includes the following:

- **Learning period:** In the first few years (usually 2 years), the operator needs to learn about the functional and operational requirements of the system, which typically incur higher costs than those budgeted for normal operation.
- **Financial gap:** Since the plot connection, wastewater flow and revenue streams continue to be low in the beginning, the operator must budget for the full operation cost and the the cost of learning (see Figure 3.12).

It is recommended to plan for the cost of operation for the first 1 or 2 years and to incorporate these costs fully or partly into the initial investment budget.

Operational Cost

For publicly owned and managed wastewater infrastructures, there are two major operational cost categories, as illustrated in Figure 3.10:

- Operational management-related costs; and,
- Technical operational costs.

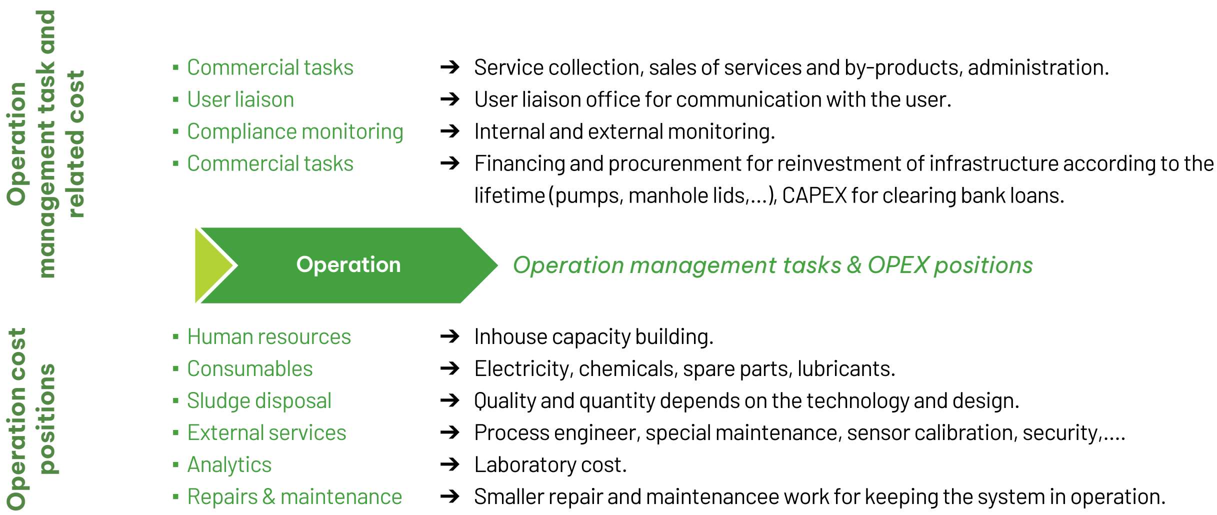
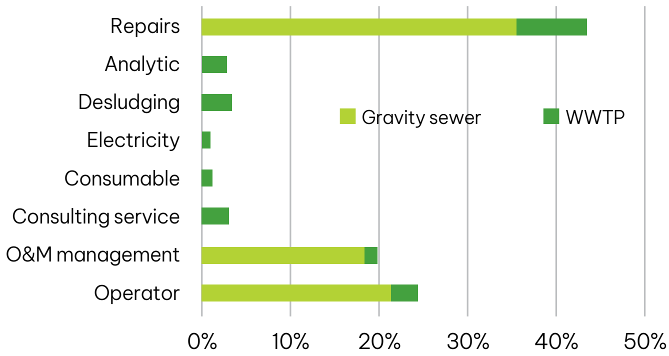


Figure 3.10. Indirect and direct project costs for a municipal decentralised wastewater project *(Source: Authors)*

In the available literature, most of the figures provided for operational costs often do not specify the different expenses covered. While such literature can provide general guidance, a project-specific thorough assessment of local technical and non-technical conditions and requirements is necessary to responsibly budget for operational costs and set appropriate service fees or tariffs. For each implementation project, the municipality should request a comprehensive breakdown of all expenses, replacement and maintenance intervals and operator manpower time from the designer or technology supplier. This will help to conduct a full life cycle cost analysis (see Chapter 4) before approval and procurement.

Figure 3.11 shows the same project example as in Figure 3.12. This study focuses on the specific operating costs (OPEX) for a DEWATS project and shows the cost distribution between the physical project components, namely, the sewer and the WWTP. The figures clearly show that the sewerage system incurs the highest costs, with repairs being the costliest item in the budget. A public sewer network is exposed to various human activities and environmental factors such as flooding, high water tables and misuse. All of these factors can affect its functionality and maintenance expenses. Sewer systems installed in low-income communities with inadequate soil cover (<0.5 m), numerous inspection chambers or areas prone to flooding typically have higher repair needs. Other influencing factors include construction design standards and quality of workmanship. Construction design standards include aspects such as manhole cover type, pipe material and jointing system, pipe bedding design and pipe/wall connections. Many municipalities enforce mandatory sewer design standards for all projects within their jurisdiction (see Chapter 3). This is primarily to mitigate the risks associated with poor quality construction, which can result in significant, unpredictable operating and repair costs. While wastewater service fees and tariffs are typically set for a fixed period, unanticipated operating costs can create financial gaps, which cannot be easily rectified by the operator. Neglecting necessary repairs to the sewer system can lead to problems such as leaks, overflows, odour problems, blockages and stormwater infiltration.

Distribution of operation cost



- Example: DEWATS
- Region: ASEAN
- System: Municipal wastewater scheme for residential and commercial areas costings of plot connections, gravity sewer and DEWATS treatment plant + discharge into the stormwater drain
- Capacity: 4,770 people, 409m^3/d
- Initial investment cost: 2,01 mio. USD (448 USD/cap)
- Annual operation cost (OPEX): 45,100 USD/a
- Specific OPEX: 0.3 USSD/m^3 or 9.4 USD/cap/a

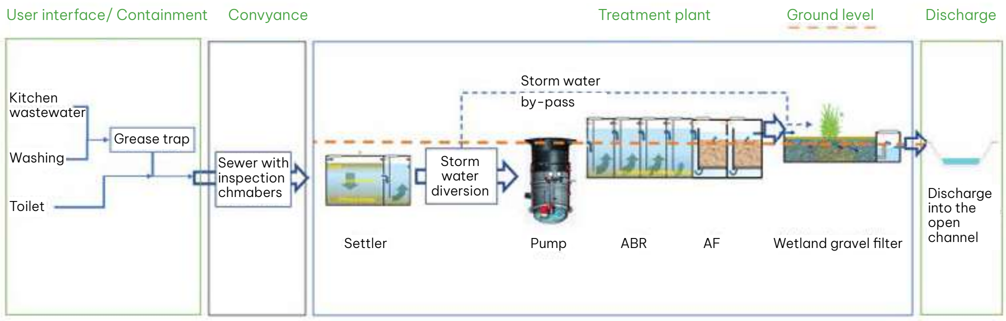


Figure 3.11. Example of the operation cost distribution for a municipal decentralised wastewater project
(Source: authors)

Repair costs include major repairs, renovations and replacements. Many technologies have components that require periodic replacement, such as UV lamps, bearings, filters and sensors. Any technology supplier or designer should provide a comprehensive list of equipment and parts that require periodic replacement, along with information regarding the intervals of replacement and costs. An alternative method for estimating replacement costs is to apply an annual average percentage of the initial investment costs. Under normal conditions, the average annual repair and replacement costs can be estimated as follows:

- Renovation of civil structures: 1.0%–3.0% of investment costs per year;
- Mechanical equipment: 2.0%–4.0% of investment costs per year;
- Electrical and electronic equipment: 3.0%–6.0% of investment costs per year.

Using these figures for a lifecycle cost analysis, an additional inflation index needs to be considered.

3.5.6. Considerations for setting wastewater service fees

Setting appropriate wastewater service charges and tariffs involves both economic (balancing revenues and expenses) and political considerations. In a well-developed and effective wastewater sector, the wastewater fee accounts for 60%–70% of the total wastewater and water bill, while 30%–40% is allocated to water. In most ASEAN countries, the situation is reversed, with wastewater accounting for 20–40% and water accounting for 60%–80% of the bill. Similar to Europe, service charges and tariffs are designed to recover all operational costs, capital investment, as well as re-investment or depreciation. However, in many ASEAN countries, only the water supply sector has gradually reached a level where the water bill fully covers the operating costs and, in some cases, even some or all of capital or depreciation costs. Unfortunately, this is not the case regarding wastewater treatment. Many decentralised wastewater projects rely on wastewater service charges to cover operating costs, including basic maintenance, but not capital or major repair costs.

When setting wastewater service fees, it is critical to consider a tariff system that promotes social equity, ensuring that commercial activities and high-consuming users pay higher rates than residents or low-consuming users.

Another aspect to consider is that in the early years of operation, not all properties may be connected to or served by the project. In such cases, the operator will be faced with lower revenues from wastewater service fees, while operating expenses will remain almost the same. This situation can create a significant financial gap, posing a threat to the continued operation of the system. It is important to develop a strategy during the planning phase to address this gap. One option is to calculate the financial gap and include it in the initial investment of the implementation project. Other approaches include covering the gap through government budgets or setting higher wastewater service charges to refinance the financial gap.

Figures 3.11 and 3.12 are based on the same example project. Figure 3.12 visualises the specific cost per m³ of treated wastewater over a 20-year project projection (lifecycle 20–30 years):

- Increase in the plot connection (blue line);
- OPEX without major repairs (grey line);
- OPEX with major repairs and periodic re-investment (red dotted frame);
- OPEX with major repairs and average annual investment (orange dotted line);
- OPEX with major repairs for system maintenance (orange bold line).

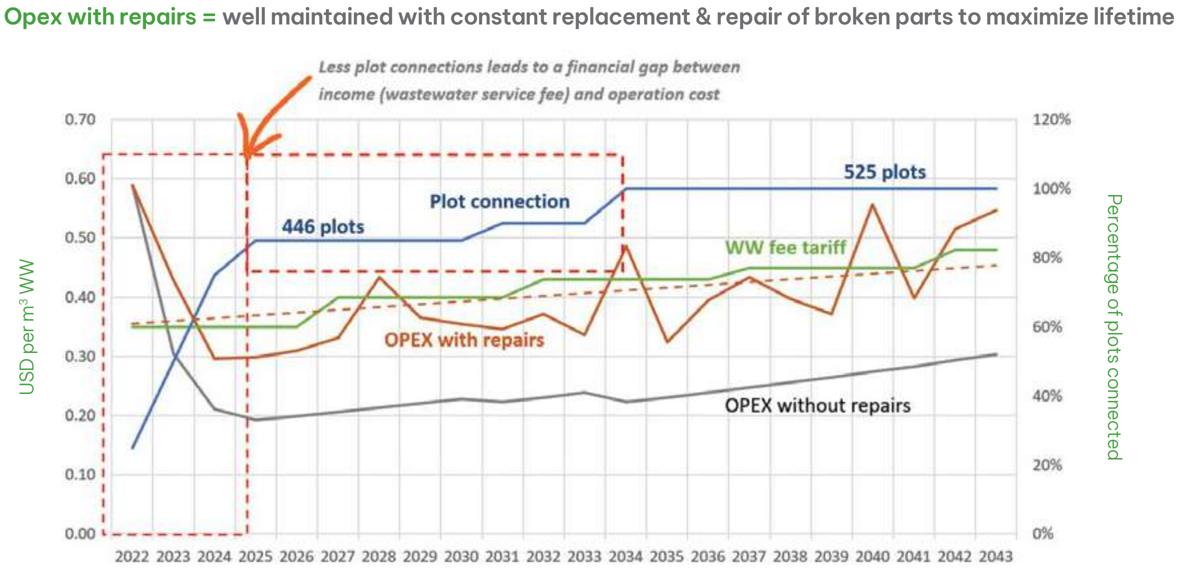


Figure 3.12. Example for a municipal decentralised wastewater project showing the plot connection rate and specific OPEX over a 20-year project period. *(Source: Authors)*

Figure 3.12 indicates that the project achieved a plot connection rate of approximately 80% within 2 years. In this project, the revenue collection rate for water was 95% and the same rate was assumed for sanitation. The low connection rate and the consequent low wastewater revenue collection rate in the first years created a financial gap that needs to be considered.

The specific cost line *OPEX with repairs* does not consider capital cost for reinvestments; rather, it considers all expenses to keep the infrastructure functioning through its lifetime through regular or periodic replacement (pumps) or major repairs to structures (concrete, pipes, inspection chambers,...). It is recommended to break down these expenses into investment components:

- Civil works structure (earthworks, concrete and brick structures, etc.);
- Mechanical equipment;
- Electrical and electronic equipment (pumps, electrical panels, etc.)
- Sewage pipe;
- Plot connection.

Only minor repairs are considered in the specific cost line *of OPEC without repairs*. Such budgeting can create financial challenges, usually after 5 years of operation, when major repairs or replacements occur.

In the specific project case shown in Figure 3.12, the wastewater service fee was determined based on the operating expenses calculated by the *OPEX with repairs*.

The average annual cost of these repair activities is indicated by the orange dotted line. All revenues and expenses were projected over 20 years by using an estimated annual increase (inflation rate) of 3.5%.

Typically, tariff calculations of this type are performed by financial and institutional experts within a project. However, it is important for the technical team to provide well-considered financial inputs to support these calculations.

3.5.7. Cost example of different wastewater treatment technologies

The following figure shows the cost versus treatment capacity of eight different wastewater treatment technologies (no sewer) based on a case study assessment conducted in India from 2016 to 2018 (Rajan et. al 2019).

ASP	Activated sludge bed process;
MBBR	Moving bio-bed reactor;
DEWATS	Decentralised wastewater treatment system (here only with anaerobic baffled reactor and filter);
EA	Extended aeration system;
SBR	Sequencing batch reactor;
MBR	Membrane Bioreactor;
SBT	Soil bio-technology (constructed wetlands).

For a technical explanation of these systems, see Chapter 4.

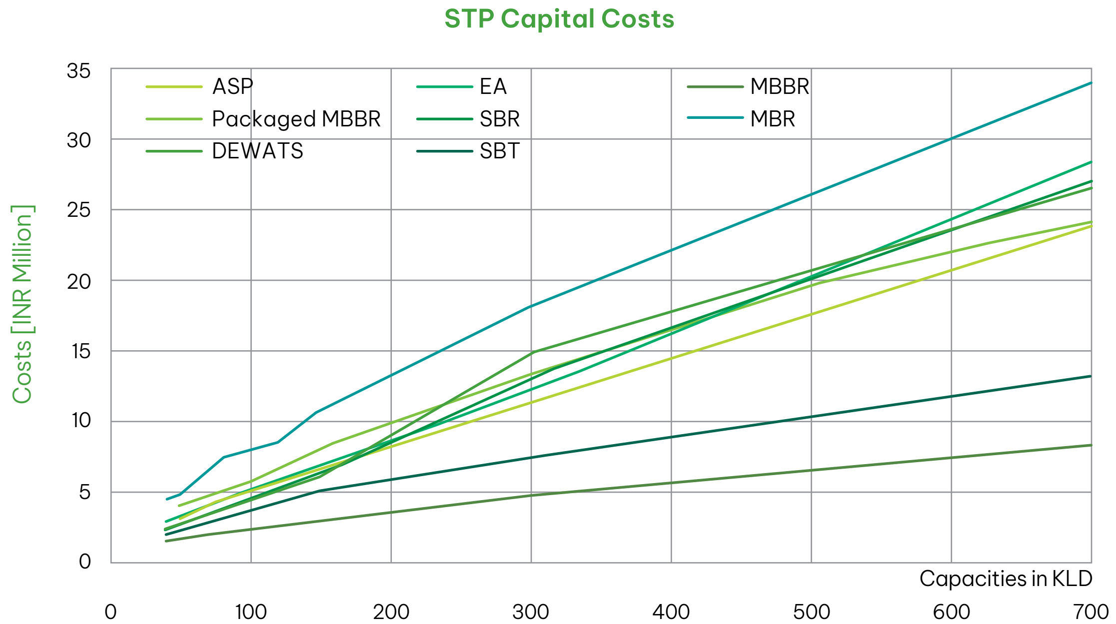


Figure 3.13. Overview of CAPEX of eight wastewater treatment technologies with a capacity of 35–700 m^3/d or 35–700 kilolitre per day (KLD)
(Source: Rajan et al 2019)

Figure 3.13 does not show the quality of the treated effluent, although it is an important consideration in the project. A simple DEWATS system, while having the lowest operating cost, produces a lower quality effluent (COD > 150 mg/l, E. coli 10,000 MPN/100 ml) as compared to that by a membrane bioreactor (COD < 50 mg/l, E. coli < 500 MPN/100 ml). This means that achieving better treatment quality is associated with higher investment and operating costs. However, it is critical to assess the sustainability of operating an advanced treatment system. If it cannot be effectively maintained, the investment may not be worthwhile, following the principle that what cannot be maintained should not be built.

Additionally, the figure excludes the cost of land acquisition. For example, an SBT (constructed wetland) can provide the best treatment quality at the lowest operating cost, but it requires a significant amount of land (roughly 1–2 m^2 per capita). This can be a challenge in urban contexts where such land may not be available or prohibitively expensive.

Figures 3.13 and 3.14 shows the relationship between O&M costs and the capacity of each treatment technology. Except for MBR, SBT and DEWATS, most technologies exhibit similar monthly O&M costs, which are primarily influenced by the expenses associated with a full-time operator. DEWATS boasts the lowest O&M costs among the technologies under study due to its minimal labour and electricity requirements. In contrast, MBR has the highest monthly O&M costs, stemming from its substantial energy demands and the need for highly skilled operators to manage the system. When operating at a capacity of 700 KLD, the costs for most technologies increase because of the necessity for additional operators and supervisors. EA, in particular, incurs the highest O&M costs at this scale, driven by elevated electricity expenses resulting from its extensive aeration requirements. However, MBR reaps certain operational scale benefits at this level, such as the use of premium components that lead to reduced maintenance and replacement costs.

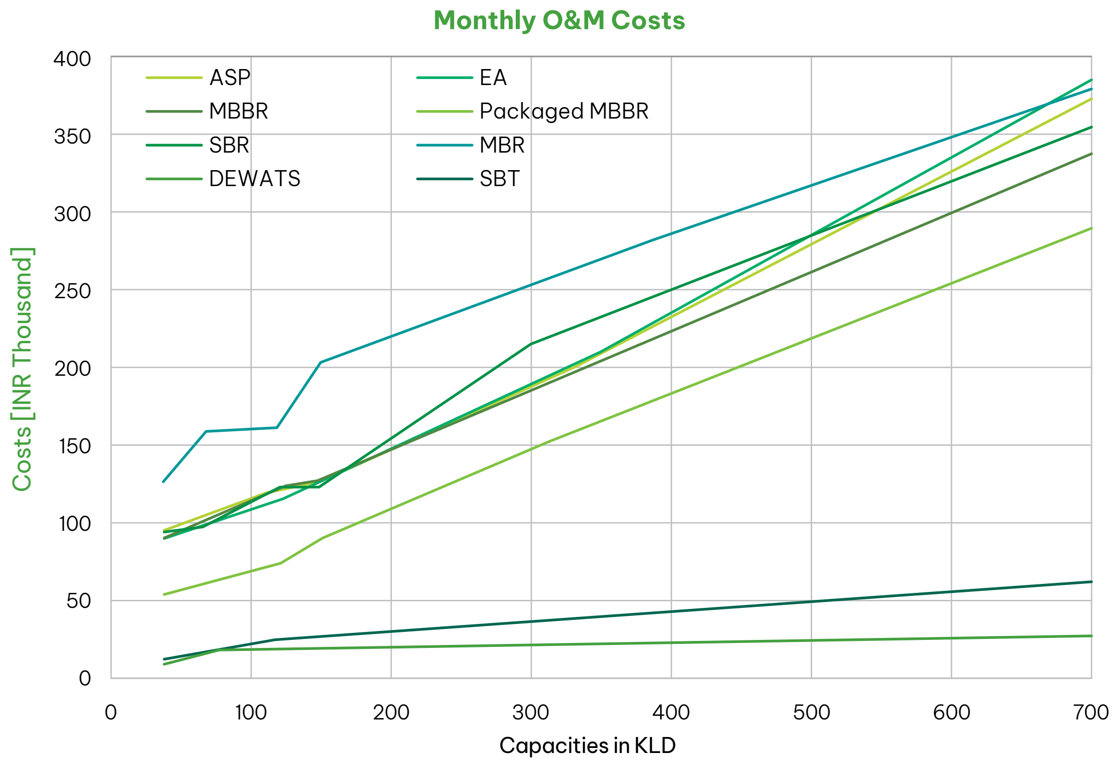


Figure 3.14. Overview of the O&M cost of eight wastewater treatment technologies with a capacity of 35–700 m³/d or 35–700 kilolitre per day (KLD)
(*Source: Adapted from Rajan et al 2019*)

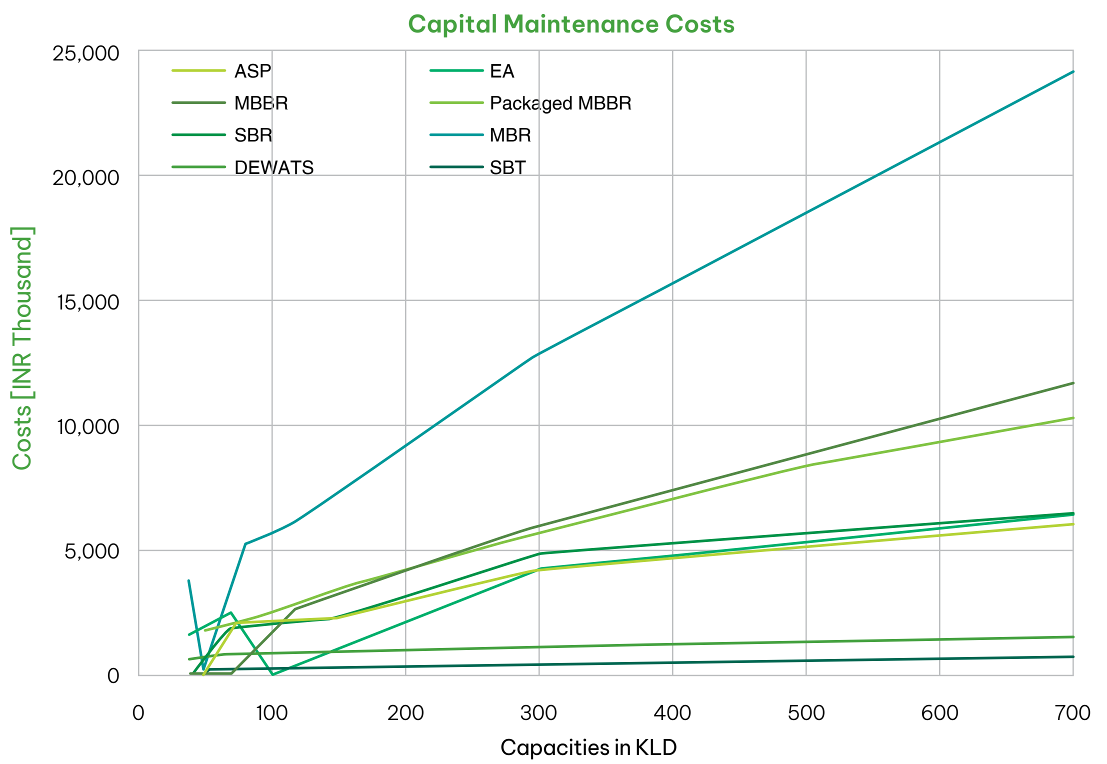


Figure 3.15. Repair and maintenance cost overview of the eight wastewater treatment technologies with a capacity of 35–700 m³/d or 35–700 kilolitre per day (KLD) over 10 years
(Source: Rajan et al., 2019)

3.5.8. Operational Cost-Recovery Options in a Decentralised Wastewater Project

Table 3.15. Cost-recovery options

Cost-recovery option	Source	Requirements/comment
Sanitation service fee	Collected with the water bill	In many municipalities, the sanitation fee is collected along with the water bill. However, this arrangement relies on the condition that the water supplier provides water to all the plots that are served by the wastewater system. Additionally, it is preferable to have a commercial water revenue collection rate of over 70% to prevent the service fee per unit (such as per m^3, per household or person) from becoming excessively high. The wastewater billing is directly linked to water consumption—which equals wastewater generation—regardless of whether the water billing system is metered or flat rate.
	Collected as separated wastewater or sanitation fee	Where a combination with the water bill does not work, the households or plots can be charged periodically (monthly or quarterly) with a separate bill. The disadvantage of this system is that water consumption equaling wastewater generation is not linked to the water bill. Households with less water consumption may pay the same fee as households with higher water consumption (e.g. Dumaguete City model, Philippines).
	Sales of plumbing or sewer cleaning services to the client/ community	This service is an additional service provided by the utility provider or operator to the user and cannot substitute for the periodical wastewater service fee.
Sanitation tax	Collected with the property tax or other taxes	Since the combination of the sanitation fee with the water bill is not possible and separated fee collection is limited in scaling up, the wastewater service fee can be collected through the annual property tax system. This tax collection system is a robust system; however, it requires a larger legal and financial regulatory framework at the municipal or even national level.

Cost-recovery option	Source	Requirements/comment
Sales of by-products	General note	The potential (see Chapter 2.8) of generating marketable products from wastewater is significantly low and depends largely on the local conditions and on an operator with a business mind-set. However, the potential exists, but this revenue stream should not be considered to replace or substitute the wastewater service fee.
	Sales of water for irrigation, construction or other local demands	Revenue can be generated directly by selling to local consumers such as farmers or construction sites, but the demand is less predictable. The operator may sell crops irrigated with effluent if the associated conditions are applicable. In this case, the revenue stream is controlled and higher, but the operation efforts are also controlled. Direct revenue can be generated by substituting purchased freshwater before it is used for irrigation or other purposes. **Case study:** Farming in a semi-desert with water and nutrients from sewage: Gerga, Sohag Governorate, Egypt. Treated water from the Gerga municipal treatment plant was used for irrigation.
	Sales of bio-solids/ fertilizer	Solid by-products are usually produced from the sludge, either FS or surplus sludge and are more relevant for FSTPs and not for wastewater plants.
	Sales of energy (biogas, electricity)	Biogas generation from a decentralised wastewater treatment system is possible, as outlined in Section 2.8; however, this has little commercial relevance. Revenue generation is often very difficult. **Case study:** Devanhalli FSTP, Bengaluru, India. Sale of co-composted manure (treated solids with organic solid waste from the municipal area)
Subsidy	Any government source	A subsidy can be established; however, this is not sustainable and not recommended, but can be considered as an option if any better alternative is not available. **Case study:** The Philippine Water Revolving Fund (PWRF) was established to provide loans to water service providers to finance local water and wastewater projects. The repayments made are used to fund other projects.

(Source: Authors)

For further reading resources, please see:

Andersson, K., Rosemarin, A., Lamizana, B., Kvarnström, E., McConville, J., Seidu, R., Dickin, S. and Trimmer, C. (2020). Sanitation, Wastewater Management and Sustainability: from Waste Disposal to Resource Recovery. 2nd edition. Nairobi and Stockholm: United Nations Environment Programme and Stockholm Environment Institute.

Chapter 4
Technology selection

4.1. General considerations

The wide variety of technical options and customised solutions in decentralised wastewater treatment presents both opportunities and challenges. While it offers the flexibility to choose from various solutions available on the market, it also requires a high level of expertise in the design, approval, implementation, operation and monitoring of these diverse systems.

The objective of this chapter is to guide the selection process of technical options regarding decentralised wastewater applications. It is intended to help stakeholders understand the selection criteria and evaluate the technical options available for both city-wide and site-specific contexts, as well as refer to existing design standards, manuals and guidelines. Specifically, this chapter focuses on the system components related to wastewater collection (sewer) and treatment.

First, we highlight the different types of municipal wastewater streams as follows:

Municipal wastewater is generally divided into:

- **Domestic wastewater** → From toilets, bathing, laundry, kitchen, washing sinks, etc.
- **Commercial wastewater** → From offices, schools, hotels, restaurants and markets.
- **Industrial wastewater** → Usually only organic wastewater with characteristics similar to domestic and commercial wastewater; other types of industrial wastewater cannot be discharged into municipal wastewater systems or require permits and monitored pre-treatment.
- **Mixed wastewater** → Municipal wastewater combined (mixed) with stormwater.
- **Separated wastewater** → Municipal wastewater separated from stormwater.

Domestic wastewater can be sub-divided into:

- **Blackwater** → Toilets.
- **Greywater** → Bathing, laundry, kitchen, washing sinks.
- **Yellowwater** → Urine.

The distinction between wastewater streams is important in determining the appropriate wastewater treatment technologies. It is important to note that kitchen wastewater is often classified as greywater in most literature because it is typically not contaminated with human faeces. However, the authors of this Guidebook recommend that kitchen wastewater should be connected to the blackwater stream rather than the greywater stream when implementing source separation. The main reason for this recommendation is the high solid content in kitchen wastewater, which makes it more practical to treat it as blackwater.

4.2. Wastewater collection and conveyance

4.2.1. General considerations

For centralised systems as well as sewer-based decentralised wastewater projects, the sewer component typically requires 50% to 80% of the total project construction and operation costs.

From a cost perspective, investing in a well-designed and efficient sewer system is critical because inefficient systems result in significantly high O&M costs. Additionally, the appropriate functioning of the sewer system directly affects the overall performance and effectiveness of the treatment plant.

Consequently, it is essential to allocate adequate resources and attention to wastewater collection and conveyance systems to achieve cost-effective and sustainable decentralised wastewater projects.

Figure 4.1 illustrates the most common challenges associated with gravity sewer systems. House connections, pipe joints, pipe bedding, inspection chambers and manhole covers are the primary weak points in the sewer system and must be well-designed and constructed with high-quality materials and skilled labour.

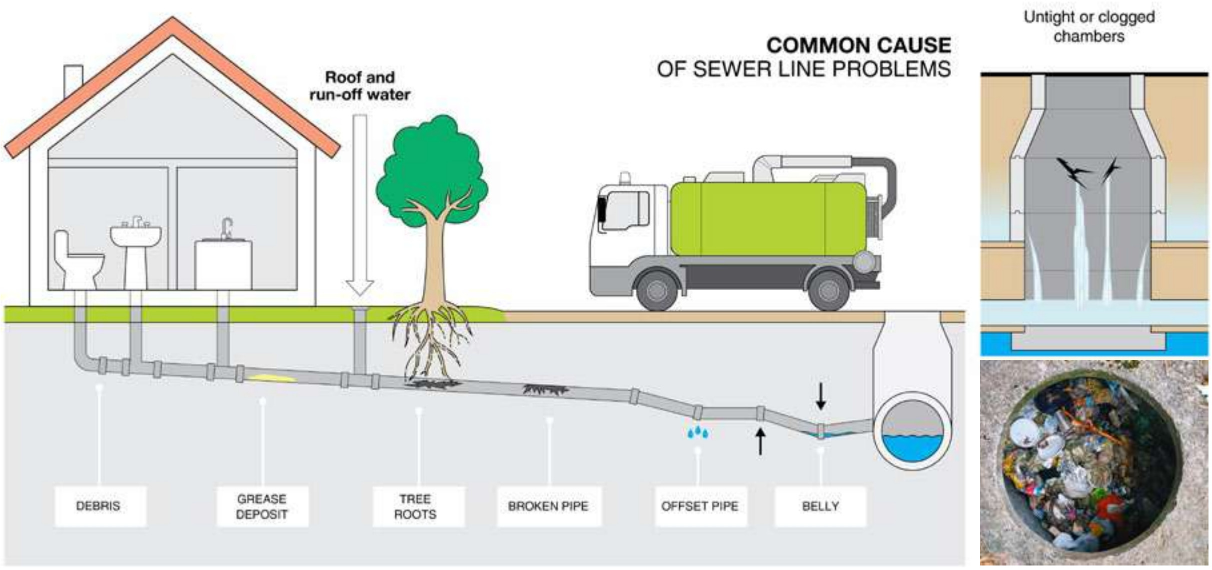


Figure 4.1. Typical challenges associated with wastewater pipes and inspection chambers *(Source: Plumbers24x7.com, Shutterstock.com)*

4.2.2. Household or plot connections

The house connection is the interface between the private and public responsibility regarding wastewater management, with its main purpose being the collection of the defined wastewater. 'Defined wastewater' or what can be connected and discharged into the public sewer system, should be effectively communicated and agreed upon with the end user. Usually, the communication occurs through the municipal liaison office and is defined in the local by-laws. Non-domestic activities, such as restaurants or industrial operations are subject to specific regulations and may require special discharge permits. It is important to ensure that non-domestic wastes, such as chemicals or organic materials, are not discharged into the sewer system. In the case of decentralised wastewater systems, it is essential to minimise and restrict the discharge of stormwater run off from the ground and roof. This is necessary to avoid negative hydraulic impacts on the treatment plant. Efforts should be made to manage stormwater separately to avoid overloading the treatment system.

Specifically, in the context of ASEAN countries, the following should be considered:

- Installation of grease traps in sewer pipes because of the relatively high amount of oil and fat discharged into the sewer;
- Existing septic tanks;
- Flood-resistant design;
- Controlling stormwater and outside open drain run off.

Generally, it is advisable to install grease traps after the kitchen drain to collect and remove grease and fats from the wastewater. These grease traps are usually installed near the house on private property and the property owner has the responsibility to manage and maintain these traps.

Connecting the outlet of an existing septic tank to the public sewer is an interesting concept from a technical standpoint, especially in the context of solids-free sewers. However, this approach requires addressing the management responsibilities associated with septic tanks installed on private plots.

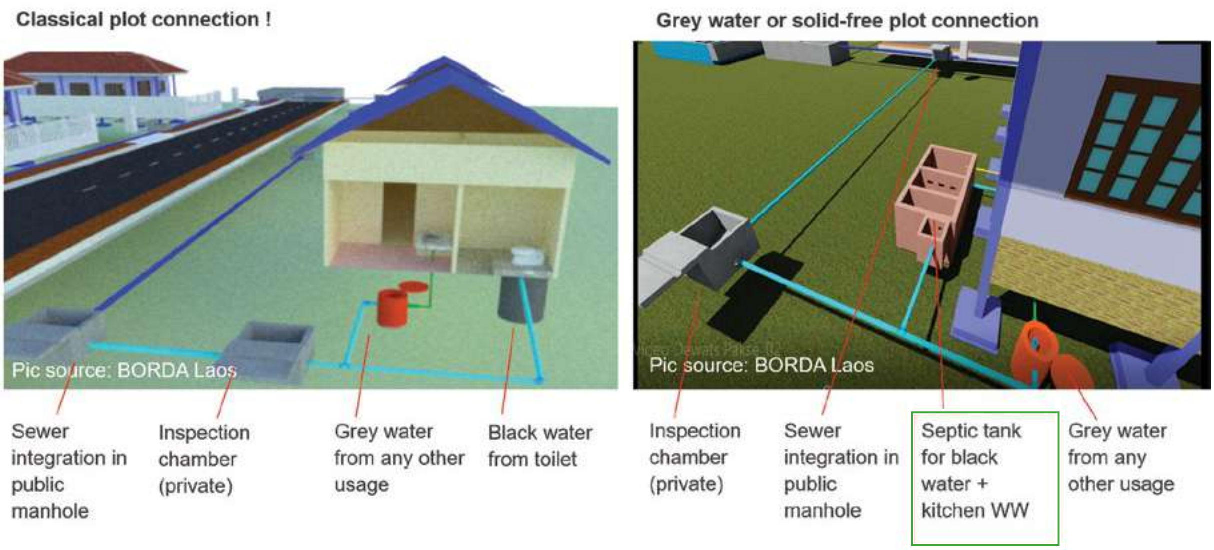


Figure 4.2. Typical components of household connections in the ASEAN region *(Source: BORDA Laos)*

4.2.3. Sewer systems

The purpose of a sewer system is to transport wastewater and its solids from the point of collection to the point of treatment or discharge the collected wastewater without harming the environment. This seemingly simple objective can be challenging to achieve in reality. The main associated challenges and impacts are listed in Table 4.1.

Table 4.1. Challenges and impacts of sewer systems

Challenge	Impact
Loss of water (leakage)	Pipe blockages, environmental pollution, structural damage to nearby buildings and high maintenance costs
Increase in water (intrusion and uncontrolled intakes)	Hydraulic overload on the sewer and WWTPs
Blockages	Sewer overflow and environmental pollution and high maintenance costs
Gas generation	Odour, material corrosion (concrete pipe and inspection chambers) and explosion

To avoid and minimise such challenges while optimising investment costs, several technical systems have been developed and applied. Some of these systems are specified below.

Separated sewer system

This mechanism involves separating wastewater from rainwater, which is essential for a decentralised system.

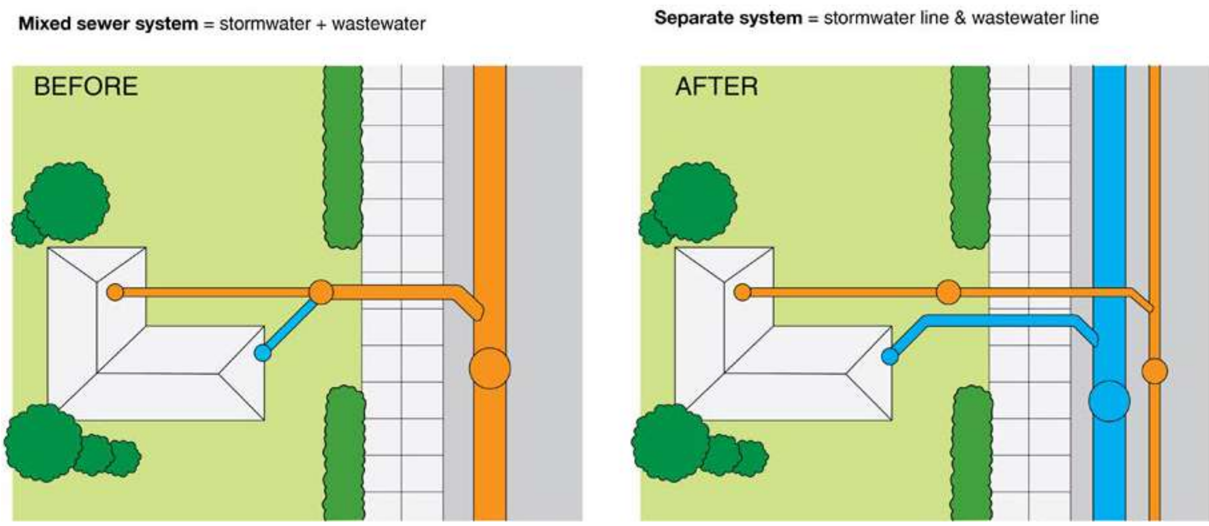


Figure 4.3. Illustration of mixed and separate sewer systems
(Source: www.sswm.info)

Condominial system

The condominial system was developed to minimise pipe length and reduce road reconstruction costs by locating pipes on private or community land, as shown in various versions in the accompanying sketch in Figure 4.4. This approach, combined with community contributions, results in a significant reduction in construction costs. However, a disadvantage of this system is the potential dispute of ownership and access for maintenance and repair. Many municipalities and/or water utilities do not prefer this option because of this disadvantage.

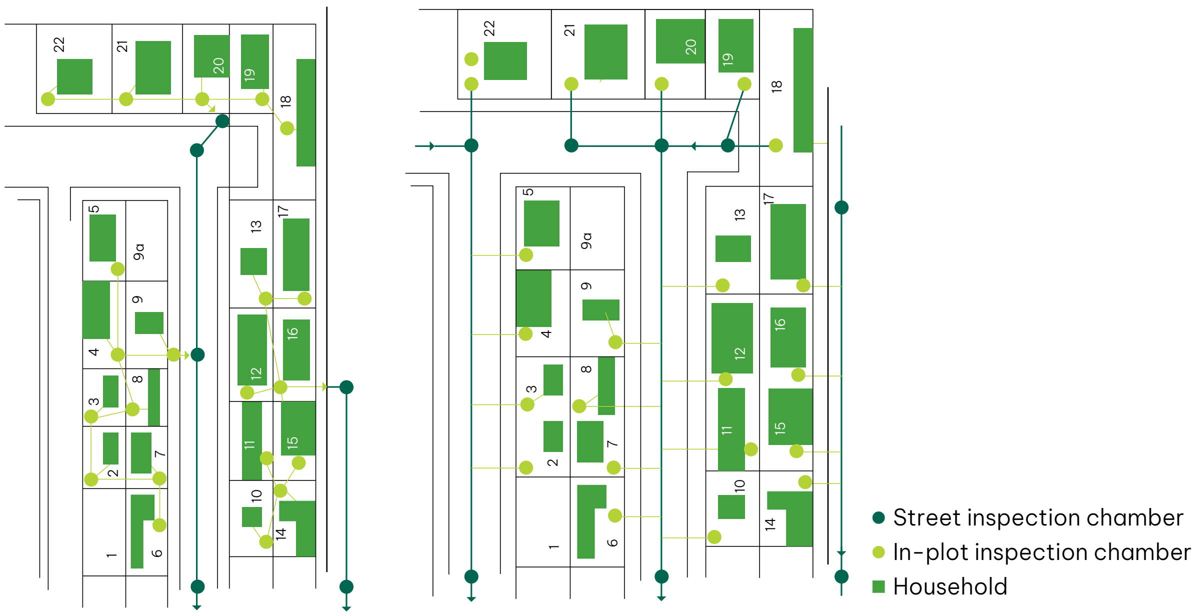


Figure 4.4. Illustration of the condominial system (left) and conventional system (right) *(Source: PC-based simplified sewer design from University of Leeds 2001)*

However, even the traditional method of placing pipes in public areas can be optimised in several ways, as shown below:

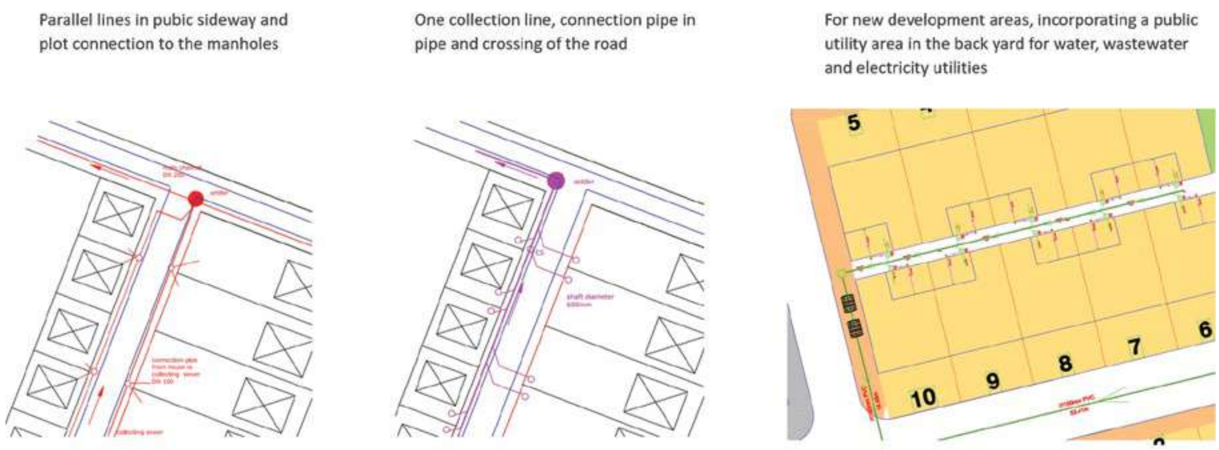


Figure 4.5. Illustration of different ‘conventional’ systems for plot connections *(Source: UrbanWaters ConsultingGmbH)*

Simplified sewer system

As defined by the University of Leeds, simplified sewerage is an off-site sanitation technology that removes all wastewater from the domestic environment. It is conceptually the same as a conventional sewer system; however, in this system, a conscious effort is made to eliminate unnecessarily conservative design features; additionally, the system design is adapted to local conditions.

The key features of the simplified sewer system are as follows:

- The design values to be used for wastewater flow;
- The properties of a circular section (condominial system);
- Gauckler–Manning equation for flow velocity;
- Hydraulic design based on the minimum tensile stress, minimum channel gradient and channel diameter.

The team at the University of Leeds has made a remarkable effort to develop design guidelines for simplified sewer systems. These guidelines are based on the experience of implementing this system on a large scale in low-income communities in Brazil.

Reference: *PC-based simplified sewer design from the University of Leeds, 2001*

The authors of this Guidebook wish to share their professional opinions and experience as follows:

- Decentralised wastewater systems face the challenge of relatively low water flows, especially in service lines and smaller sewer networks. Thus, traditional sewer hydraulic design formulas may have limitations in such cases. The University of Leeds recommends a minimum peak flow of 1.5 l/s for a simplified sewer system, which is a practical and useful guideline.
- Other recommendations, such as using a sewer pipe diameter of less than 150 mm or a pipe slope of 0.5%, as well as the condominium concept, should be approached with caution for each specific project site, considering their practical implications. For example, the condominium system may present challenges in terms of accessibility and liability and smaller pipe diameters may be susceptible to blockage from waste disposal. Additionally, a 0.5% pipe slope may present construction challenges and a lack of buffer capacity in the event of uncontrolled earth movement.

Solids-free sewer system

Solids-free sewer is a system that addresses solids in wastewater. In a gravity sewer system, it is critical to ensure that wastewater solids are effectively transported throughout the system without settling or accumulating. This requires a special hydraulic sewer design and a high level of construction quality and effort.

The solids-free sewer system involves the integration of settlers, either at the property level (septic tanks) or within the sewer network (interceptors). These settlers trap and break down solids so that only wastewater with minimal or no solids is conveyed. This approach helps reduce the load on the sewer system and improves its overall performance.

The benefits of this systems include the following:

- Less tensile force is required, resulting in lower pipe slopes/gradients of 0.5%–1.0%. Less pipe depth and earthwork and less susceptibility to construction and operational errors.
- BOD and COD reduction of up to 65% and TSS reduction of up to 80%, resulting in less required wastewater treatment capacity.
- Less solids in the sewer system, thus protecting lift pumps; there is also less risk of clogging and fewer inspection chambers are required.

This system requires the allocation of land for the installation of underground settlers and the establishment of an operational management system. In practice, the settlers must be periodically emptied by a vacuum truck according to the design specifications. Alternatively, the settlers can be designed as biogas plants, which provides an additional benefit in terms of energy/revenue generation. This concept is particularly attractive for low-income communities. However, it should be noted that the biogas yield is relatively low; for example, wastewater from 10 families may produce biogas that is sufficient to meet the cooking needs of one family alone. There are numerous technical and social challenges to implementing biogas interceptors, which significantly limit their practicality.

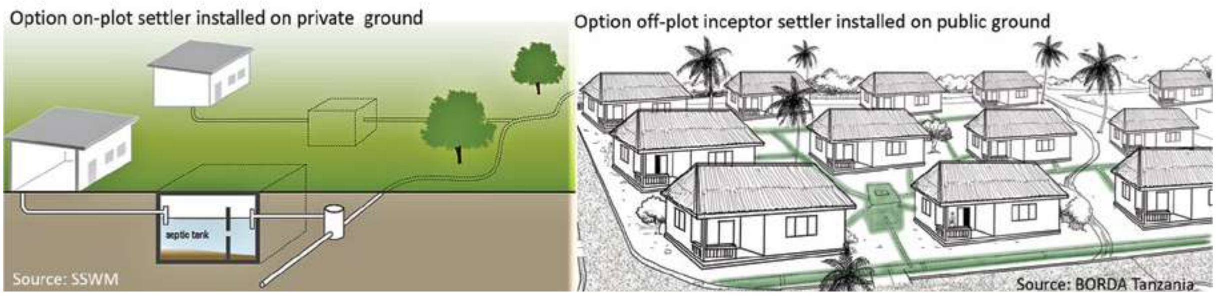


Figure 4.6. Illustration of the on-plot (on-site) and off-plot concepts for integrating settlers into the sewer system
(Source: www.sswm.info and BORDA Tanzania)

Figure 4.7 shows a project implemented in Zambia that integrated four biogas settlers into the sewer system to optimise the pipe level and the treatment plant and to minimise the operating costs of the sewer networks.

Figure 4.7. A project in Zambia integrated biogas settler into a sewer network
(Source: Andreas Schmidt IWA Conference 2002)

4.2.4. Flow design

This section outlines the most common hydraulic methods for wastewater conveyance and their relevance to decentralised wastewater management concepts.

Gravity-Flow Sewer

Pipes are typically laid with a slope of 1.0%–3.0% to facilitate the transport of wastewater and its solids using natural gravity flow, thus eliminating the need for energy consumption. However, this approach has certain disadvantages. Vertical changes in pipe position due to settling, floating or leakage can alter the hydraulic characteristics of the flow and affect the overall performance of the sewer system. Additionally, the construction process requires high accuracy and high investment costs because of the open trench installation method and the required installation depth, especially in flatland areas.

Relevance for DWM:

It is highly applicable for DWM and is the most common sewer flow design with the least reliance on electricity and electro-mechanical devices.

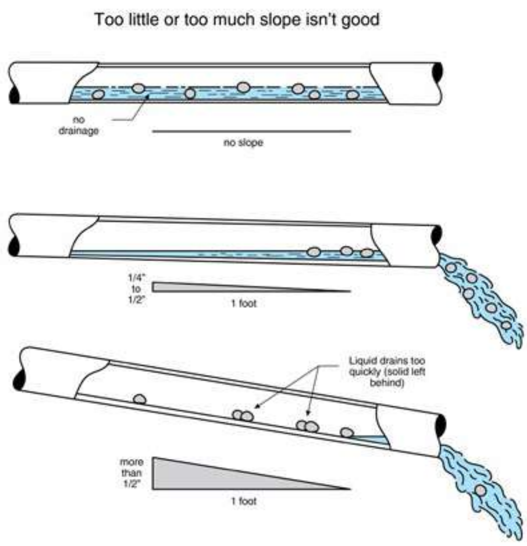


Figure 4.8. Ideal slope for a gravity-flow sewer
(Source: www.wastewater101.net)

Sewage Lift Station

The combination of a gravity sewer and lift station is often used in areas where the sewer pipe would require an uneconomically deep installation. Hence, the lift station helps optimise the investment and operating costs of a gravity sewer network where there is insufficient natural slope in the service or catchment area. However, it is important to consider the disadvantages of this approach. The pump(s) are the weak point of the system and need to be protected against breakdown, clogging by solid waste, lack of power and theft. Furthermore, additional pumping may be required in the event of uncontrolled storm water infiltration, resulting in additional costs. Additionally, scheduled O&M tasks are necessary for the lift station to function effectively.

Relevance for DWM:

It is recommended in combination with wastewater cluster solutions and/or a solids-free sewer system to reduce O&M costs. In the same cases, only one lift station may be required upstream of the treatment plant.

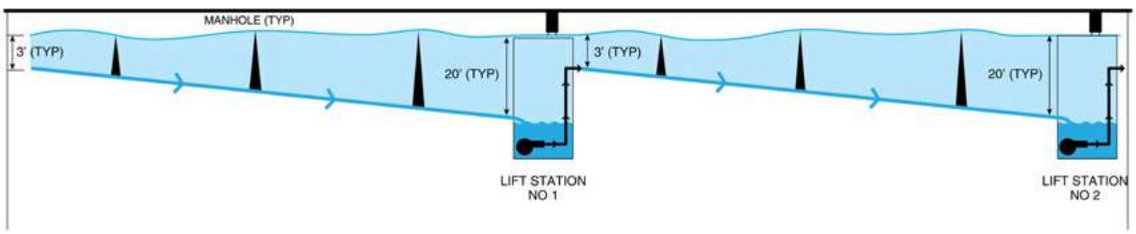


Figure 4.9. Gravity sewer with lifting stations
(Source: www.redrundrain.wordpress.com)

Pressure Pipe System

These systems are typically used in hilly and rural areas or in locations with high water tables, where wastewater from individual properties is pumped to an elevated gravity sewer or treatment plant. Landowners are generally responsible for the cost of electricity and O&M of these systems. The pumping stations used in these systems are often standard commercial products. Overall, these systems offer advantages such as lower pipe installation costs due to smaller diameters, the use of trenchless installation technologies and simple installation techniques. However, these systems have some disadvantages. Because each house requires its own pumping station, a higher number of pumping stations need to be maintained.

Relevance for DWM:

These systems are applicable for on-site or institutional wastewater systems and areas prone to flooding. However, appropriate O&M management must be ensured.

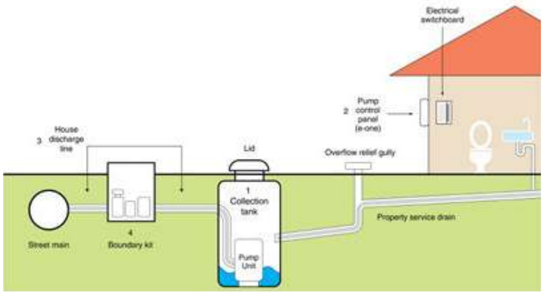


Figure 4.10. Pressure pipe system
(Source: www.gippswater.com.au)

Vacuum System

This type of sewer system operates under pressure, with each plot having a storage tank and a vacuum valve connected to a central vacuum station. It is often used in areas with high groundwater levels or a high risk of flooding. Vacuum sewer systems are standard products in the market. These systems offer the advantage of lower pipe installation costs due to the use of smaller diameters, trenchless installation technologies and simple installation techniques. However, these systems have some disadvantages. Vacuum sewer systems are highly technical and sensitive, requiring relatively higher levels of O&M as compared to that for other sewer systems with a 24/7 response service.

Relevance for DWM:

These are applicable only for hotels, high-end properties, and industrial complexes.

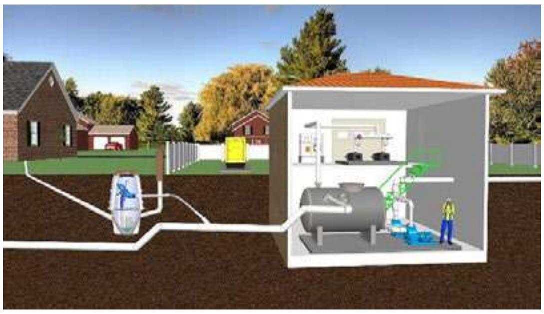


Figure 4.11. Vacuum System
(Source: www.wikipedia.org)

Sewer Equipment

The main components of a gravity sewer system are pipes, manholes and connections. The weak points in the system are the joints and connections between pipes and walls, pipe slopes, inspection chamber bases and manhole covers. It is critical to select the most appropriate design, materials and installation method based on a careful evaluation of the site conditions.

While it may be tempting to cut costs when implementing a sewer system, it is important to not compromise on the quality of the sewer system equipment. **Substandard equipment and installation can result in unpredictably high operating costs and effort.** Each piece of equipment and material used in the sewer system serves a specific purpose and has its own range of applications and limitations. Therefore, it is essential to prioritise quality and dedicated site engineering when selecting the most cost-effective sewer routing and positioning.

Concrete pipes

Concrete pipes with diameters over 200 mm are a cost-effective and durable option with a life expectancy of over 50 years. The socket joint should be sealed with rubber rings. They require less pipe bedding and allow for shallow ground cover. However, concrete pipes have some disadvantages. The quality of locally available pipes can vary considerably, affecting their performance and service life. Additionally, these pipes are not internally coated, making them susceptible to damage from anaerobic effluent and corrosion. Furthermore, they can easily develop leaks if they are not placed and connected accurately.

Figure 4.12. Concrete pipes *(Source www.balkanplumbing.com)*

Relevance for DWM:

The pipes available locally are typically shorter, in the range of 1–2 m, which results in a greater number of joints (weak points). It is recommended to use pipes with a length of 6 m, certified coating and reinforcement. They can be used effectively in areas prone to flooding or with shallow ground cover.

uPVC

The most commonly used pipe material in the world for diameters between 70 and 400 mm is uPVC. These pipes are typically supplied in 6-m bars with a plug-in joint sealed with rubber rings. These pipes are installed by using the open trench method, which requires proper sand bedding and accurate levelling. It is important to note that these pipes are available in a variety of materials and qualities, which can affect their durability (load-bearing capacity) and service life. However, there are certain disadvantages associated with these pipes. First, they can have a negative environmental footprint. Additionally, they are sensitive to mechanical impact or load and can be affected by UV exposure.

Figure 4.13. uPVC pipes
(Source www.flotekafrica.com)

Relevance for DWM:

uPVC with a spigot connection and rubber ring seal should be used for outdoor purposes alone. Additionally, uPVC with an adhesive connection should be used only for indoor purposes.

HDPE (High-Density Polyethylene) and PP (Polypropylene)

Worldwide, there is an emerging material known for its durability and improved environmental impact as compared to uPVC. These pipes are typically available in rolls of 50–100 m or in 6-m bars. Joints for HDPE pipe are welded, while PP pipe is welded or use a spigot connection and socket. They may be suitable for trenchless pipe installation, although proper sand bedding and precise grading are required for gravity-flow sewers. It is important to note that the durability and life of these pipes can vary depending on the different materials and qualities available.

Figure 4.14. HDPE pipes
(source:www.watersandfarr.co.nz)

Relevance for DWM:

For gravity-flow pipes, only fitting joints (electrofusion welding) should be used, and plate or butt welding should not be used.
For pressure pipes, both jointing systems are possible.

Inspection chambers and manholes

Inspection chambers are typically constructed at pipe junctions, inlets or at regular intervals of 20–50 m to provide maintenance access and flow control. If not built on-site, prefabricated chambers constructed of PVC-U, PP or concrete are commonly available as standard market products in various diameters and heights. The sump within the inspection chamber is a critical element in ensuring smooth flow, while the manhole cover prevents unauthorised access by people, animals, waste, and stormwater. For on-site construction, the manhole is usually constructed of plastered brick. It is important to ensure the high quality of the chamber; therefore, prefabricated products are a recommended choice. Poorly constructed inspection chambers can significantly impact sewer maintenance costs. In areas prone to flooding, it is important that manhole covers are watertight and raised above the flood level.

Relevance for DWM:

These have a high relevance in DWM; any high-quality material can be used to construct a manhole; however, appropriate construction must be ensured.

Figure 4.15. Brick- built manhole *(source:www.watersandfarr.co.nz)*

Figure 4.16. Concrete ring manhole *(source: www.holcim.com.au)*

Manhole cover

Manhole covers are specifically designed to provide controlled and convenient access to sewer pipes. Poorly constructed or designed manhole covers can be a significant cause of high O&M costs. If they break, fail to close properly, are stolen or are too heavy for the operator to open, they become weak points in the sewer system. This can lead to the infiltration of waste and stormwater, resulting in various consequences, including blockages and flooding. A range of manhole covers are available, including light and heavy-duty options, with or without ventilation and with locks or hinges. They can be manufactured from materials such as cast steel, concrete, and polymer composites.

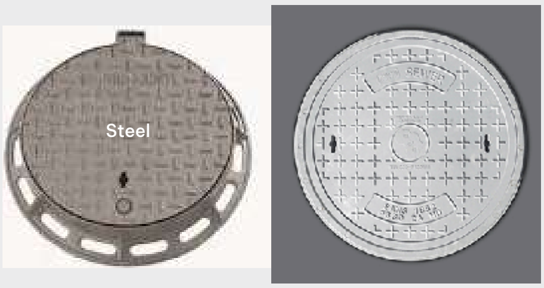


Figure 4.17. Manhole lids *(source: www.m4a.co.za)*

Relevance for DWM:
They are highly relevant to DWM systems; manhole covers made of materials that are not prone to theft (i.e. not steel materials) are recommended; additionally, manhole covers need to be sufficiently watertight and easy to open, such as those made of reinforced polymer composite.

Figure 4.18. Negative example: Ill-designed sewer system
(Source: Authors)

4.2.5. Pipe bedding

Incorrect pipe bedding can lead to pipe damage and movement; this can result in various operational problems for a gravity-based sewer system. Therefore, it is essential to carefully plan the pipe installation process by considering the local conditions and requirements. It is essential to strictly adhere to the technical specifications for laying, joining, bedding and testing the pipe system and to closely monitor the implementation process for ensuring efficient functioning of the pipe system. Decentralised sanitation projects are often implemented in cities where the sanitation sector is still in the development stage and the local project implementation capacity may be limited or in need of development. It is important to note that installing wastewater pipes is different from laying water pipes and requires specific tools, methodologies and skills. Unfortunately, the effort required to lay wastewater pipes is often underestimated by implementing agencies and contractors.

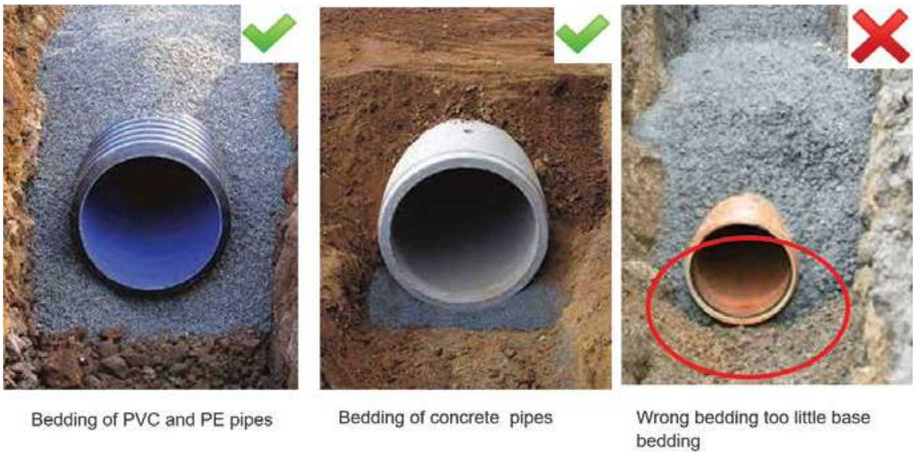


Figure 4.19. Examples of sewer pipe bedding applications
(Source: www. fpmccann.co.uk and www.jet2clear.co.uk)

Specifically, in decentralised wastewater projects, thorough field engineering is essential to optimise the sewer network and achieve maximum network length without the need for pumps. This often results in relatively shallow pipe depths with low ground cover and other challenges. Hence, it is critical to have a clear understanding of how to best protect pipes under these conditions.

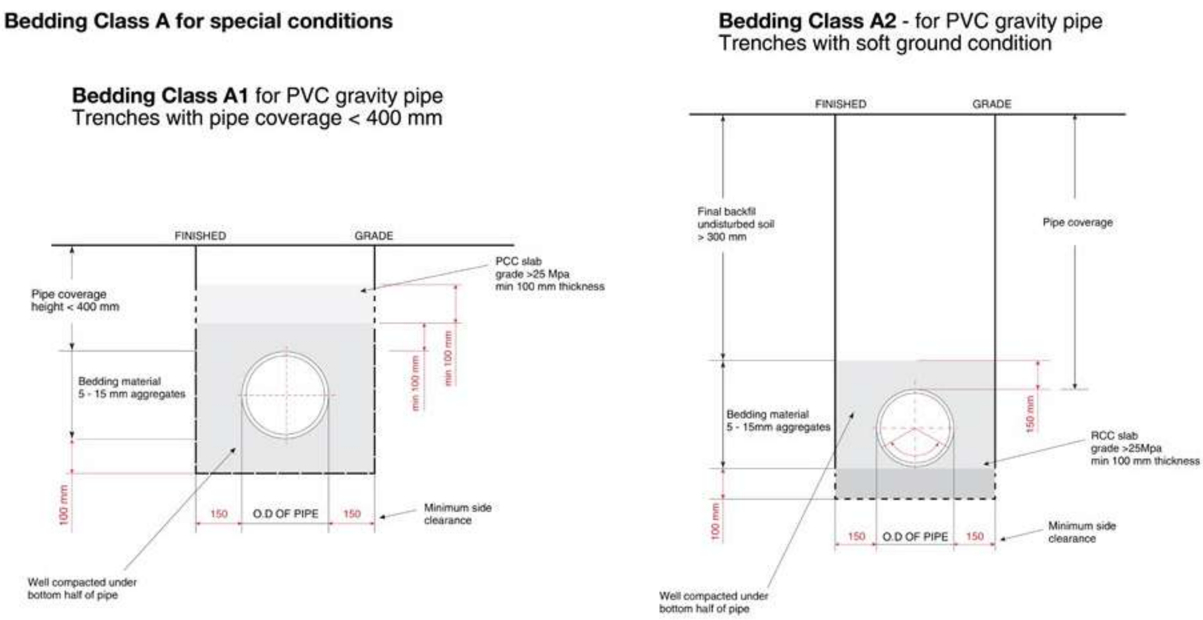


Figure 4.20. Examples of the sewer pipe bedding option
(Source: UrbanWaters Consulting GmbH)

4.2.6. Technical specifications

As noted above, careful on-site engineering, detailed technical specifications and close monitoring during implementation are essential for ensuring the effectiveness and sustainability of a sewer system. This is particularly important given the significant impact of the above-mentioned factors on sewer operating costs. Under the administration of countries, ministries, municipalities and utility providers, the technical specifications of wastewater systems must be closely monitored and localised guidelines must be developed—which must be followed for all public wastewater projects. This ensures adherence to standardised practices and promotes efficient and reliable sewer systems with predictable O&M costs.

Selected references:

'Design Manual: Small Sewerage Systems' by the Water Research Commission (WRC) - This manual provides practical guidelines for the design of small sewerage systems, including sewer network layout, pipe sizing, hydraulic design and construction considerations. It covers both gravity and pressure sewer systems and offers guidance specific to smaller-scale applications (WRC 2009).

1. 'Small-Diameter Gravity Sewers' by the Water Environment Federation (WEF) - This publication focuses on the design and construction of small-diameter gravity sewer systems. It provides guidance regarding material selection, trenchless installation techniques, maintenance considerations and relevant design standards.
2. 'Sewers for Adoption' by Water UK - This is a comprehensive guidance document produced by Water UK that provides design and construction specifications for sewerage infrastructure. Although it is primarily intended for larger-scale developments, it includes information and requirements applicable to smaller sewer networks (Water UK, 2018).
3. 'Manual on Sewerage and Sewage Treatment' by the Central Public Health and Environmental Engineering Organisation (CPHEEO) - This manual, published by the Government of India, offers guidelines for the design, construction and operation of sewerage systems. It provides detailed information regarding various aspects, including sewer network design, pipe materials, construction techniques and maintenance practices (GoI 2012).

4.3. Wastewater treatment processes and technologies

4.3.1. Overview

The primary objective of wastewater treatment is to modify the quality of wastewater to meet the conditions necessary for safe disposal or reuse. In the case of municipal wastewater, these conditions are typically defined by national and local regulations aimed at protecting public health and the environment. These regulations are guided by effluent standards that specify the physical, chemical and biological characteristics of the treated effluent using parameters such as biochemical oxygen demand, chemical oxygen demand, suspended solids, total nitrogen, E. coli and others. These wastewater parameters consider the local context, including the available financial resources and the capacity to operate the necessary treatment infrastructure. Although high environmental wastewater discharge standards may seem desirable, they may come at a significant cost. If local affordability is a challenge, it may impede the establishment of adequate and efficient wastewater treatment systems at the required scale. Therefore, it is strongly recommended to start with affordable discharge standards and gradually increase them over time.

4.3.2. Treatment Stage and Methodology

Treatment plants involve a multi-stage process, includingseveral technology options which perform different treatment functions. These stages are discussed below:

Preliminary Treatment

Preliminary treatment is usually the first treatment stage and involves the removal of coarse solids and other large materials from wastewater. It aims to prevent interference in subsequent treatment processes, such as through clogging or accumulation of solids. This typically includes the use of grease traps, coarse screens and grit removal techniques. Coarse screens, often in the form of bar screens, are used to separate large particles from wastewater. In contrast, grit chambers are elongated channels designed to achieve a sufficiently high water velocity to settle sand and grit while allowing organic solids to pass through for further treatment.

Table 4.2. Components of the preliminary treatment

Technology	Relevance for DWM
Grease traps	These are highly relevant, especially in ASEAN countries; they should they be installed at the source level after the kitchen drain. However, collection and treatment services should be considered at the city level. **The type of wastewater stream:** Kitchen wastewater or where potentially oil and fat is discharged (industries).
Grit traps	These are subordinately relevant in the DWM system. The amount of grit in decentralised systems, particularly in separated sewer systems without stormwater, is relatively low. Therefore, it is uncommon to install and operate a grit trap. The decision to install grit straps should depend on the availability of effective operation management. **The type of wastewater stream:** Usually where stormwater is combined with wastewater (mixed wastewater).
Screens	**The type of wastewater stream:** Municipal wastewater Most advanced WWTPs, including package plants, are usually equipped with screens that can be cleaned manually or automatically. Systems such as DEWATS or nature-based solutions are designed to operate even in limited operation management conditions, allowing solid waste to enter the settler.

Primary Treatment

The objective of primary treatment is to remove settleable organic and inorganic solids by sedimentation and floating materials such as scum from wastewater. This stage typically accounts for 25–60% of the BOD and 50% of the total suspended solids (TSS) in incoming wastewater streams. Septic tanks, clarifiers, aerators and biogas aerators are used to provide this level of treatment.

Table 4.3. Components of the primary treatment

Technology	Relevance for DWM
Septic tanks	These are highly relevant, especially for on-site sanitation systems or smaller WWTPs with a capacity < 10 m^3/d. Designed as a two-chamber system, a well-operated septic system can achieve a 60% BOD reduction. Septic tanks in combination with solar systems also achieve significant pathogen elimination. **The type of wastewater stream:** Domestic wastewater and black wastewater
Settlers	Settlers are similar in design and operations of septic tanks, but usually have one or two chambers; they are designed with a short hydraulic retention time of 1.5–2.0 h and connected to a secondary wastewater treatment stage. Similar to septic tanks, the separated sludge accumulated in the settlers' storage needs to be removed at least once a year. **The type of wastewater stream:** Municipal and industrial wastewater
Biogas settlers	Using a dome-built biogas plant instead of a septic tank or settler aims to generate energy or a consequent revenue stream from a wastewater treatment system through the extraction of biogas. This concept has been implemented in decentralised wastewater projects in China, Indonesia, Vietnam and Thailand. However, because of the relatively low biogas yield from purely domestic wastewater, expectations often exceed the actual benefits achieved. Challenges associated with this approach include the low availability of local experts and products, ineffective biogas usage, odour emissions and desludging. Additionally, the application of adding organic waste to increase biogas production needs to be considered carefully, as it can lead to higher concentrations of organic pollutants and nutrients in the effluent. The authors of this Guidebook recommend implementing biogas plants for high-strength organic solid or liquid waste, such as blackwater streams alone or in combination with organic solid waste. **The type of wastewater stream:** Blackwater and industrial wastewater
Clarifier	Clarifiers with continuous sludge removal have a relatively low relevance in DWM systems and are typically implemented in advanced wastewater treatment systems with a capacity of 500 m^3/d or more. **The type of wastewater stream:** Municipal and industrial wastewater

Secondary Treatment

Secondary treatment, which primarily includes biological wastewater treatment, focuses on the removal of biodegradable organic matter from wastewater or similar wastewater. The goal is to achieve a specific level of effluent quality in a WWTP that is suitable for the intended disposal or reuse. Before secondary treatment, a 'primary treatment' step is often required to physically separate settleable solids. During secondary treatment, biological processes are used to remove dissolved and suspended organic matter, as measured by the BOD. These processes are performed by microorganisms in a controlled aerobic or anaerobic environment, depending on the treatment technology used. The major technology groups suitable for decentralised wastewater treatment are outlined below. While there may be additional technology groups in the wastewater market, most can be categorised into the following groups:

Wastewater ponds

- Wastewater ponds can also be called as 'nature-based systems'; they are mainly divided into three groups as follows:
- Wastewater stabilisation ponds (WSPs) are large basins for treating municipal wastewater and consist of a series of ponds with each having a defined function (land requirement 5–15 m²/capita).
- Aerated WSPs and oxidation ditches are similar to WSPs,, but the biological process is enhanced through artificial aeration (land requirement 2–8 m²/capita).
- Polishing ponds are used only as a final treatment stage after the secondary or tertiary stage (land requirement 1-3 m²/capita).

Relevance for DWM:

WSPs are a good treatment solution when sufficient land is available, particularly for smaller cities or villages. Polishing ponds, especially when combined with dedicated nature-based technologies, can serve as an effective tool for final wastewater treatment, integrating with existing urban wetlands, stormwater retention areas/ponds or even recreational areas.

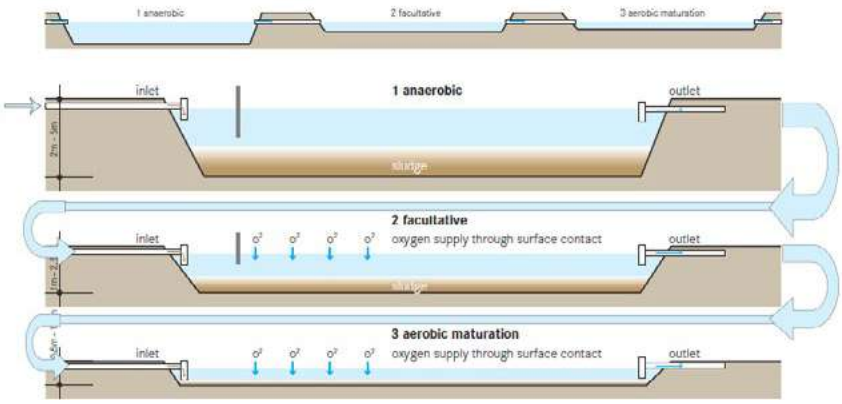


Figure 4.21. Waste stabilisation ponds
(Source: www.sswm.info)

Activated sludge process (ASP)

This process uses aerobic microorganisms to degrade and eliminate organic matter and nutrients. It is an advanced treatment system. The key parameters for designing and operating an ASP for secondary or tertiary treatment include the amount of oxygen (air), concentration of the activated sludge and hydraulic retention time. Consequently, ASPs typically incorporate preliminary and primary treatment stages to remove grit, trash and primary sludge. ASPs are particularly effective in cold climates, show high removal rates for BOD, COD, TSS and NH4-N and can be configured to achieve additional nitrogen and partial phosphate removal. Noteworthy variations of ASP technology include SBR, combinations with carrier materials such as fixed-bed reactors or MBBRs or MBRs. ASPs offer notable treatment efficiency while requiring relatively modest land requirements (0.1–0.3 m² per capita) and energy consumption. Their operation demands a significant level of automation, dedicated design engineering and operational expertise.

Relevance for DWM:

ASPs are applicable to both decentralised and centralised wastewater treatment because of their compact size and availability as package plants. They are widely used in various applications.

However, it is important to note that ASPs are energy-intensive and require stringent process control. Additionally, a well-established supply chain for services and spare parts is necessary to ensure their smooth operation.

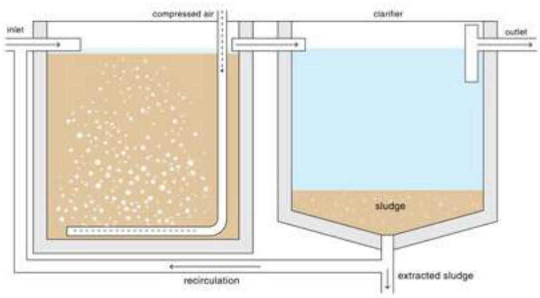


Figure 4.22. Activated sludge process *(Source: www.sswm.info)*

Figure 4.23. Activated sludge process as a prefabricated package plant *(Source: www.kubota.com)*

Up-flow anaerobic sludge bed (UASB) system
Also known as an up-flow anaerobic sludge blanket system, UASB uses anaerobic microorganisms to degrade and eliminate organic matter and is primarily employed as an energy-efficient secondary treatment method in warm climates. It offers the additional benefit of biogas capture and generates significantly less surplus sludge as compared to that by ASP (up to 95% reduction). The design and operation of UASB systems are influenced by parameters such as hydraulic height (4–6 m), temperature, anaerobic sludge concentration, hydraulic retention time and up-flow velocity. In this system, pre-treated wastewater flows from the bottom to the top through a settling sludge bed/ blanket. The effectiveness of UASB is determined by the characteristics of the wastewater and the up-flow velocity. It is important to note that UASB is not a standalone system and is typically combined with preliminary and tertiary treatment stages based on the specific wastewater characteristics and treatment objectives.

Relevance for DWM:
Due to the operational complexities and construction depth of UASB, it is not commonly used in DWM applications.

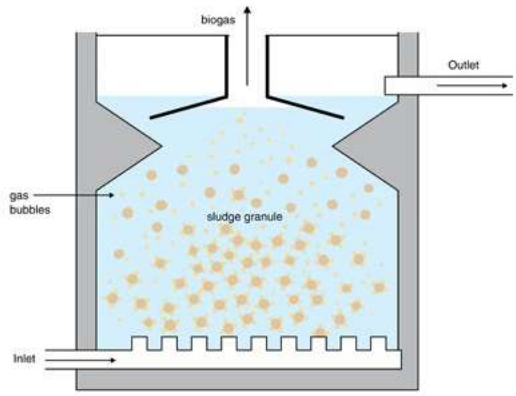


Figure 4.24. Up-flow anaerobic sludge bed system
(Source: www.sswm.info)

Trickling filter (TF) and Rotating Disc Contactor (RDC)
These are biological fixed-bed reactors used for aerobic treatment. In TFs, pre-treated wastewater is sprayed over a filter media bed, trickling from the top to the bottom through the filter bed. In RDC systems, active microorganisms are located on the disc surface; they come in contact with wastewater and air through rotation. The active bio-film present on the filter degrades the organic pollutants in the wastewater. The main parameters for designing and operating TFs are hydraulic and organic rates. TFs and RDCs require effective primary treatment and are applied mainly as secondary and partially tertiary treatment stages. Both systems have been at the forefront of aerobic wastewater treatment methods and show a good BOD, COD and NH_4-N removal rate with a footprint of 0.3–0.8 m^2/capita. They consume minimal energy, generate a small amount of surplus sludge and can operate effectively under various climate conditions, demonstrating robust performance in terms of wastewater treatment.

Relevance for DWM:
Due to the limited resource requirements and overall simplicity of operation, TFs are suitable for DWM. However, due to their structure being typically elevated 2–3 m above the ground and the associated potential issues with insects and odours, they have limited prevalence in DWM applications.

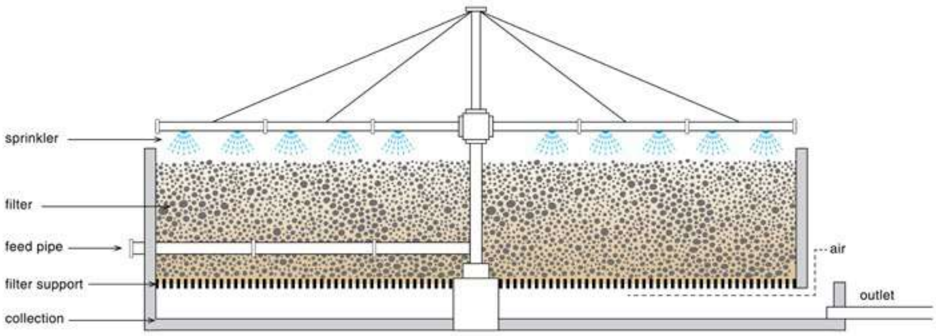


Figure 4.25. Trickling filter
(Source: www.sswm.info)

Constructed Wetlands (CW)

These are open nature-based aerobic treatment systems that provide effective primary, secondary and tertiary wastewater and sludge treatment with the help of different types of mineral filter media (sand and/or gravel), hydrophilic plants, and macro/microorganisms,. Constructed wetlands are land-intensive systems designed and operated as horizontal (3 – 6 m^3/cap) and vertical flow systems (1 – 3 m^3/cap). The design parameters are hydraulic and organic loading rates. The loading rate, ambient temperature and filter media type determine the treatment efficiency.

Relevance for DWM:

The simplicity of operation and low energy demand make it an appropriate technology for DWM. However, because the land footprint required is relatively high, finding an appropriate location is challenging. Along with an effective anaerobic or aerobic secondary treatment, it is recommended for decentralised application in urban areas.

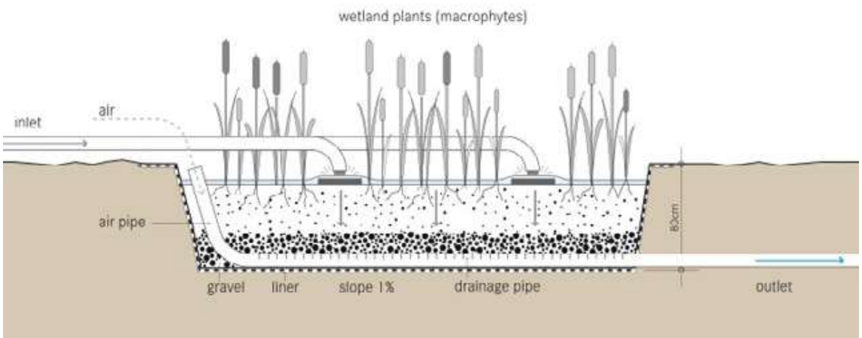


Figure 4.26. Constructed wetlands
(Source: www.sswm.info)

Anaerobic baffled reactor (ABR) and anaerobic filter (AF)

ABR and AF are biological reactors which are used for wastewater treatment without the need for electrical energy or chemicals. They operate through sedimentation and the action of anaerobic microorganisms. ABRs require preliminary and partial primary treatment, whereas AFs require effective primary treatment. Consequently, these systems are often implemented in a sequence of settler units, followed by 3–5 ABR chambers and 1–3 AF chambers. ABRs and AFs have demonstrated effective BOD and COD removal rates, ranging from 60% to 90%. Notably, they can be designed, implemented and operated in areas with limited wastewater expertise. With a footprint of 0.15–0.3 m2 per capita and the ability to be installed as underground tanks, they can be easily accommodated in various locations. Prefabricated products for ABR and AF systems are currently available in China, Thailand and Indonesia. The main design parameters for these systems are the up-flow velocity and hydraulic retention time.

Relevance for DWM:

The German non-profit development organisation BORDA (www.borda.org) has introduced and promoted the combination of ABR and AF technologies, with or without simple constructed wetlands, under the name DEWATS. This concept has proven to be effective in providing sustainable sanitation services to under-privileged communities worldwide. With thousands of successful implementations, BORDA and other development agencies have played significant roles in advancing DWM approaches. While ABR and AF technologies are highly relevant for DWM, it is important to note that they need to be combined with effective post-treatment technologies to meet increasingly stringent effluent discharge standards and climate-sensitive design requirements.

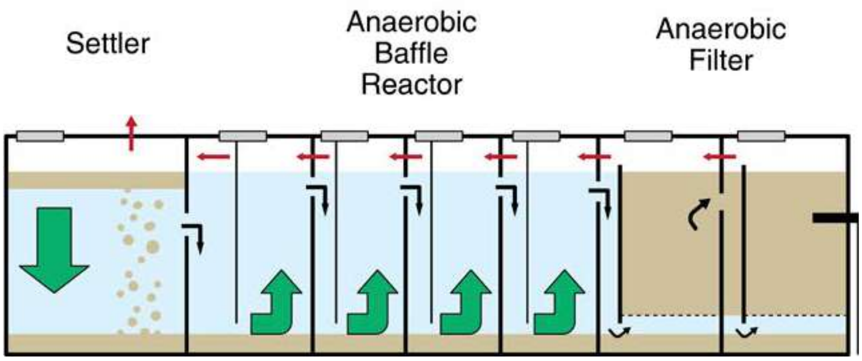


Figure 4.27. Anaerobic baffled reactor and anaerobic filter
(Source: www.borda.de)

Tertiary Treatment

The purpose of tertiary treatment is to remove wastewater pollutants that remain after secondary treatment, such as residual COD, BOD; nutrients such as nitrogen and phosphorus; and, pathogens.

Table 4.4. Components of tertiary treatment

Technology	Relevance for DWM
Denitrification	This removes nitrogen from wastewater. The denitrification process requires the prior oxidation of NH4-N nitrogen to nitrate and the presence of BOD . Constructed wetlands and polishing ponds can also be designed to provide partial or complete denitrification.
Biological phosphate removal	This removes phosphate from wastewater through a biological process by binding the phosphate to the excess sludge for removal. This process is often integrated or combined with ASPs for effective treatment.
Precipitation	Aluminium sulphate or alum ($Al_2(SO_4)_3$), ferric chloride ($FeCl_3$) and ferric sulphate ($Fe(SO_4)_3$) are the most commonly used flocculants for TSS and phosphate precipitation. This technique requires a constant supply and accurate dosing of chemicals and effective sludge management. Phosphate precipitation is becoming more common, even in small WWTPs, especially where stringent phosphate effluent standards must be met and phosphate recovery is desired.
Sand filters	Sand filters are effective in removing pathogens and treating low concentrations of BOD and COD. To avoid clogging or the need for frequent cleaning, sand filters work best when installed after effective secondary treatment and when total suspended solids (TSS) concentrations are low (<50 mg/l). Although small and compact, rapid sand filters require pumps, valves and regular backwashing. In contrast, slow sand filters are simpler but require a larger footprint and specific sand characteristics. Considering their advantages and disadvantages, rapid sand filters are commonly used in decentralised wastewater treatment applications, often in combination with ASP systems.
Constructed wetlands	Constructed wetlands, especially those with planted sand filters, are highly effective treatment systems for removing pathogens, TSS, residual BOD/COD and even emerging contaminants (ECs). Using special filter media, constructed wetlands can also remove phosphate. CWs are of great importance in DWM because of their low operating costs, effectiveness and flexibility for local integration.

Technology	Relevance for DWM
Advanced oxidation	The term 'advanced oxidation' encompasses technologies such as ultraviolet (UV) light, ozone and electrolysis. UV systems primarily target pathogens (bacteria and viruses) by exposing them to UV light. They are effective at TSS levels below 30 mg/l; this indicates that UV treatment requires prior effective secondary treatment and TSS removal, limiting its use in decentralised wastewater systems. In contrast, ozone and electrolysis technologies generate active oxidising radicals that are less sensitive to higher TSS and COD concentrations, making them more suitable for DWM. Ozone can pose a health and safety risk to operators and for small WWTPs, only on-site ozone generators are recommended. All these systems require electricity; however, the amount needed is relatively small and can be provided by solar systems if desired. Electrolysis systems are an emerging wastewater treatment technology which is being used in the domestic wastewater sector for several years. These systems, derived from industrial applications, can not only oxidise but also remove phosphate from wastewater.
Chlorination	Chlorination is the most common method of wastewater disinfection (pathogen removal). However, too high a concentration of free chlorine in wastewater effluent discharged to the environment can cause several problems due to the formation of disinfection by-products (DBPs). When chlorine reacts with organic compounds, it can form DBPs such as trihalomethanes (THMs) and haloacetic acids (HAAs). These DBPs have adverse health effects on humans and aquatic life. To mitigate these problems, it is essential to control the free chlorine concentration, ensuring that the concentration does not exceed the most used international level of 0.5 mg/l. Adding chlorine to the effluent stream is relatively simple; however, controlling the dosage requires constant monitoring and dosage adjustment. This increases the complexity of the system; hence, it is not popularly used in small wastewater systems. An alternative is to install and periodically replace the activated carbon filter.
Activated carbon filter	Activated carbon (AC) filters function via the process of adsorption, whereby hydrophobic components that repel water are adsorbed onto the carbon surface. These components include oil, chlorine, heavy metals, dyes, polyaromatic compounds (PACs) and others. However, AC filters are not effective in removing pathogens. It is important to note that the adsorption capacity of AC filters is limited. While low-loaded AC filters have a certain self-regeneration capacity for adsorbing organic pollutants, high-loaded filters need to be regularly replaced. Because of their ease of installation, they are often used in DWM.

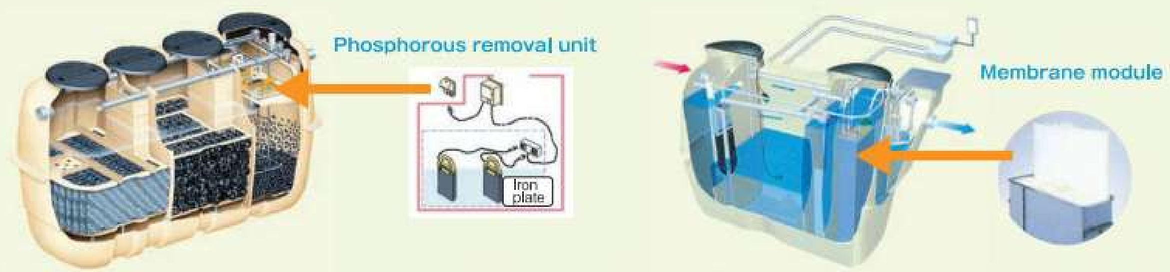
Example of Johkasou:

Although the treatment principles of Johkasou are similar to the technologies mentioned above, the main feature of Johkasou is the introduction of new technologies in the secondary treatment to achieve high performance, for example, the bio-film filtration process, the moving bed bio-film process and so on. The table below shows the major certified structure, treatment process, capacity and treatment performance.

Table 4.5. Outline of the structural standards for Johkasou.

Class	Type of treatment	Treatment process	Number of users for design (5 / 50 / 100 / 200 / 500 / 2000 / 5000)	BOD removal rate	Treatment performance – Effluent quality (mg/ℓ): BOD	COD	T-N	T-P
1	Combined domestic wastewater treatment	Separation-contact aeration process		90% or more	20 or less	—	—	—
		Anaerobic filter-contact aeration process					—	—
		Denitrification type anaerobic filter-contact aeration process					20 or less	—
4	Flush toilet wastewater treatment	Septic tank process		55% or more	120 or less	—	—	—
5		Land infiltration process		SS: 55% or more	SS: 250 or less	—	—	—
6	Combined domestic wastewater treatment	Rotating biological contactor process		90% or more	20 or less	30 or less	—	—
		Contact aeration process						
		Trickling filter process						
		Extended aeration process						
		Conventional activated sludge process						
7		Contact aeration and trickling filter process		—	10 or less	15 or less	—	—
		Coagulation separation process						
8		Contact aeration and activated carbon absorption process		—	10 or less	10 or less	—	—
		Coagulation separation and activated carbon absorption process						
9		Nitrified water recirculation type activated sludge process		—	10 or less	15 or less	20 or less	1 or less
		Tertiary treatment type denitrification dephosphorization process						
10		Nitrified water recirculation type activated sludge process			10 or less	15 or less	15 or less	1 or less
		Tertiary treatment type denitrification dephosphorization process						
11		Nitrified water recirculation type activated sludge process			10 or less	15 or less	10 or less	1 or less
		Tertiary treatment type denitrification dephosphorization process						
12	Emission standard under the Water Pollution Control Law	Class: 6-11, COD (mg/ℓ): 60, SS (mg/ℓ): 70, n-Hex (mg/ℓ): 20, pH: 5.8-8.6, Total coliforms (N/mℓ): 3,000 or less 6-11: 45, 60, 20, 5.8-8.6, 3,000 or less 6-11: 30, 50, 20, 5.8-8.6, 3,000 or less 7-11: 15, 15, 20, 5.8-8.6, 3,000 or less 8: 10, 15, 20, 5.8-8.6, 3,000 or less						

note: Class 2 and Class 3 were deleted in 2006.



A phosphorous removal type small-scale Johkasou (FRP-made) A membrane type small-scale Johkasou (FRP-made)

Figure 4.28. Johkasou
(Source: Ministry of the Environment, Government of Japan (MOEJ). Available at: https://www.env.go.jp/recycle/jokaso/en/pamph/pdf/wts_full.pdf)

4.3.3. Wastewater Treatment Technology and the Associated Treatment Objectives

As discussed in the previous sections, each wastewater treatment system has its own specific range of applications and treatment objectives. This important fact is often overlooked when comparing different treatment systems and should only be compared with technologies with the same treatment objective. It is also important to note that WWTPs consist of a series of treatment stages, each using a specific treatment process or technology with a specific objective and only in combination can the overall project objective be achieved.

An example is the combination of an anaerobic baffled reactor for 70%–80% BOD removal with an aerated system (ASP, SBR, RDC) for the removal of the remaining 20%–30% BOD and NH_4-N. In ASEAN countries, where high temperatures prevail, municipal wastewater often undergoes anaerobic conditions already in the sewer network. By taking advantage of this condition, applying anaerobic treatment technologies such as anaerobic baffled reactors and anaerobic filters for removing organic matter saves 60%–70% energy consumption in the aerobic post-treatment stage. Subsequently, the energy-intensive processes, such as aeration, are specifically used for the polishing removal of limited parameters such as NH_4-N. This approach not only saves energy but also increases the robustness of the treatment plant. Figure 4.29. provides an overview of the different technologies and their treatment objectives.

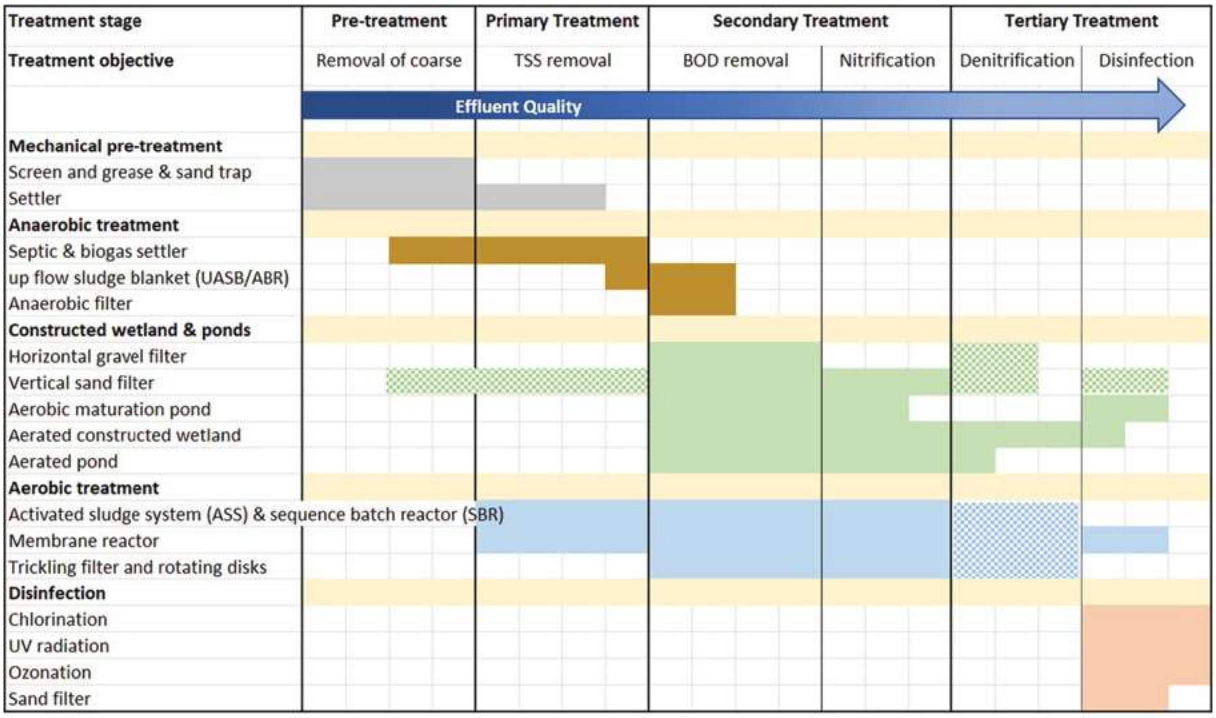


Figure 4.29. Wastewater treatment technology and the associated treatment objectives *(Source: Authors)*

4.3.4. Practical Guide for Assessing and Selecting Wastewater Treatment Technologies

The success of a wastewater project depends on key critical factors such as the establishment of an enabling environment, the selection of appropriate technologies and the careful and high-quality implementation of these technologies. Even seemingly simple technologies, such as an anaerobic baffled reactors, can perform poorly if they are poorly designed and constructed. This failure can jeopardise the sustainability of the entire project. In contrast, advanced technologies that are designed and applied to local conditions have the potential to be sustainable and effective in achieving the desired outcomes. Therefore, it is crucial to ensure that the most appropriate technologies are selected and implemented with the necessary expertise and attention to detail.

The selection of technologies can occur at both the city and/or project level:

Table 4.6. Levels of technology selection

Level	Objective
City level	To streamline and standardise wastewater management within a city's administrative boundaries, it may be beneficial to limit the number of technology options that can be implemented. This limitation helps establish consistent technical specifications and operational procedures that ensure high-quality implementation and operation of wastewater systems. It also promotes economies of scale, making the overall process more affordable. It simplifies the approval process and improves capacity-building efforts. The selection of appropriate technology options should be based on a thorough evaluation of different technical alternatives in relation to the specific conditions and experience of the site.
Project implementation level	To select the most appropriate and cost-effective technical option that is adapted to the specific conditions of the project.

The selection of the technical option should always be driven by the treatment objective and sustainability aspects specific to the local conditions. Literature data, such as that provided in this Guidebook, can provide guidance and highlight important issues to consider before implementation. However, a more critical aspect is the detailed assessment of local conditions and the most feasible technical options as well as the collection of data from local suppliers.

A detailed site-specific technical assessment can quantify and evaluate all aspects regarding the project-specific objectives and conditions. For example, if there is a lack of available land, the installation of constructed wetlands may not be a viable option. However, if land is available, a constructed wetlands system may have a higher initial capital expenditure (CAPEX) as compared to that of an activated sludge process (ASP) system; however, the former's operating expenditure (OPEX) is significantly lower. The constructed wetlands system may prove to be a more cost-effective and sustainable technology eventually. However, to reach this decision, it is necessary to conduct an assessment of all capital and O&M costs over the lifetime of the system. This assessment is known as Life Cycle Cost Analysis (LCCA) and should include site-specific costs such as local construction conditions (earthworks and foundations), which can have a significant impact on CAPEX. It should further consider the local availability of the supply chain for parts and services (engineering and operations). No technology option should be selected if a reliable local supply chain for parts and services is not available.

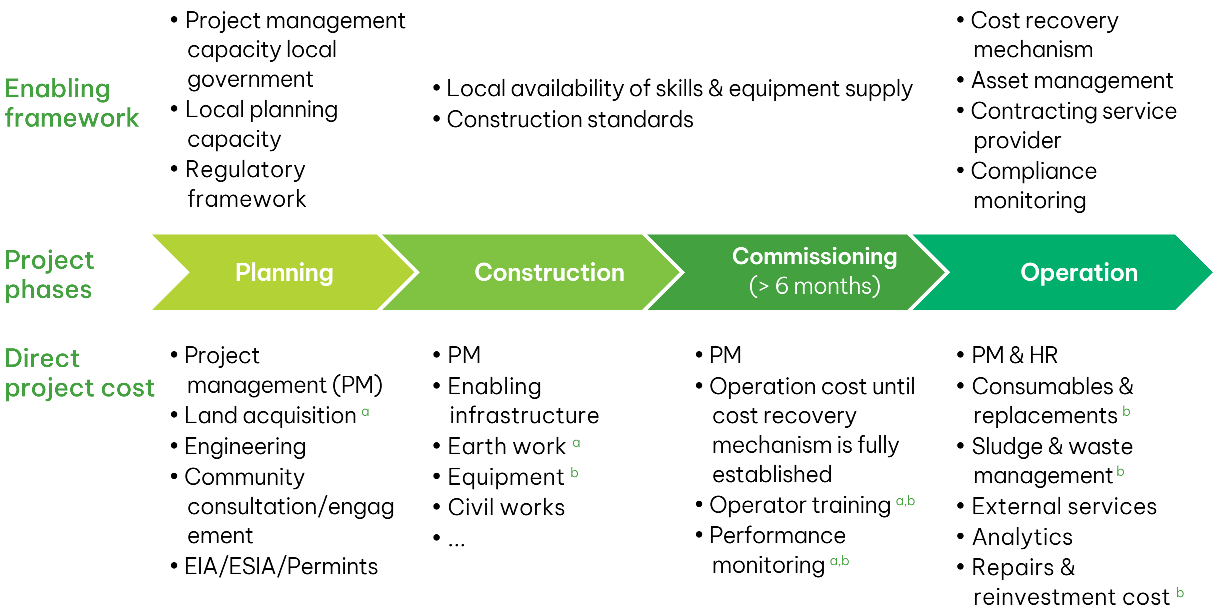


Figure 4.30. Overview of the cost of each component of wastewater projects

Figure 4.30. provides an overview of the major cost drivers and framework conditions for a wastewater project. The type of technology has a significant impact on the value of each cost position. Let us look again at the example of the constructed wetlands and SBR systems as representatives of ASP systems. Constructed wetlands (a in Figure 4.30) have a significant impact on cost items such as land acquisition and earthwork, whereas SBR systems have a significant impact on equipment costs, consumables (energy), sludge management and repairs (b in Figure 4.30).

An SBR system may be a more cost-effective solution considering installation costs; however, it requires significantly higher operating costs and effort.

Several financial assessment methods are available for selecting and evaluating different wastewater infrastructures. Some common methods include:

1. Cost-Benefit Analysis (CBA): CBA assesses the economic feasibility of a wastewater infrastructure project by comparing the costs of implementing and operating the project with the monetary value of the project's benefits. Benefits can include factors such as improved public health, environmental protection, increased property values and cost savings. The CBA calculates a net benefit by subtracting the project costs from the total benefits.
2. Life Cycle Cost Analysis (LCCA): LCCA considers all costs associated with a wastewater infrastructure project over its entire life cycle, including initial investment, O&M costs and potential replacement or rehabilitation costs. LCCA evaluates the total cost of each option to determine the most cost-effective choice over the long term. For DWM projects, a 20-year projection is recommended.
3. Discounted Cash Flow (DCF) Analysis: DCF analysis evaluates the financial viability of a wastewater infrastructure project by considering the time value of money. It calculates the present value of all projected cash flows, including costs and revenues, by using a discount rate. The net present value (NPV) of the project is determined by subtracting the initial investment from the sum of the present values of cash flows. A positive NPV indicates a financially viable project.

The choice of the financial assessment method depends on the specific objectives, priorities and available data for the wastewater infrastructure project. It is often beneficial to use several methods in combination to gain a comprehensive understanding of the financial implications and benefits of different options.

CBA helps compare costs with the overall impact of the project. The challenge in this analysis is to quantify the monetary value of the benefits of improved sanitation services. NPV helps to deduce the cost of a project or technology to a single figure, thus enabling easier comparison. LCCA is usually the basis for NPV and projects all expenditures (CAPEX and OPEX) and revenues (such as wastewater service charges or required subsidies) over a projected lifetime of at least 20 years. It is important for all analyses that all items are outlined and quantified in monetary terms. See also Section 3.5.6 and Figure 3.12. In many feasibility studies, engineers often do not outline and quantify all cost items. The same is true for technology suppliers, most of whom provide minimal information regarding all operational requirements, efforts and associated costs, especially for consumables, replacement, labour and maintenance services.

To make an informed decision, it is recommended to follow the steps outlined below:

Table 4.7. Decision-making process for technology selection

Step	Input
(1) Defining the project and treatment objectives	• Overall local conditions and requirements • Environmental standards
(2) Assessing the financial framework for covering investment and operation costs (cost per m^3 or cost per capita])	• Available funding source for investment • Capacity and reliability of the operating cost-recovery mechanism
(3) Redefining the project and treatment objectives (Project development phase)	• Input from steps (1) and (2)
(4) Technical and non-technical aspects of the project-specific conditions and requirements	• Site selection and assessment
(5) Technical and financial assessment of the pre-selected technical options	• CAPEX and OPEX data • LCCA
(6) Assessing outcomes from step 1.5 against 1.2 and making an informed decision.	• Outcomes from steps 1.5 and 1.2.

Many projects use a multi-stakeholder selection process in which quantified or qualified selection criteria are weighted and scored. This process facilitates the proactive involvement of stakeholders in the decision-making process. However, this process has the following disadvantages:

- Not all stakeholders have the expertise to validate the weighting and scoring of selection criteria;
- Numerous selection criteria and different contributions of relevant stakeholders;
- In the end, the decision of the consultant and experts is based on how the data is prepared.

The strength of this process lies in its ability to engage stakeholders and elicit their consideration about the key technical and non-technical aspects that should be considered as selection criteria.

The following selection criteria are recommended; however, they should be adapted to the specific project context. These criteria must be applied to the entire wastewater system, consisting of the collection (sewer), treatment and disposal/ reuse components.

Table 4.8. Selection criteria to be applied to the entire wastewater system

Selection criteria	Comment/explanation
Total CAPEX	The CAPEX should include all direct project costs involved until the end of commissioning the operation.
Effort or cost of the enabling framework	In addition to quantifying the direct costs of the project, is it important to consider the framework that a particular technology approach would require; it is also important to consider whether the necessary capabilities are in place.
Land requirement	This involves the required land area [m^2] and the associated acquisition and development costs, if applicable.
Total OPEX	The OPEX should include all direct project costs.
Power consumption	The required electricity connection (2 or 3 phase) for power consumption that is, power security is always a critical point for WWTPs. This criterion can be represented as [kW] or [kW/m^3 WW] or as annual monetary value.
Consumables and their replacement	In addition to power requirements, many technologies require regular replacement of filters, UV lamps, bearings, seals, motors, sensors and grease. It is important to know what needs to be replaced, when it needs to be replaced, what the associated costs are and where the replacements will come from (supply chain). Each item may have different replacement intervals. This criterion can be effectively represented as an annual monetary value.
Skills and efforts	Due to the high level of automation, the time required for advanced wastewater treatment systems is usually no more or even less, than that for so-called low-tech systems. However, the level of skill required is different. For example, in an anaerobic baffled reactor, if a pipe gets clogged, it can be easily unclogged. On the other hand, in an sequential batch reactor plant, if a sensor fails, the operator must determine a) that it is only the sensor that has failed and b) where to obtain a replacement. This criterion can be expressed as an annual monetary value that reflects the operator's time and salary (qualification). If external operator services are required, they must also be considered.

Selection criteria	Comment/explanation
Supply chain of parts	This criterion is reflected in the question 'Are equipment and spare parts available locally or where can they be sourced and at what additional logistical cost?'
Supply chain for services	This criterion is reflected in the question, 'Are engineering capabilities for design and supervision and/or external operations services available locally or from where can they be sourced and at what additional logistical cost?'
Level of automatisation	The automation of wastewater systems increases the level of complexity and reduces the human factor. However, an intelligent automation system also helps to remotely control the operation and performance of the treatment system and prevents uncontrolled failures. A certain level of automation of decentralised WWTPs combined with a local response service helps to reduce costs and increase the effectiveness of the plants.
Gravity flow	Automating wastewater systems increases the complexity while reducing the reliance on human intervention. However, intelligent automation systems also facilitate remote control and monitoring of operations and performance, thereby preventing uncontrolled treatment system failures. A certain level of automation in decentralised WWTPs, combined with a local response service, can result in cost savings and improve the overall effectiveness of the plants. When this criterion cannot be expressed in monetary terms, it is helpful to provide a qualitative value.
Closed or open	Ponds are open wastewater systems that provide a high degree of exposure to the surrounding community. Constructed wetlands, although open, typically have no exposed water surface, whereas anaerobic systems such as septic tanks, settlers, ABR and AF are closed and contained systems. Advanced Aerated Systems such as ASP systems for decentralised wastewater management applications are also often closed and contained. The level of human exposure and the flexibility of building integration are important criteria in selecting a wastewater technology.

Selected reading documents:

(1) 'Wastewater Engineering: Treatment and Resource Recovery' by Metcalf & Eddy, Inc., George Tchobanoglous, Franklin L. Burton, H. David Stensel, Ryujiro Tsuchihashi and Franklin L. Burton – This comprehensive textbook covers various aspects of wastewater treatment and infrastructure, including selection, design and evaluation. It provides a detailed understanding of the principles and practises involved in wastewater engineering.

(2) 'Cost-Benefit Analysis: Concepts and Practice' by Anthony Boardman, David Greenberg, Aidan Vining and David Weimer. This book focuses on cost-benefit analysis, which is a fundamental tool for evaluating wastewater infrastructure projects. This study provides a comprehensive overview of the concepts, methods and applications of cost-benefit analysis, including practical examples.

(3) 'Wastewater Treatment and Reuse: Theory and Design Examples' by Syed R. Qasim - This book presents a detailed exploration of wastewater treatment and reuse, including the design and selection of treatment processes and systems. It offers design examples and case studies that illustrate the application of different wastewater treatment technologies.

(4) 'Life Cycle Costing for Engineers' by B. S. Dhillon - This book focuses on life cycle costing, which is an essential component of evaluating the financial feasibility and long-term costs of wastewater infrastructure projects. This study provides insights into the methodologies, techniques and considerations involved in conducting life cycle cost analysis.

(5) 'Water and Wastewater Finance and Pricing: A Comprehensive Guide' by George A. Raftelis - This book addresses the financial aspects of water and wastewater infrastructure projects, including financing options, pricing strategies and economic analysis. It offers guidance on the financial management and sustainability of water and wastewater utilities.

4.3.5. Sludge treatment

All wastewater treatment systems produce sludge, which varies in quantity and quality. In the context of decentralised wastewater management, appropriate sludge management is a critical component of overall city-wide sanitation and environmental protection efforts. This includes the collection, transportation and treatment of sludge generated by on-site or decentralised public wastewater infrastructure. This is essential because many decentralised or small-scale wastewater systems temporarily store sludge and rely on external sludge management services, also known as FSM. The topic of sludge management, with its technical and non-technical aspects, is extensive and goes beyond the scope of the underlying wastewater guidelines. Hence, by referring to well-developed FSM-specific manuals and guides, the authors of this Guidebook provide more detailed information on this topic.

Chapter 5
Operation and maintenance (O&M)

5.1. General considerations

One interpretation of DWM is many small or medium-sized wastewater infrastructure installations scattered throughout the city. Therefore, one of the key questions is, *'Who takes care of all these facilities?'*. This was addressed in Chapter 3, which provided the individuals/bodies responsible for running these facilities by referring to the regulatory framework. The goal of this chapter is to outline the 'What' required to run these facilities that is, the tasks required to ensure the continuous and efficient operation of wastewater facilities.

The following is a brief explanation of some terms used in the context of wastewater systems.

Operation refers to the day-to-day management and execution of activities necessary for the appropriate functioning of wastewater systems. This includes tasks such as starting up and shutting down equipment, monitoring and controlling process parameters, optimising treatment processes and conducting periodic inspections and sampling. The activities under operation focus on the overall management and control of the system to ensure its efficient and effective performance.

Maintenance involves activities aimed at preserving and restoring the physical condition of the equipment, machinery and infrastructure within the wastewater system. This includes tasks such as routine inspections, preventive maintenance, repairs and replacement of worn or malfunctioning components. Maintenance activities are designed to keep the system in good working order to minimise equipment failures and extend the life of the infrastructure.

Operations management refers to the planning, coordination and control of activities involved in the day-to-day operation of a system or organisation. This includes the management of human resources, the management of contracts with external service providers and the operation of the user liaison office.

Asset management is a strategic and systematic approach to managing physical assets throughout their lifecycle to achieve the desired performance by minimising risk and maximising value. This involves the identification, acquisition, operation, maintenance and disposal of assets in a manner that optimises their performance, reliability and cost-effectiveness. Asset management ensures that assets are used efficiently and maintained effectively in line with the organisation's objectives. It includes activities such as asset inventory, condition assessment, asset planning, maintenance strategies and financial analysis.

A user or community liaison office is a department or unit within an organisation that serves as a liaison and facilitator between the organisation and its users or the community it serves. The primary purpose of a user or community liaison office is to establish and maintain effective communication channels, build relationships and respond to the needs, concerns and feedback of users or community members.

Making strategic investments in the financial and institutional capacity of stakeholders involved in O&M is essential for mainstreaming and increasing the acceptance of the DWM approach. This includes well-trained and certified professionals and appropriate tools and equipment.

The objective of this chapter is to provide a broad overview of the technical aspects and tasks associated with DWM. It is intended to raise awareness and guide the reader to seek more detailed information in specialised manuals and guides that cover specific areas in greater depth.

5.2. Sewer system

As mentioned earlier, the O&M costs of a sewer network can account for 50–80% of the total O&M budget. These costs can increase significantly and unpredictably if the sewer network is implemented with poor engineering and construction quality.

The O&M activities associated with the sewer network largely depend on the design and complexity of the system. The following table outlines the most common activities associated with DWM.

Table 5.1. O&M activities associated with DWM

<table>
<tr><th rowspan="2">System components</th><th colspan="2">Operation</th><th rowspan="2">Maintenance</th></tr>
<tr><th>Operation task</th><th>User liaison</th></tr>
<tr><td rowspan="3">House/plot connection</td><td>Site inspection to verify that only domestic wastewater or approved wastewater is connected to the public sewer</td><td rowspan="3">Issuing by-laws
Informing the user
Operating a point of contact (office) and responding</td><td rowspan="3">Repair of broken pipes, manhole covers and fittings</td></tr>
<tr><td>Site inspection and/or smoke test to verify that no roof or ground stormwater is connected to the public sewer</td></tr>
<tr><td>Site inspection to verify that the installed grease traps are cleaned at regular intervals</td></tr>
<tr><td rowspan="4">Manholes, manhole covers, inspection chambers and pipes</td><td>Site inspection to check for blockages and, if needed, cleaning</td><td rowspan="6">Informing the user
Operating a point of contact (office) and responding in case of overflows, wet spots or smell</td><td rowspan="4">Repair of broken pipes, manhole covers and fittings</td></tr>
<tr><td>Site inspection to check for broken and leaky pipes, chambers and covers</td></tr>
<tr><td>Site inspection to verify that no uncontrolled stormwater run-off enters in the chambers</td></tr>
<tr><td>Site inspection to check whether the position of the pipes has changed (settling/floating) after an irregular flooding event</td></tr>
<tr><td rowspan="2">Lifting/pump station</td><td>Site inspection or inspection of the remote control system to ensure functionality</td><td rowspan="2">Repair of broken parts, electricity connection and pump. Replacement of pump (5–7 years)</td></tr>
<tr><td>Cleaning, removal and safe disposal of waste captured by screens, solid waste and sump contents if applicable</td></tr>
</table>

Tools and skills

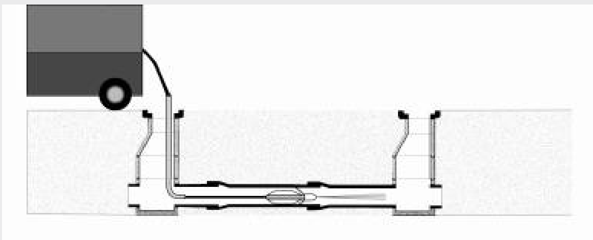
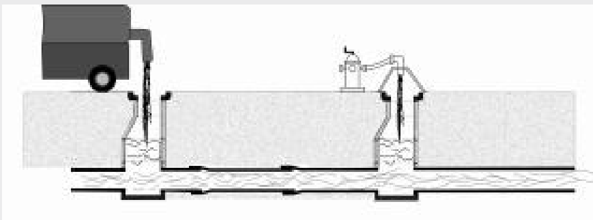
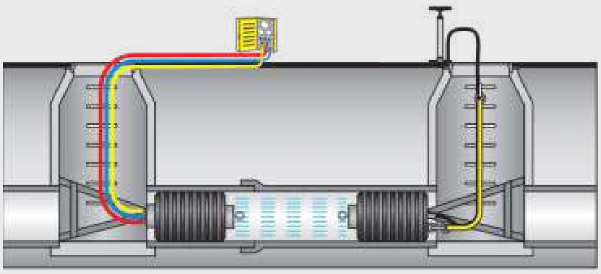
In the past, septic tanks and sewer lines were typically cleaned and maintained by workers known as 'sewer cleaners' or 'septic tank cleaners'. These individuals were responsible for manually removing accumulated sludge, debris and clogs from septic tanks and sewer lines.

The work of sewer cleaners was physically demanding and often involved working in confined spaces and encountering unpleasant odours and potentially hazardous conditions. They used various tools such as vacuum trucks, suction hoses, wands and shovels to remove accumulated waste and clear blockages.

The sewer cleaning profession has evolved over time with advances in technology and equipment. Today, many cleaning operations are performed by using specialised equipment and remotely operated devices to minimise the need for manual entry and ensure worker safety. However, in some regions or situations where advanced equipment is not available or feasible, manual cleaning methods may still be used.

Table 5.2. Tools and equipment for O&M activities

Tool and equipment	Pictures
Hooks for the manhole cover Providing equipment for opening manhole covers helps prevent back injuries of the operator.	 www.allpipe.co.uk
Manual and motor-powered rods A sewer rod that can be manually inserted into a sewer to clear a stoppage or to prevent a stoppage from developing.	 www.allpipe.co.uk

Tool and equipment	Pictures
Hydraulic cleaning Cleaning the pipe with a high-pressure water stream. (1) Using a high-velocity cleaner. (2) Using a ball, kite or similar sewer cleaning device. (3) Using a scooter. (4) Flushing.	 www.americanwatercollege.org
Flushing Equipment Water truck fire hose ***Uses:*** Moves decaying organic material downstream.	 www.americanwatercollege.org
Air Testing Air testing is conducted to determine the pipe integrity following a repair. Air, rather than water, will leak through smaller cracks; therefore detecting vapour leaks that can attract roots is necessary. The test pressure is between 3—5 psi.	 www.cherneind.com
Disc Seals are designed to block the flow or provide a bypass flow in underground pipes with a low backpressure. Used for pipe construction, rehabilitation, cleaning and testing, these seals can be separated into two halves to effortlessly fit through any manhole. They are available for different pipe diameters. Jacks are used to support driving rods or other devices.	  www.cherneind.com

Tool and equipment	Pictures
Use of personal protective equipment (PPE) and professional gear while working in teams and following standard operation procedures (SoPs) ensures workers' safety. Additionally, they should be vaccinated against hepatitis A and B.	 www.cleaner.com
Hazards of H_2S and CH_4 H_2S and CH_4 are toxic corrosive explosives which are by-products of anaerobic processes that occur if organic materials accumulate in sewers or manholes. Appropriate measuring instruments, ventilation and teamwork are required, especially when working in deeper manholes. Many devices also measure oxygen concentration as part of the work and safety regulations.	 www.jjstech.com

5.3. O&M of the decentralised wastewater treatment plants

5.3.1. General considerations

Why is maintenance necessary?

The figure below is an illustration of a settler. This settler, when operated at the right hydraulic condition of 1–2 h (hydraulic retention time), is designed to separate suspended and colloidal wastewater components by flotation (scum) and sedimentation (bottom sludge). Additionally, because of the anaerobic condition, a partly biological degradation and mineralisation of both scum and bottom sludge occurs. Commonly, the accumulation rate of scum and bottom sludge is higher than the degradation and mineralisation rate leading to accumulation. Once the design storage capacity is exhausted, sludge and/or grease can be washed out, subsequently affecting the next treatment stage.

To obtain consistently good treated water quality, it is necessary to periodically inspect the increase in scum and accumulated sludge in the settler and changes in treated water quality; it is also necessary to clean the tank when the sludge storage capacity has been reached. The Ministry of the Environment of Japan has launched a video clip YouTube which explains how to properly maintain a Johkasou system and dispose the accumulated sludge.

Operation and Maintenance, and Desludging of Johkasou
https://youtu.be/8DP4fkigSwE?feature=shared

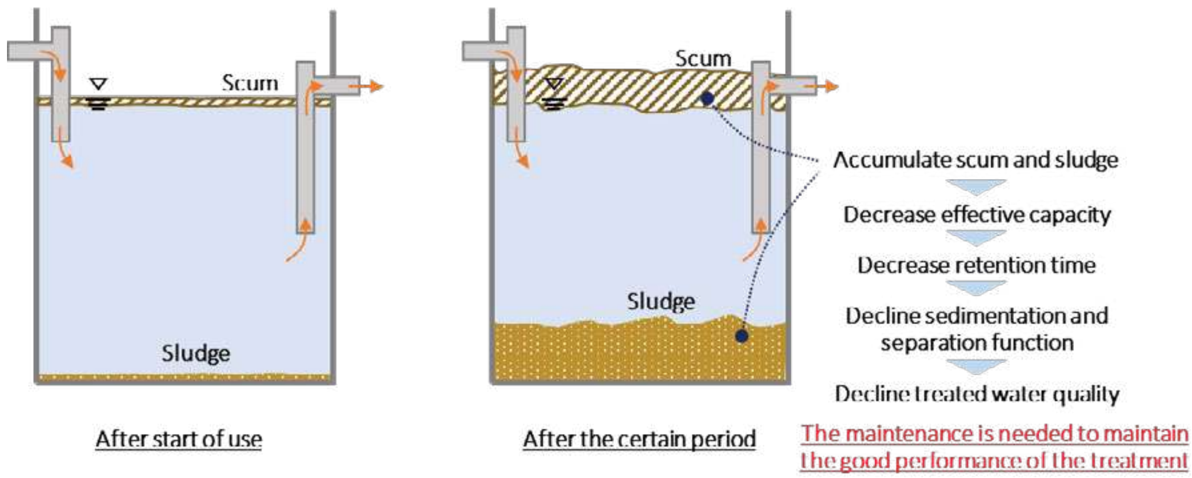


Figure 5.1. Necessity of O&M to maintain good performance of the treatment system *(Source: JECES, 2012)*

5.3.2. Overview

In accordance with the slogan '*What can't be maintained shouldn't be built!*', the objective of O&M is to ensure that the wastewater system continues to achieve its intended purpose throughout its lifetime. Assuring sustainable O&M is one of the most significant challenges facing decentralised wastewater systems. This difficulty is not primarily attributable to the O&M requirements of these systems; rather, it is the result of poor planning and construction quality, which has led to unforeseen operational costs. Ineffective institutional and financial O&M frameworks may also fail to answer essential questions such as '*Who is responsible for what?*' and '*How to finance the operation cost?*'

The magnitude of the O&M effort is highly dependent on the type of technology, its service capacity, the local context and the complexity of the wastewater system. A small septic tank with a soak pit requires less O&M effort than a wastewater system that includes sewers, advanced treatment and effluent reuse. However, 'low' O&M should not mean 'no' O&M. Even a septic tank requires periodic desludging and maintenance to continue serving its purpose.

This section focuses on the technical aspects of O&M, consequently providing direction and raising awareness regarding the required O&M effort. O&M requirements, activities and costs are always technology- and project-specific and the planning engineer and/or technology providers must detail them during the planning phase. Understanding the project-specific O&M requirements and costs and comparing them to the project's institutional and financial capacity before procurement is frequently undervalued; however, this is essential for ensuring the sustainability of projects.

Figure 5.2. Monthly inspection of a decentralised wastewater system
(Image source: UrbanWaters Consulting GmbH)

5.3.3. O&M activities

Table 5.3 outlines the most common activities for typical wastewater treatment components in DWM.

Table 5.3. Common O&M activities regarding wastewater treatment components

Components	Operation	Maintenance
Grease trap	• Weekly or monthly grease removal and safe disposal.	• Repair of broken parts on demand
Screen	• Daily or weekly waste removal and safe disposal.	• Repair of broken parts on demand
Settler	• On-demand scum removal • Desludging as per design (usually annually or as per demand) • Monthly inspection • Quarterly or annual measurement of the sludge level	• Repair of broken parts on demand
Biogas settler*	• Similar operation requirements as that of the regular settlers • Use of the biogas produced	• Repair of broken parts on demand • Checking for and repairing leakages in the gas system • Cleaning of the water traps and biogas burner
Anaerobic baffled reactor (ABR)	• On-demand scum removal • Desludging as per demand • Monthly inspection • Annual measurement of the sludge level	• Repair of broken parts on demand
Anaerobic filter (AF)	• On-demand scum removal • Desludging as per demand • Monthly inspection • Annual measurement of the sludge level	• Repair of broken parts on demand • Filter cleaning either in situ or outside

Components	Operation	Maintenance
Activated sludge bed processes (ASP)*	• Manual or automatic regulation of aeration based on dissolved oxygen (DO) concentration. • Monthly inspection of the functionality of the pumps and air blower, sensors, DO concentration, surplus sludge concentration and visual effluent monitoring.	• Repairing or replacing broken parts on demand • Cleaning of the sensors • Annual greasing depending on the blower type
Membrane Bioreactor (MBR)*	Similar operation requirements as that of an ASP	• Similar maintenance requirements as that of an ASP • Cleaning or replacing of the membrane is usually performed annually or every 2 years.
Trickling filter (TF) and rotating disc contactor (RDC)*	• Manual or automatic regulation of the recirculation pump or rotation speed • Monthly inspection of the functionality of pumps and moving mechanical equipment	• Repairing or replacing broken parts on demand. • Annual greasing depending on the moving mechanical parts • Cleaning of pumps annually
Secondary setter for surplus sludge	• Manual or automatic pumping of the sludge into the primary settler or a separate sludge treatment system • Monthly inspection of unwanted scum development and functionality of pumps and moving mechanical equipment	• Repairing or replacing broken parts on demand. • Cleaning of pumps annually
Constructed wetland filter*	• Monthly inspection regarding free flow (i.e. no blockages in the water distribution and collection system) • Removal of solid waste • Application of pesticides and herbicides	• Repair or replacement of broken parts on demand. • Cleaning of pumps annually if required. • Cleaning of distribution pipes on demand
UV-based disinfection*	• Monthly inspection of the recycling pump	• Repairing or replacing broken parts on demand. • Cleaning of the pumps annually. • Replacing the UV lamp annually or every 2 years

Components	Operation	Maintenance
Disinfection with an ozone generator*	• Monthly inspection of the recycling pump • Quarterly releasing of condensate water	• Repairing or replacing broken parts on demand. • Cleaning of pumps annually
Disinfection with chlorine*	• Daily or weekly preparation of the chlorine solution • Weekly or at least monthly measurement of the free residual chlorine and adjustment of the dosing pump accordingly (if not done automatically).	• Repairing or replacing broken parts on demand. • Cleaning of the dosing and storage tanks annually.
Storage tanks	• Monthly inspection and visual effluent monitoring	• Annual cleaning

Practical comments regarding Table 5.3:

- Technologies marked with a (*) should only be considered if there is a local supply chain for O&M services or spare parts since these technologies require specific spare parts and/or technology/product-specific expertise beyond the common skill set of operators.
- The owner or WWTP operation manager needs to decide how the O&M activities can and shall be performed by the in-house caretaker or operation staff or by external specialised service providers. The necessary O&M manpower input is usually only a few hours per month and is hardly a full-time job. Especially for the technologies marked (*), procuring annual maintenance contracts and outsourcing specialised tasks to specialised service providers is recommended.
- In most decentralised WWTPs, the primary and surplus sludge are stored and removed from the primary settler by a vacuum system and disposed of in a centralised sludge treatment plant. For aerated sludge bed processes (ASP, MBBR, MBR) with treatment capacities over 100 m^3 per day, additional sludge storage and on-site dewatering systems may be required to handle the surplus sludge in a more cost-effective way. For all aerated systems during the planning phase, the daily and annual surplus sludge generation should be calculated and a sustainable sludge management concept should be outlined.

- Supply of O&M tools, commissioning of the operation and operator training need to be part of the construction phase and should be included in the procurement of O&M services.
- The weak parts for electro-mechanical equipment such as pumps are mostly the components of the power supply (fuses, surge protection, control box).
- The construction quality has a significant impact on the repair cost.

5.3.4. Troubleshooting

Table 5.4 outlines the typical trouble indicators for the most common decentralised wastewater treatment technologies, the potential reason for the problem and proposed countermeasures to resolve the problem.

Table 5.4. Troubleshooting list for wastewater treatment components

Trouble indicator	Technologies	Potential reason	Proposed action
Overflow or unusually high water table in tanks, inspection chambers or filters	All technologies	Blockages of wastewater pipes or filters due to sludge, waste or debris accumulation	Cleaning of respective blockages and removal of scum and accumulated sludge. In the case of filters such as the up-flow filter (AF or activated carbon filter), the filter media may be washed inside or outside the tank. The clogged sand filter needs to be taken out of operation for 2-4 months and the surface should be cleaned subsequently. Gravel filter often require complete removal and washing before reinstallation. Any blockages of filters are an indication of wrong design and operation or missing desludging of the treatment stage before the filter.
	All technologies or application in which a pump is installed	Malfunction of the pump	Identifying the reasons for electrical problems in the power supply; identifying blockages in the pump suction area or pressure pipe and slammed floating switch.

<table>
<tr><th>Trouble indicator</th><th>Technologies</th><th>Potential reason</th><th>Proposed action</th></tr>
<tr><td rowspan="3">Unusual scum and foam</td><td>Chlorination tank</td><td>High organic content (BOD and COD) in the mixing tank</td><td>Stopping chlorine dosing and improving the BOD/COD removal performance of the treatment plant</td></tr>
<tr><td rowspan="2">Settler, biogas settler, ABR, aeration tank</td><td colspan="2">Grease trap or settler needs to be cleaned or desludged</td></tr>
<tr><td rowspan="2">Uncontrolled disposal of organic waste or chemicals</td><td rowspan="2">Finding the reason for such uncontrolled disposal and instructing the staff to stop these activities</td></tr>
<tr><td>Wastewater colour different from greyish, blackish or light brownish</td><td>All technologies</td></tr>
<tr><td>Cracks in buildings near the wastewater plant</td><td>All technologies</td><td>Leaky settlers or septic tanks that destabilise the ground</td><td>Urgent leakage detection and repair</td></tr>
<tr><td rowspan="3">Unusually high flow of clear water</td><td rowspan="3">Inlet of all technologies</td><td>Leaky indoor water system (taps, pipes)</td><td>Urgent leakage detection and repair</td></tr>
<tr><td>Groundwater intrusion</td><td>Detection and repair of a broken pipe, tank wall or inspection chamber</td></tr>
<tr><td>Stormwater intrusion</td><td>Detection and repair of broken pipes, inspection chamber or missing manhole lids; ensuring improved stormwater management</td></tr>
<tr><td rowspan="3">Smell</td><td rowspan="3">Inspection chamber, settlers, aeration tank, ABR, AF and storage tanks</td><td>Ineffective or insufficient aeration in aerated systems</td><td>Checking, adjusting or repairing the aeration system</td></tr>
<tr><td>Malfunction of the biological treatment process</td><td>Wastewater overloading, blockages or the disposal of toxic components may be the reason of such malfunction; hence, the pertinent issue needs to be resolved immediately.</td></tr>
<tr><td>Ineffective ventilation</td><td>Improving the ventilation</td></tr>
</table>

Trouble indicator	Technologies	Potential reason	Proposed action
Insects	Settler, ABR, AF, constructed wetlands, trickling filter	Stagnating wastewater	Finding the reason for water stagnation, cleaning the pipe and inspection chambers and ensuring that all inspection chambers have a proposed, appropriately fitting lid
		Missing or loose manhole lids	Replacing or repairing manhole lids

The following photos illustrate typical challenges in decentralised WWTPs.

In a rotating disc contactor, the reactor surface is dry and without bio-film; thus, the disc is not operational, resulting in no treatment

The manhole lids of the collection tank are extremely heavy; hence, it is difficult to maintain the tank and it becomes a source of odour and insects

Poor construction quality has led to a broken dam structure in a wastewater pond, thus causing leakage

Poor construction quality has led to leakages in the settler, subsequently causing environmental pollution in the adjoining area

DEWATS under tropical stormwater conditions

Brownish water indicates heavy stormwater intrusion in an ASP

Air bubbles in the aeration tank of an ASP; as the bubbles are too large, this indicates a broken or ineffective air diffuser

Yellowish and whitefish accumulation and dissolving concrete surface indicate ineffective ventilation of an anaerobic tank (settler, septic tank, ABR, AF) and the presence of sulphurous gases in the wastewater.

Unusual high scum accumulation in the settler and septic tank; in this case, this is due to a very high grease concentration in the incoming wastewater.

Scum development in an ABR chamber due to a high organic loading rate or due to a extremely high sludge accumulation rate caused by missing regular desludging appointments

Pounding wastewater in a vertical flow constructed wetland indicates that the wetland is clogged and has lost its infiltration capacity

This is the same constructed wetland as that in the photo to the left, after removal of the pounding water and plants. The blackish sand indicates unwanted anaerobic zones and deep organic sludge penetration into the sand filter. This is caused due to overloading and long-term pounding of water.

Non-domestic wastewater entering a decentralised municipal WWTP

Scum development in a mixing tank after dosing chlorine due to the high organic concentration (BOD/COD) in the effluent

Figure 5.3. O&M challenges and trouble indicators for decentralised WWTPs
(Image source for all photos: UrbanWaters Consulting GmbH)

5.3.5. Basic O&M tools

For any type of institutional or communal WWTP, the operator should possess and maintain the basic O&M equipment listed in Table 5.5. In situations where the entire O&M is outsourced to an external and specialised service provider, these tools may not need to be stored at the treatment plant. In cases where an external service provider visits only once a year for a service and maintenance check, these tools should be accessible to the operator or caretaker performing routine (daily, weekly or monthly) inspection and operational tasks.

Table 5.5. Basic O&M tools and equipment

Task	Tool and equipment
Operation	Logbook
	Personal protective equipment (PPE)
	First aid kit
	Hooks for lifting manhole lids
	Rake, shuffle and wheelbarrow
	Aluminium safety ladder
	Scum remover
	Wastewater pipe rods up to 20 m long

Task	Tool and equipment
Basic maintenance of the electro-mechanical treatment components	Electrical and mechanical toolbox assembled based on the respective technologies and technical components installed
Monitoring	1x wastewater sample comprising a 4,000–5,000 mm long telescopic rod and 500 ml plastic bucket
	2x plastic funnel
	1x sludge sampler length of 8 feet (2,400 mm) comprising 4! Case, 1-3/8' sampler diameter, sludge sampler extension kit and sludge sampler replacement rope plug
	pH indicator paper strips with a minimum pH range of 4–10, with a resolution pH value of 0.5
	Imhoff funnel set consisting of 2x 1000 ml funnels with a holding stand
	1x mobile device to measure dissolved oxygen in wastewater, consisting of a submersible sensor and a reading device (only for aerobic treatment systems)

Figure 5.4. Basic O&M tools and equipment

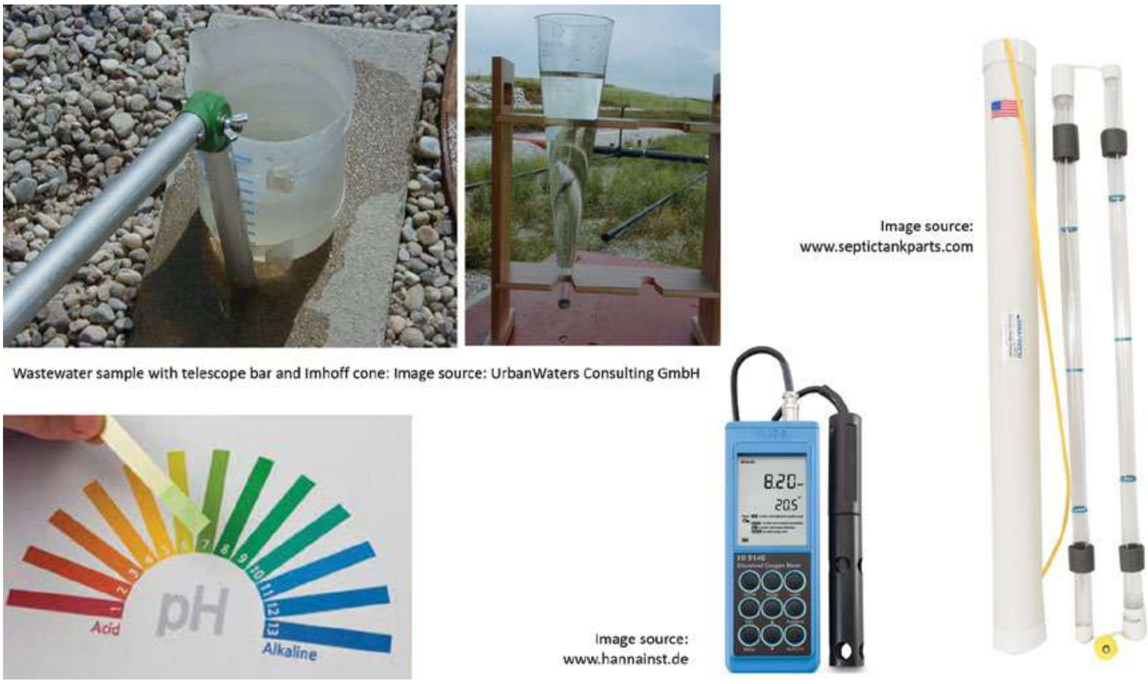


Figure 5.5. Basic monitoring equipment

5.3.6. Monitoring

Monitoring of a WWTP can be differentiated into the following:

a) Compliance monitoring

Monitoring of the effluent quality against relevant local environmental discharge standards. Water analysis and sometimes even sampling needs to be executed by an accredited laboratory.

b) Self-monitoring

Internal operational activity to check and/or improve the treatment performance of the entire WWTP or individual treatment processes.

To adhere to the applicable national standards or specific treatment objectives, the in-house operator or an external service provider should undertake routine self-monitoring and inspections. For most biological decentralised wastewater treatments, there is no need to conduct complex chemical analyses. Simple tests, such as visual observation, sedimentation tests in an Imhoff cone, pH measurements and on-site measurements of dissolved oxygen, frequently provide a practical first indication of whether the treatment process is operating appropriately. However, the operator should possess basic knowledge of wastewater and the treatment process of the treatment plant.

Table 5.6. Practical indicators for effective basic self-monitoring

Indicator	Description
Turbidity (Visual observation)	The effluent discharged into the environment should be mostly clear without visible suspended solids. Turbidity should be constantly improved over several treatment stages. Medium or high turbidity is usually an indicator for high suspended solids or organics (BOD & COD) and is often associated with odour.
Colour (Visual observation)	The effluent discharged into the environment should be mostly clear without colour. The colour of the wastewater effluent can indicate the following: • Light brownish colours due to low turbidity occurring in constructed wetlands. • Light greenish colours due to low or medium turbidity occurring in maturation ponds due to the presence of micro algae. • Light blackish or greyish colour due to medium turbidity occurring after anaerobic conditions (after setter, ABR, AF); however, it should not be visible after any aerobic system or constructed wetland filter. • Sludge in anaerobic conditions is black and in aerobic conditions light brownish. • Any other colours are mostly an indicator that the system is receiving non-domestic wastewater.
Smell	• The effluent discharged into the environment should mostly be without any strong odour. • The effluent from all anaerobic treatment stages, including septic tanks, anaerobic baffled reactors, or anaerobic filters, emits a light to medium unpleasant odour. • The effluent from all aerobic treatment stages, including activated sludge processes, trickling filters, rotating disc contractors, constructed wetlands, and maturation ponds, should not emit any unpleasant odors. The presence of such odors indicates that the treatment is not performing optimally.
pH Value	For all decentralised WWTPs operating based on mechanical and biological processes, the pH should be between 6.8–8.0.
Sludge level	When the sludge level reaches 50% of the water level in the settlers or anaerobic baffled reactor chambers, it needs to be removed. (Note: for inoculation proposes always leave 20 cm sludge on the bottom, that is, do not completely remove the sludge from the chambers).

Indicator	Description
Dissolved oxygen	For aerated systems such as activated sludge processes, trickling filter or rating disc contractors, the dissolved oxygen concentration should be between 2.0–4.0 mg/l (Note: Please check instructions provided by the technology supplier).
Suspended solids	For activated sludge processes, it is essential to obtain the right active sludge concentration in the reactor; (Note: Please check instructions provided by the technology supplier).

5.3.7. Documentation

Documentation is essential for implementing accurate monitoring measures, transparency and knowledge management; it comprises the following types of documents and utilizations.

Table 5.7. Documents required to operate and maintain a wastewater system effectively

Document	Reference and purposes	Responsible for updates	Responsible for approval
As-built documents	Update of the technical design with the construction and position of pipes, cables, connections, etc.	Planning engineer and/or contractor	O&M manager and operator
General O&M manual and plan	Technology-specific O&M manual to operate and maintain the entire system	O&M manager and operator	O&M manager
Specific O&M manual	All manufacture manuals for pumps, blowers, sensors, etc.. incorporated into the general O&M plan	Operator	O&M manager
Suppliers' warranties and contacts	Reaching out to the supplier in case of liability or services	Operator	O&M manager
Operator logbook	Recording activities and observations, including desludging	Operator	O&M manager
Monitoring reports	Recording performance parameter	Operator	O&M manager

Document	Reference and purposes	Responsible for updates	Responsible for approval
Technical emergency contacts	Accessible for everyone to contact the responsible technical person in case of technical breakdown, overflow or malfunction	O&M manager	N.A.
First aid contacts	Accessible for everyone to contact to ensure adequate first aid response in case of an accident	O&M manager	N.A.

5.3.8. O&M budgeting

The O&M costs of wastewater systems are influenced by the chosen technology, quantity of technical components and construction quality. During the planning and procurement phases of a new project, the technical project team needs to analyse, quantify and gain approval for the specific cost elements detailed in Table 5.8. The project-specific O&M cost plan needs to consider the project's financial capabilities. Table 5.8 provides a broad overview of potential O&M cost aspects related to decentralised wastewater treatment systems.

Table 5.8. General O&M cost position

<table>
<tr><th>Budget position</th><th>Items</th></tr>
<tr><td>Salary of the O&M management</td><td rowspan="2">Human resource wages depend on local rates and time input, the type and size of the treatment plant and the overall system complexity. Usually, the time input for the sewer network is combined with the wastewater treatment. However, for institutional treatment plants, it is often only a part-time job with few hours per month. For municipal wastewater systems with sewer networks, there may be a need to employ 1–2 full-time operators. The time input should be elaborated during the planning phase.</td></tr>
<tr><td>Salary of the operator / caretaker</td></tr>
<tr><td>Electricity</td><td>Depending on the technology, electricity should be budgeted for:
• Blower;
• Lifting pump;
• Sludge pump;
• Engines;
• Dosing pump;
• Recirculation pump.</td></tr>
</table>

Budget position	Items
Consumables	Depending on the technology, the following needs to be budgeted: • Grease for the bearings; • Chlorine; • PPEs.
Spare parts	Depending on the technology, the following needs to be budgeted: • Bearings, chains; • Engine (blowers, pumps); • Sensors (O_2); • Activated carbon filter; • Electrical fuses; • Manhole cover or lids; • Pipes; • O&M equipment.
Desludging	The daily and annually generated volume of sludge to be disposed and its cost need to be elaborated during the planning phase or as indicated by the technology supplier.
Analysis	Cost of sampling and external analysis

Repairs	Annual repair costs are usually estimated based on a recommended percentage multiplied by the initial investment cost differentiated by the type of installation as follows:
	• Renovations of civil structures (wall, tanks, chambers, pipes, earthwork)
	  - Sewer system: 1.0%–2.0 % of investment costs per year.
	  - Treatment plant: 0.5%–1 % of investment costs per year.
	• Electro-mechanical equipment (pumps, engine, bearings): 2.0%–4.0 % of investment costs per year.
	• Electrical and electronic equipment (sensors, switches, control panel): 4.0%–5.0 % of investment costs per year.

External services	Depending on the technology and knowledge of the operator: Repair of a process-controlling system, membranes, rotating discs, etc.

5.3.9. O&M Management

If effective O&M management is not in place, none of the aspects of O&M described above will be sustainable or relevant. This management ensures that a qualified operator, whether internal or external, supervises the operation and maintenance of the treatment plant, ensures compliance with procedures and provides adequate financial resources. Regarding the organisational structure and allocation of responsibilities, O&M management can be distinct from the operator, as shown in Table 5.9.

Table 5.9. Human resource description for the O&M of a wastewater system

Job position	O&M management	Operator/caretaker
General job description	• Human resource management regarding the operator/caretaker: - Employing operators based on site-specific job description. - Ensuring updated training specifically for the wastewater system. - Ensuring that the operator/caretaker fulfils their job description, including documentation and obeys the health and safety SoP. - Regular inspection/monitoring (monthly) of the functionality of the wastewater system and documentation. - Time management and payment of salary. - Defining regular and incident-based system reporting. • Asset management: - Managing the O&M budget position to finance consumables, materials, monitoring and repairs. - Contracting outside service providers (servicing, repairs, sludge collection, etc.).	• Conducting all required O&M tasks as per the operator manual/guideline for the respective technology and technical equipment . • Conducting self-monitoring activities to control system functionality and performance. • Conducting stock keeping and maintenance of O&M equipment, tools and consumables (chlorine and others). • Maintaining operator logbooks to document daily or weekly activities • Filing and updating all operator manuals for the treatment system and, if required, additional device manuals for pumps, sensors and others. • Filing all suppliers' warranties. • Using appropriate safety gear (PPE) during O&M activities. • Following the reporting system set by the management.

Job position	O&M management	Operator/caretaker
Qualification	• Intermediate vocational education. • Environmental engineering. • Facility management.	• Operator - Plumber, electrician and machine fitter. • Caretaker - Any practical background.
Specific training requirements	• Medical wastewater management training course. • Basic wastewater training course. • Wastewater monitoring and sampling. • O&M management training course. Health safety training course.	• Medical wastewater management training course. • Basic wastewater training course. • Wastewater monitoring and sampling. • O&M management training course. • Health safety training course. • Technology-specific O&M training course.

Alternatively, the tasks of the operator can be fully or partially outsourced to specialised service providers. This strategy is recommended for decentralised WWTPs installed in institutions and smaller municipal applications where a full-time operator may not be required. In many cases, outsourcing to specialised service providers is the most cost-effective option. However, the availability of local service providers who are familiar with the selected and installed wastewater treatment technology is a prerequisite for outsourcing operation tasks.

In many countries, operation service providers are emerging. In countries where the wastewater sector is well-developed, government bodies mandate training, registration and certification for these service providers. Public and partly non-government expert organisations offer training and certification services for these service providers. Asia has a well-established Johkasou wastewater treatment system and a training institute, JECES that offers certification for Johkasou operators (www.jeces.or.jp).

Chapter 6
Resource recovery

6.1. General considerations

This chapter stimulates critical thinking and inspiration to view wastewater as a valuable resource in the context of a circular economy through a few selected cases that reflect efforts made worldwide. It aims to provoke questions about whether our current approach to wastewater management is the most effective and whether there are alternative, forward-looking solutions that can lead us to a more sustainable future.

The authors of this Guidebook also recommend rethinking the terminology used to refer to *wastewater*: they propose the use of the term *'used water'* in place of 'wastewater'. This shift in language is intended to highlight the potential value and resourcefulness of used water and to emphasise the need for sustainable management practices.

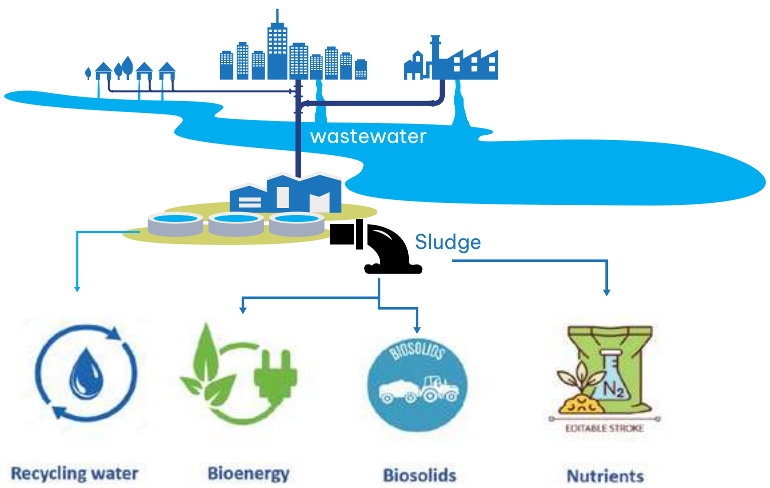


Figure 6.1. Type of resources that can be extracted from municipal wastewater

Figure 6.1 illustrates the effort to extract valuable resources from municipal wastewater. While the figure highlights an end-of-the-pipe approach, this chapter emphasises the importance of implementing solutions, that enable resource recovery at the source. By focussing on source, separation and decentralised treatment systems, we can maximise resource recovery and minimise the need for centralised, resource-intensive treatment processes. Although larger municipal WWTPs in countries with a well-developed wastewater sector have made progress towards energy neutrality and nutrient recovery, it is difficult for small-scale wastewater projects to afford the necessary technologies. However, for DWM initiatives, it is critical to implement localised solutions that are appropriate for the scale of the projects and available resources. This may require a fundamental rethinking of DWM or the selection of simpler, inexpensive technologies that contribute to effective treatment and resource recovery. The focus should be on tailoring solutions to the specific needs and constraints of the local context.

6.2. Potential for resource recovery

Domestic wastewater has significant resource recovery potential and through various treatment processes, valuable resources can be extracted and reused. Here, are some important resources that can be extracted from domestic wastewater:

(1) Water reuse: Treated domestic wastewater can be reclaimed and reused for non-potable applications such as irrigation, industrial processes, toilet flushing and groundwater recharge. This reduces the burden on freshwater resources and provides a sustainable water supply alternative.

(2) Nutrient recovery: Domestic wastewater contains essential nutrients such as nitrogen and phosphorus. These nutrients can be recovered through processes such as biological nutrient removal and struvite precipitation. The recovered nutrients can be used as fertilizer in agriculture, reducing the need for synthetic fertilisers and promoting nutrient recycling.

(3) Energy recovery: Wastewater contains organic matter which can be converted to heat and/or electrical energy through the combustion of biogas (a by-product of anaerobic digestion) or direct combustion of dried bio-solids.

(4) Bio-solids and bio-resources: The solid residue from wastewater treatment, known as bio-solids, can be treated and converted into a valuable resource. Bio-solids can be used as soil amendments in agriculture or for land reclamation. Advanced technologies such as thermal hydrolysis and pyrolysis can further enhance the energy and nutrient recovery potential of bio-solids.

(5) Urban cooling: Providing treated wastewater for irrigation conserves freshwater and enhances the green cover of urban areas; hence, the social and microclimatic benefits of the increased green cover are enjoyed by the community, such as cooling of buildings and urban areas.

It is important to note that resource recovery potential and feasibility may vary depending on the specific characteristics of the wastewater, the treatment processes used and local regulations and infrastructure. Advances in technology and research continue to expand the opportunities for resource recovery from domestic wastewater, driving the transition to more sustainable and resource-efficient wastewater management practices. Figure 6.2 attempts to quantify the resource potential of a volume of typical domestic wastewater. Bio-solids (yellow arrow) are the primary energy resource, whereas nutrients are present in both the water and bio-solids (purple arrow).

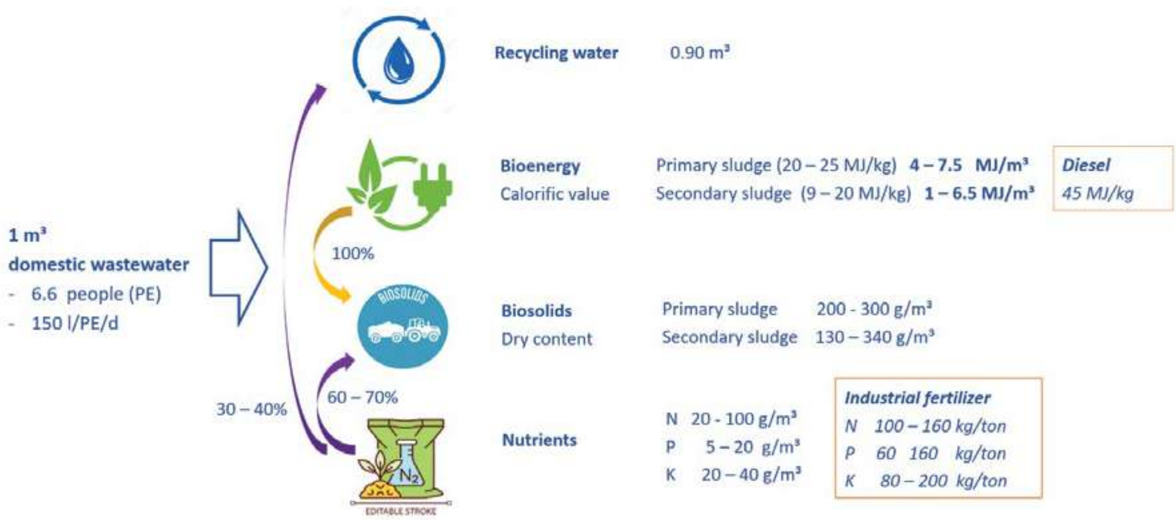


Figure 6.2. Potential resources that can be extracted from domestic wastewater
(Source: UrbanWaters Consulting GmbH)

As shown in this figure, considering the energy concentration of diesel fuel and the nutrient concentration of industrial fertiliser, the resource concentration in wastewater is relatively low. In the past, when global primary sources of fresh water, fertiliser and energy were available at low cost, wastewater was perceived as waste after use. However, today, this perception is changing and there is a growing focus on rethinking and innovating technologies to valorise wastewater.

For example, growing wheat requires 210–260 kg of nitrogen per hectare per year and domestic wastewater contains an average of 50 g of nitrogen per m^3. Approximately 4,300 m^3 of wastewater per year would be needed to cover the nitrogen needs of one hectare of wheat or 12.6 m^3 per day.

F. Meinziger's team at the Technical University of Hamburg conducted a fractionation and analysis of domestic wastewater (Figure 6.3) to understand how resources are distributed within itWastewater. This understanding led to the concept of source separation. For example, significant investments are made in WWTPs to remove nitrogen and urine is the primary source of nitrogen. Separating urine at the source, specifically at the toilet, allows a valuable resource to be extracted in a relatively simple manner and helps to avoid the high costs associated with wastewater treatment.

Daily loads per person in [g/d] for Greywater, Feaces & Urine

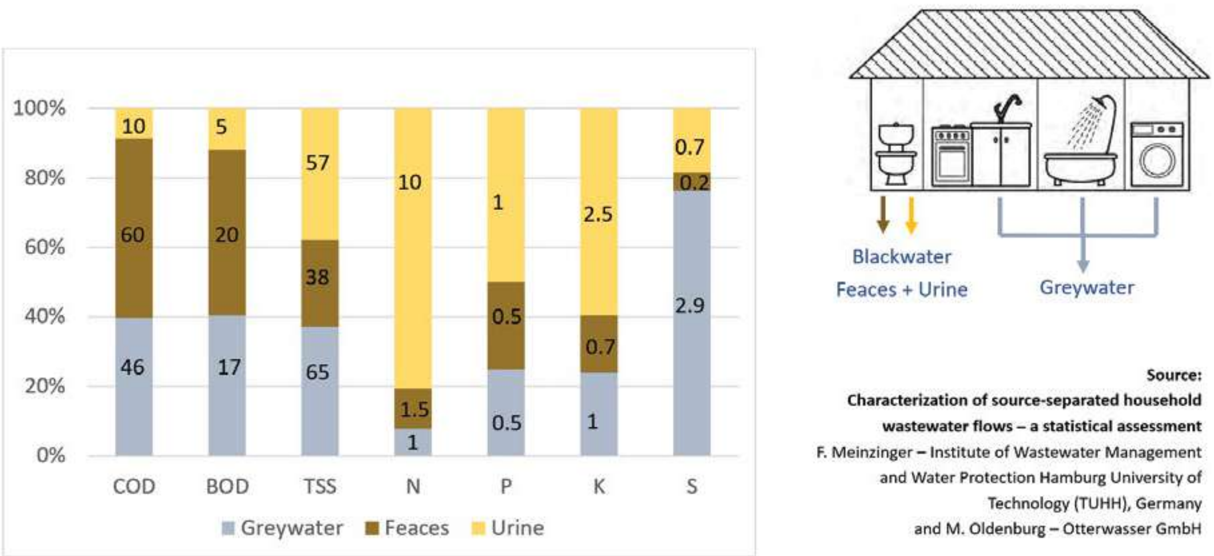


Figure 6.3. Detailed assessment of nutrient distribution in domestic wastewater.
(Source: F. Meinziger, 2009)

The technical solutions for source separation concepts that have emerged in the last decade are highly innovative and forward-looking. Source separation considers the following three streams:

- Faeces or blackwater from toilets
- Greywater
- Urine

Separation at the source has the following advantages:

- A relatively clean source that is not mixed with other waste.
- Treatment technologies can focus on the specific characteristics of each stream.
- Greywater has the highest volume and least pollution and wastewater infrastructure with only the essential components could be used to treat only greywater.
- Faces and urine are low in volume and high in resource concentration, which simplifies logistics and processing.

However, despite these advantages, there exist many challenges regarding source separation, such as:

- Buildings must be redesigned to accommodate source separation with additional piping and storage.
- User-friendly technologies for urine separation have been launched in the market only in the last few years.
- Market value for process by-products and economies of scale for technologies and services continue to be too low to create a strong business case for scaling.
- Relatively high investment costs.
- User perceptions and ‘old school’ administrative barriers.

Indeed, the challenges posed by global urbanisation, scarcity of freshwater, energy, phosphates and fertilisers and increasing heat in urban areas require a rethinking of water and wastewater management practices. People, communities and entrepreneurs are responding to these challenges with innovative and context-specific solutions. By fostering a spirit of innovation and collaboration, we can address these challenges and work towards sustainable and resilient water and sanitation systems that meet the needs of growing urban populations while conserving valuable resources and mitigating environmental impacts.

6.3. Case studies

Separation of greywater and blackwater streams at the household level

Figure 6.4 shows a concept promoted by the New South Wales (NSW) Department of Health in Australia, which emphasizes the importance of local greywater separation and reuse, especially in water-scarce regions. In some countries, such as India, there is a growing emphasis on zero-discharge concepts, requiring all wastewater to be treated and reused locally in new developments where there is no public sewer access. The image on the right in Figure 6.4 shows a greywater treatment constructed wetland in Tanzania, where greywater is reused for toilet flushing and gardening, while blackwater is infiltrated into the ground after treatment. The design of the constructed wetland also includes recreational areas for the tenants, providing additional benefits to the community.

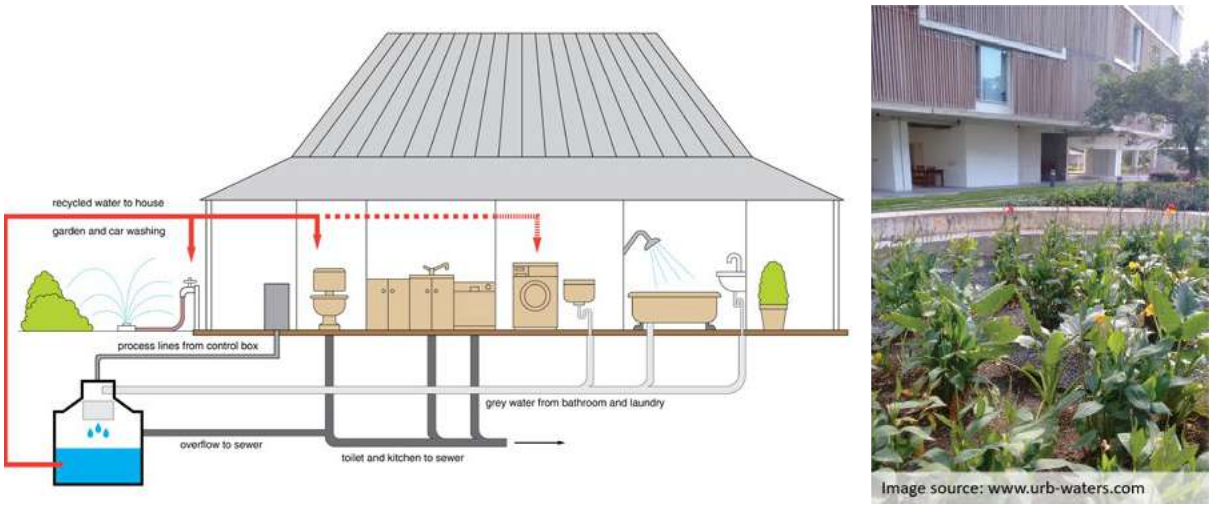


Figure 6.4. Local greywater separation and reuse
(Source: NSW Dept of Health, Australia)

Figure 6.5 illustrates a concept implemented in the city of Hamburg, Germany, for a residential area comprising approximately 2,000 residents. The concept involves the separation of greywater and blackwater within the residential area. It is managed by the public water and sewerage utility, Hamburg Wasser. The greywater is treated and used for greening purposes, while any excess water is discharged into a nearby water body. The blackwater is collected through a vacuum sewer system and undergoes anaerobic treatment, with biogas extraction used to generate additional heat and electricity for the residents.

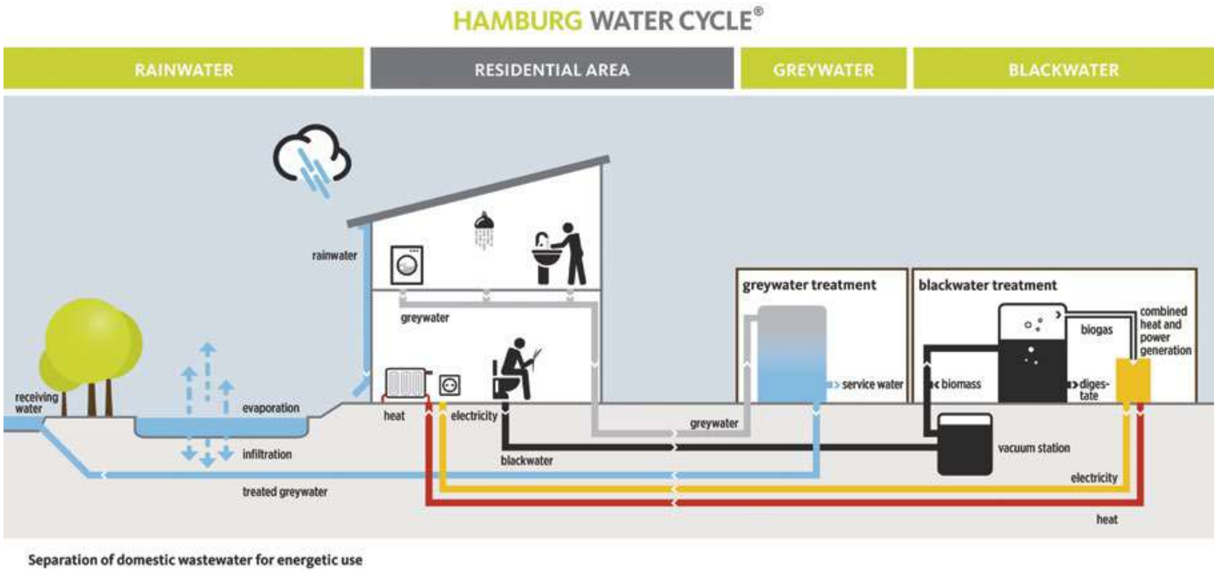


Figure 6.5. Illustration of the Hamburg Water Cycle concept
(Source: www.hamburgwasser.de)

Separation and processing of urine

Figure 6.6 shows a newly invented toilet seat with a user-friendly and maintenance-free urine diversion system from the Austrian company EOOS.

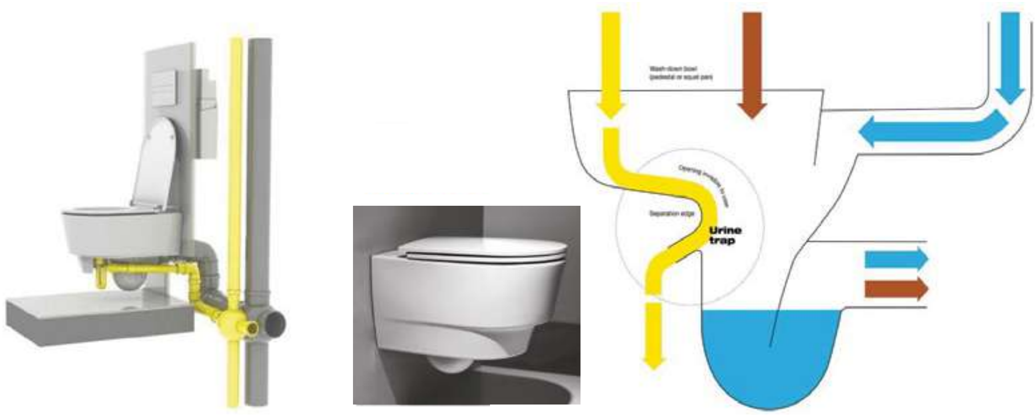


Figure 6.6. Urine diversion toilet
(Source: www.eoos.com)

Figure 6.7 shows a webpage of the Swiss company VUNA, which uses the struvite process to convert urine into a marketable, high-value liquid fertiliser.

Figure 6.7. Liquid fertiliser made from urine by the company VUNA
(Source: www.vuna.ch)

Faecal sludge treatment

FS refers to the sludge and wastewater that accumulate in on-site sanitation and wastewater systems. Figure 6.8 shows an example of the many potential benefits that can be derived from this wastewater stream. In this particular case, FS is treated by using a sludge-treating constructed wetland, also known as planted sludge drying beds. The sludge is dewatered, composted and dried on these filter beds. Over a treatment period of 3–5 years, the sludge is transformed into bio-soil, which is subsequently removed, cleaned, packaged and sold as a soil conditioner in the local market. The treated effluent is diverted to a bamboo plantation for additional benefits. This system has the capacity to treat approximately 100 m³ of FS per day and significantly offsets its operating costs through the sale of by-products.

Feacal sludge treatment plant (100 m³/d) municipality Vientiane / Laos

Figure 6.8. FSTP in Vientiane, Laos
(Source: Google maps and UrbanWaters Consulting GmbH)

6.4. Wastewater Reuse

In addition to nutrients, the water component of treated wastewater holds significant value as it can be used to replace and conserve freshwater resources.

International Guidelines

Over the past decades, countries worldwide have established quality standards to define acceptable water quality for various reuse applications by considering the associated risks.

Table 6.1. Overview of the selected international guidelines for wastewater reuse

Organisation	Guidelines
World Health Organisation (WHO)	Guidelines for the safe use of wastewater, excreta and greywater (2006)
United Nations Environment Programme (UNEP)	Guidelines for municipal wastewater reuse in the Mediterranean region (2005) Development of performance indicators for the operation and maintenance of treatment plants and wastewater reuse (2011)
United Nations Water Decade Programme on Capacity Development (UNW-DPC)	Proceedings on the UN-Water project, 'Safe use of wastewater in agriculture' (2013)

Organisation	Guidelines
International Organization for Standardisation (ISO)	ISO/TC282 Water reuse (under development)
Food and Agriculture Organisation (FAO)	Water quality for agriculture (1994)
European Commission (EU)	New regulation on minimum requirements for water reuse for agricultural irrigation (applicable from June 2023)

Most international guidelines and national environmental standards distinguish between categories of use and restricted and unrestricted use, as shown in Table 6.2.

Table 6.2. Category of use and descriptions

Category of reuse		Description
Urban Reuses	Unrestricted	For non-potable applications in municipal settings where public access is not restricted.
	Restricted	For non-potable applications in municipal settings where public access is controlled or restricted by physical or institutional barriers.
Agricultural Reuse	Food Crops	For irrigating food crops intended for human consumption.
	Restricted	For irrigating crops that are either processed before human consumption or not consumed by humans.
Impoundments	Unrestricted	For use in an impoundment where no limitations are imposed on body-contact water recreation activities.
	Restricted	For use in an impoundment where body contact is restricted.
Environmental Reuse		For creating, enhancing, sustaining or augmenting water bodies, including wetlands, aquatic habitats, and stream flow.
Groundwater Recharge: Non-potable reuse		For recharging aquifers that are not used as potable water sources

Examples of Wastewater Reuse

In the context of DWM, the main applications for the reuse of treated wastewater (recycled water) are:

- Agriculture;
- Urban greening;
- Recreational areas;
- Industrial reuse (cooling, cleaning, construction).

(1) Example of wastewater reuse at the research scale

A research study conducted by Prof. Chris Buckley and his team at the eThekwini Municipality in South Africa focussed on investigating the impacts of nutrient-rich treated wastewater on soil properties. The findings of the study revealed that while increased crop biomass growth was observed when irrigated with treated wastewater, this effect was only significant when the soil had the capacity to absorb and retain the nutrients delivered by the wastewater. In poor sandy soil conditions, the nutrients were washed away and proved to be ineffective for plant use.

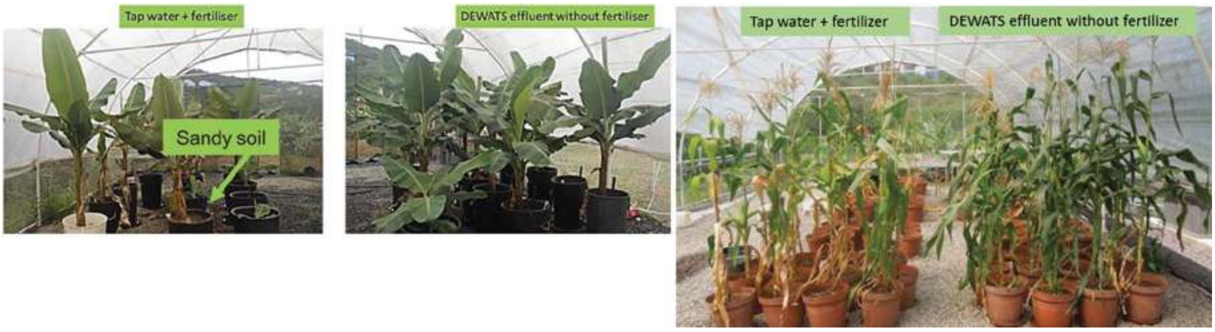


Figure 6.9. Irrigation with treated wastewater
(Source: Odindo et al. (2016))

(2) Example of wastewater reuse for irrigation

There are several technical options for using wastewater in irrigation.

Furrow irrigation

While this is a low-cost system, it requires dedicated levelling.

Figure 6.10. Furrow irrigation

Sprinkler irrigation

This is a medium-cost system with effective distribution; however, it is prone to salinity accumulation in an agricultural context.

Figure 6.11. Sprinkler irrigation

Surface irrigation

Drip irrigation → This is a medium-cost system; it is effective, requires pre-treatment and allows controlled irrigation.

Figure 6.12. Drip irrigation of olive trees

Sub-surface irrigation

Drip irrigation

This is a high-cost system, requiring pre-treatment; it is effective, allows controlled irrigation and requires no human contact.

Figure 6.13. Sub-surface irrigation

Sub-surface irrigation

French drain

This is a low-cost system that requires dedicated levelling; however, it is only applicable for using small quantities of wastewater (2–20 l/m²*d).

Figure 6.14. French drain system

The following aspects need to be considered before reusing treated wastewater for irrigation:

- Cost of treatment to obtain the required wastewater quality and cost of distribution versus benefits (cost-benefit analysis);
- Risk management to determine environmental protection and public health;
- Technical solutions for treatment to obtain the required wastewater quality and determining logistics for storage and distribution.

6.5. Risk mitigation

Table 6.3 presents an overview of the parameters found in municipal and industrial wastewater, along with their potential risks and impacts on ecosystems, public health and technical equipment. The objective of this table is not to discourage the reuse of wastewater, but rather to raise awareness and highlight the importance of considering these parameters in wastewater management and treatment processes. By understanding the potential risks associated with certain parameters, appropriate measures can be taken to mitigate them and ensure the safe and sustainable reuse of wastewater.

Table 6.3. Risks and impacts of uncontrolled application and reuse of untreated wastewater.

Parameter	Impact – ecosystem	Impact – public health	Impact - technical	Source
Total suspended solids (TSS)	→ Oxygen demand in soil and water bodies	→ Pathogens are usually attached to particles	→ Clogging of irrigation systems → Interference with the disinfection treatment	Domestic and food industry
Organics as (COD and BOD)	→ Oxygen demand in soil and water bodies			Domestic and food industry
Nutrients as N, P, K and S	→ Leading to biomass growth (eutrophica-tion) → NH_4, which is poisonous to fish → H_2S, which is poisonous to fish	→ Nitrate (NO_3-) and nitrite (NO_2-) ground and drinking water contamination	→ Concrete and steel corrosion due to H_2S	Higher concentration from food industry
Pathogen (*E.coli*, Helminth egg, etc.)		→ Diarrhoea, cholera, worms, etc.		Domestic and industry (animal stables)

Parameter	Impact – ecosystem	Impact – public health	Impact - technical	Source
Heavy metals (Cd, Zn, Ni)	→ Some are toxic and accumulate in soil and agricultural products			Industry, FS (solid waste)
pH	→ Affects metal solubility and soil alkalinity		→ Affects metal solubility	Industry
Dissolved inorganics	→ Excessive salinity damages crops			Groundwater, industry (olives), FS
Medical residues	→ Interferes with the fertility of animals	→ Increasing antibiotic resistance		Domestic
Microplastics	→ Some are toxic and accumulate in soil and agricultural products			Domestic and industry

Understanding the major pathogen transmission pathways is critical for assessing the potential public health risks associated with a specific wastewater project. It is recommended that exposed populations be identified by assessing the following pathways:

- Inhalation of aerosols;
- Body contact;
- Drinking water;
- Food.

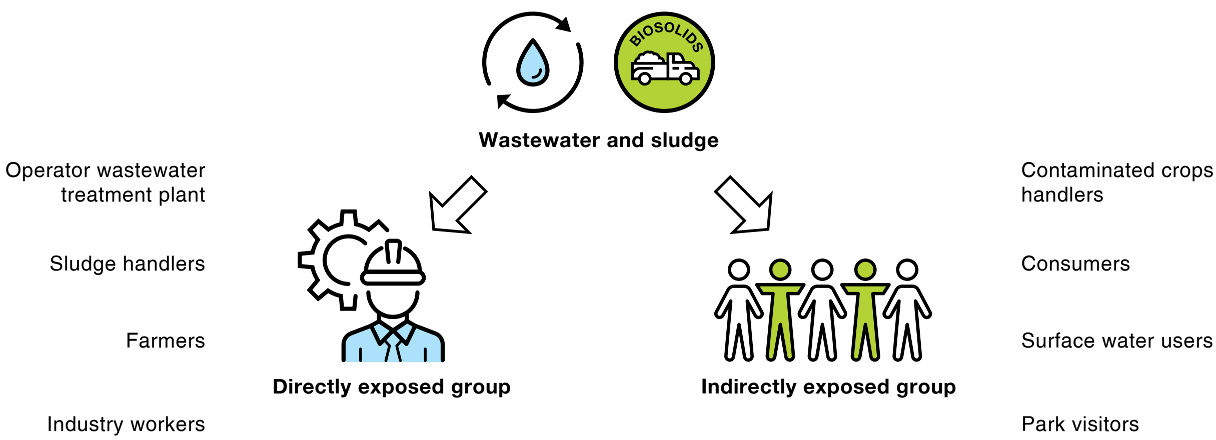


Figure 6.15. Directly and indirectly exposed groups of pathogen transmission

From a governmental perspective, addressing the potential environmental and public health risks associated with wastewater reuse requires a comprehensive, multi-faceted approach, as illustrated in Figure 6.16. This approach includes regulatory frameworks, advanced technologies, health and safety measures, selection of appropriate irrigation systems and crops and assessment of water resource availability and demand. It is also recommended to conduct project-specific risk-benefit and financial sustainability analyses. The choice of the crop and the intended application category of reuse are critical factors in mitigating risks regarding wastewater reuse and ensuring the long-term sustainability of the project.

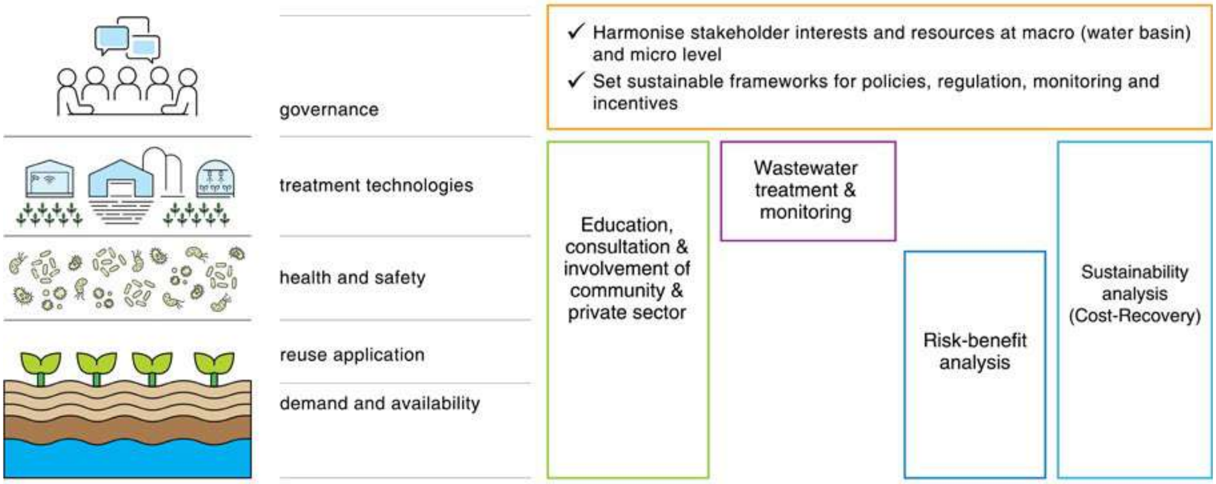


Figure 6.16. Multi-level risk mitigation approach for the reuse of wastewater *(Source: picture Milou, 2020, Text: Authors)*

Chapter 7
Managing emerging contaminants in wastewater

7.1. General considerations

Emerging contaminants (ECs) or emerging pollutants (EPs) are of increasing concern in wastewater management because they are usually generated from human activities and often discharged uncontrolled into freshwater bodies, posing a potential risk to public health and the environment. Trace levels of ECs have been detected in water sources in recent years; however, their presence, fate and transport, potential risks and regulation may not be fully understood or established. They are being recognised as potential environmental and public health concerns, often because of their persistence, bio-accumulation or harmful effects even at low concentrations.

Figure 7.1 illustrates the conceptual depiction of the origin of emerging pollutants and their route to the environment (adapted from Gogoi et.al, 2018).

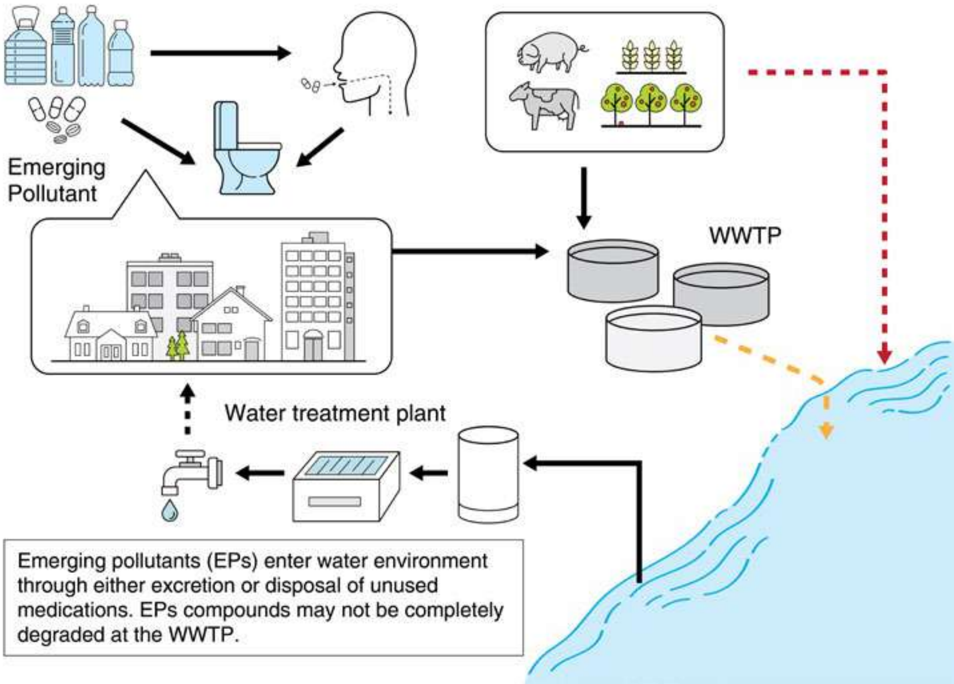


Figure 7.1. Sources of EPs and their route to the environment
(Source: Gogoi et al. 2018)

ECs are typically not monitored or regulated in standard water quality assessments; hence, they may pose potential risks to human health and the aquatic system. They can originate from various sources, including household activities, industrial processes, agriculture, pharmaceuticals and personal care products.

Some ECs include the following:

- Pharmaceuticals and Personal Care Products (PPCPs): These include medications, hormones, antibiotics, fragrances and other chemicals found in consumer products. PPCPs can enter wastewater through human excretion, improper disposal or manufacturing processes.
- Endocrine Disrupting Chemicals (EDCs): EDCs are substances that can interfere with the hormone systems of organisms, affecting reproduction, development and behaviour. Examples include bisphenol-A (BPA), plasticisers, triclosan and some pesticides.
- Illicit Drugs: Wastewater analysis showed traces of illicit drugs, such as cocaine and amphetamines, in urban wastewater. This can provide insights into drug usage patterns in a community.
- Antibiotic-Resistant Bacteria (ARB) and Antibiotic Resistance Genes (ARGs): Wastewater can contain high levels of ARB and ARGs because of the discharge of antibiotics and other antimicrobial agents into the sewage system. This contributes to the global concern of antibiotic resistance.
- Microplastics (MPs): These are tiny plastic particles measuring less than 5 mm in size. Sources of MPs include the fragmentation of larger plastic items (secondary sources) and direct inputs of MP-sized particles, such as microbeads used in cosmetics and pre-production pellets (primary sources).

The potential risks associated with these contaminants emphasise the importance of effective wastewater treatment and monitoring to safeguard both the environment and public health.

7.2. Medical wastewater and pharmaceutical contaminants

Medical wastewater primarily originates from various activities within healthcare facilities that use fresh water. These activities encompass functions such as toilet usage, handwashing at sinks, bathing, laundering, floor cleaning and procedures performed in operating theatres. Medical wastewater shares several characteristics with domestic wastewater, including parameters such as BOD, COD, ammonia, nitrogen and pathogen presence. However, it distinguishes itself by containing notably elevated concentrations of pharmaceutically active compounds (PhACs), often referred to as ECs, as well as toxic heavy metals such as cadmium (Cd), Copper (Cu), Nickel (Ni), Mercury (Hg) and Tin (Sn).

In addition to its other components, medical wastewater is a reservoir for various pathogenic microorganisms. These microorganisms not only possess pathogenic properties but may also develop resistance to antimicrobials or antibiotics. Furthermore, within the wastewater, faecal matter and urine carry unmetabolized Pharmaceutically Active Compounds (PhACs) that were administered to patients during treatment. Greywater or sullage, represents the water resulting from activities such as washing, bathing, laundry and other processes such as the rinsing of x-ray films or disinfection. This water contains stubborn compounds such as surfactants and detergents, along with cytotoxic or genotoxic agents and even radioactive elements.

The Blue Book for Safe Management of Waste from Healthcare Activities (WHO, 2014) indicates the following wastewater sources and their specific medical pollutants:

General medical areas generate wastewater comparable to domestic wastewater. The urine of patients from some wards (oncology, infectious disease) will probably contain higher numbers of antibiotics, cytotoxins, metabolites and X-ray contrast media. Additionally, higher concentrations of disinfectants can be found.

Kitchens at hospitals often generate a polluting wastewater stream containing food leftovers, food processing waste and high concentrations of disinfectants and detergents. Starch, grease, oil and an overall high organic content can create problems during wastewater management.

Laundries are places where the highest quantity of greywater is produced. Often, this wastewater is hot, has a high pH (alkaline), and may contain high rates of phosphate and Adsorbable Organically bound halogens (AOX) if chlorine-based disinfectants are used. Shower blocks also create large volumes of greywater containing dilute concentrations of detergents.

Theatres and intensive-care units generate wastewater with high concentrations of disinfectants (glutaraldehyde), detergents and pharmaceuticals. Additionally, the organic content can be high due to the disposal of body fluids and rinsing liquids (such as those from suction containers).

Laboratories are a possible source of chemicals in wastewater streams. Of special relevance are halogenated and organic solvents, colourants from histology and haematology (Gram staining), cyanides (haematology) and formaldehyde and xylene (pathology). Laboratories may also contribute to the presence of blood in wastewater from the emptying of samples into the sinks.

Radiology departments are the main generators of photochemical (developing and fixing) solutions in wastewater and potentially contaminated rinsing water. In some countries, this source of wastewater contamination is declining because of the increasing use of digital X-ray technology.

Haemodialysis requires disinfection of the dialysers and sometimes that of the used filters. Accordingly, the concentration of disinfectant in wastewater can be high.

Dental departments can contaminate wastewater with mercury (amalgam) from the filling of dental cavities if no amalgam separators are installed in the sink waste pipe system.

Central sterile supply departments (CSSD) are one of the main consumers of disinfection solutions, including aldehyde-based disinfectants. Hot water from the sterilisers and detergents from the CD (cleaning and disinfectant) machine may also increase the pollution load in the wastewater.

Pharmaceutical concentrations

Pharmaceuticals are used in hospital settings in various ways. Predominantly, hospitals employ pharmaceuticals for therapeutic purposes, with notable examples being contrast media, laxatives, analgesics, anti-inflammatories, antibiotics and cytostatic drugs. These pharmaceutical agents are predominantly excreted through urine, with a smaller portion being eliminated in faeces. Among these medications, the most significant categories in terms of usage include contrast media agents, cytostatic drugs, analgesics, anti-bacterial agents and anti-infectives, which collectively account for approximately 40% of pharmaceutical consumption. Another 20% is attributed to medications such as anti-inflammatories, anti-epileptic drugs, β-blockers and others (Verlicchi, 2018).

Pathogen content

Bacteriological categories found in wastewater include faecal coliforms and pathogens. Faecal coliforms are identified through the analysis of E. coli, which serves as an indicator of faecal contamination. E. coli is a type of facultative anaerobic bacteria that naturally resides in the gastrointestinal tract and faecal matter. In addition to coliforms, wastewater contains other bacteria, such as spores of sulphite-reducing anaerobes, as well as pathogenic viruses such as enterovirus, norovirus, adenovirus and rotavirus. Notably, compared with municipal wastewater, there tends to be a higher concentration of faecal coliforms in hospital wastewater due to dilution caused by increased water consumption. However, the presence of viruses is notably 2–3 times higher in the hospital wastewater than in municipal wastewater (Verlicchi, 2018).

Antimicrobial Resistance/ Antimicrobial Genes

Antibiotics are the primary pharmaceuticals employed for treating various infections. However, the extensive use of these medications has led to the emergence of antibiotic-resistant pathogens, particularly among gram-negative bacteria (Rozman et al., 2020). Consequently, medical wastewater is a significant contributor to the dissemination of ARB and ARGs. Once released into the environment, these organisms have the capacity to proliferate. Moreover, they exhibit the ability to exchange resistance genes among themselves and can also transfer ARGs to other bacteria that transit through the human body.

V. Parida (2022) developed a valuable and informative visualisation (Figure 7.2) that effectively illustrates the origins of medical wastewater streams, the contaminants they contain, typical disposal routes and how these contaminants find their way into the environment.

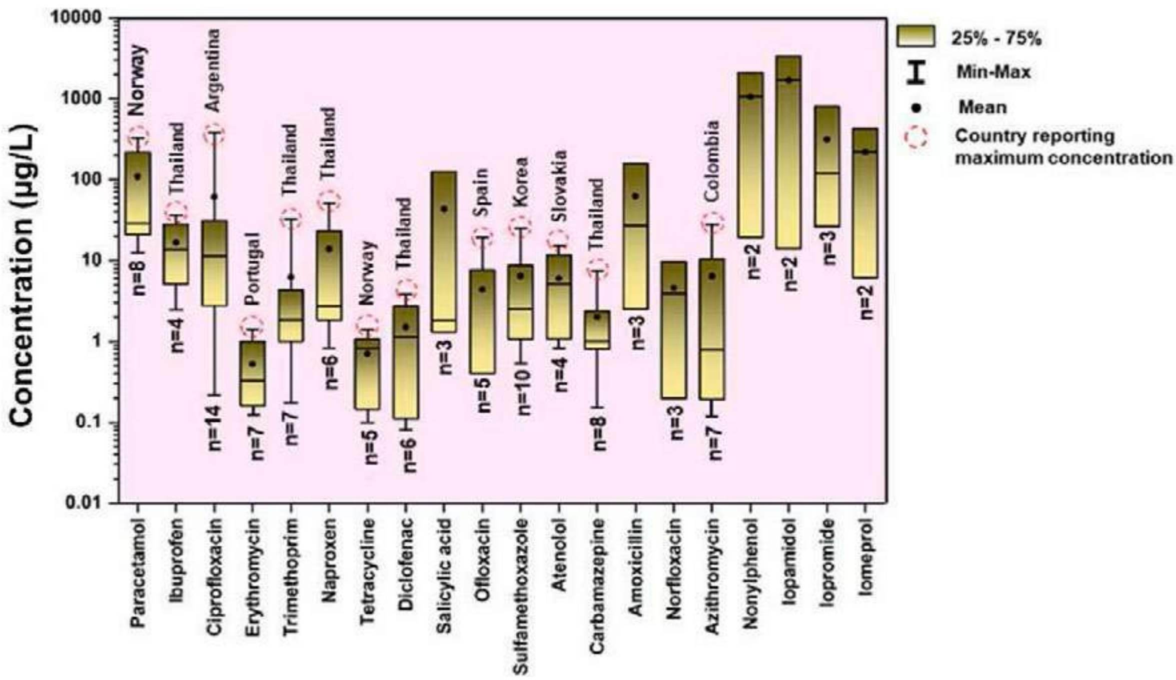


Figure 7.2. Selected ECs in medical wastewater
(Source: V.Parida, 2022)

The risk to the public and environment associated with medical wastewater is highly dependent on in-house waste management, site conditions and the following factors:

- Dilution by stormwater;
- Accumulation in the soil and groundwater;
- Open drains and open exposure to humans and animals;
- Disposal route;
- Quantity and concentration of contaminants;
- Soil conditions (absorption and infiltration capacity);
- Source, quantity, and quality of water supply accessible to the community.

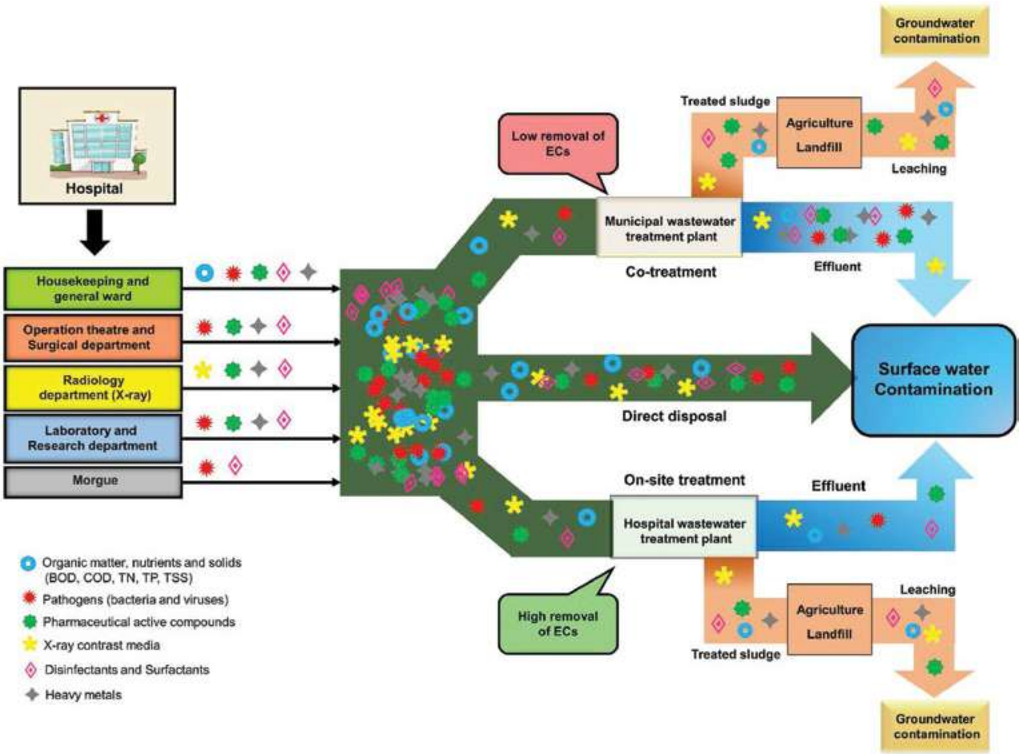


Figure 7.3. Generation of different contaminants from hospitals and healthcare facilities and their subsequent pathways into different aqueous environments
(Source: V. Parida, 2022)

The potential risks associated with these contaminants emphasise the importance of effective wastewater treatment and monitoring to safeguard both the environment and public health. Decentralised wastewater treatment systems (DEWATS) can manage ECs by employing various mechanisms and technologies; some of these are listed below.

(1) Advanced Treatment Technologies: DEWATS have the capacity to integrate advanced treatment technologies that are purpose-built for the elimination or degradation of ECs. Notable examples include activated carbon adsorption, ozonation, advanced oxidation processes (AOPs) and membrane filtration. These technologies demonstrate the capability to selectively target particular contaminants, ensuring their efficient removal from wastewater.

(2) Natural Treatment Processes: Certain DEWATS harness natural treatment processes, such as constructed wetlands or bio-filtration, to manage wastewater. These systems harness the inherent capabilities of plants and microorganisms by employing a combination of physical, chemical and biological mechanisms. Through this approach, they effectively eliminate or break down contaminants, including EPs.

(3) Multiple Treatment Stages: DEWATS have the flexibility to integrate multiple treatment stages, thus ensuring thorough removal of contaminants. Each stage can be designed to target a specific facet of treatment, whether it is primary sedimentation, biological treatment or tertiary filtration. Through the implementation of a sequence of treatment steps, DEWATS can adeptly manage a diverse array of contaminants, including EPs.

DEWATS can establish rigorous monitoring and testing protocols to enhance the management of ECs. Consistent monitoring of both influent and effluent wastewater is crucial to detect EPs and evaluate the effectiveness of treatment processes. By closely observing system performance, necessary adjustments and upgrades can be undertaken to ensure the efficient removal of contaminants, thus optimising the overall treatment process.

In summary, DEWATS are a promising approach for addressing ECs. Nevertheless, it is essential to carefully choose the appropriate treatment system based on the specific contaminant types and system design, while also ensuring the system's appropriate operation to maintain contaminant levels within acceptable thresholds. Furthermore, the realm of decentralised wastewater treatment is continually advancing, with ongoing research and innovation playing a pivotal role in the efficient management of ECs. Researchers and engineers are actively conducting studies to understand EPs, their behaviour within wastewater treatment systems and potential strategies for their treatment and removal.

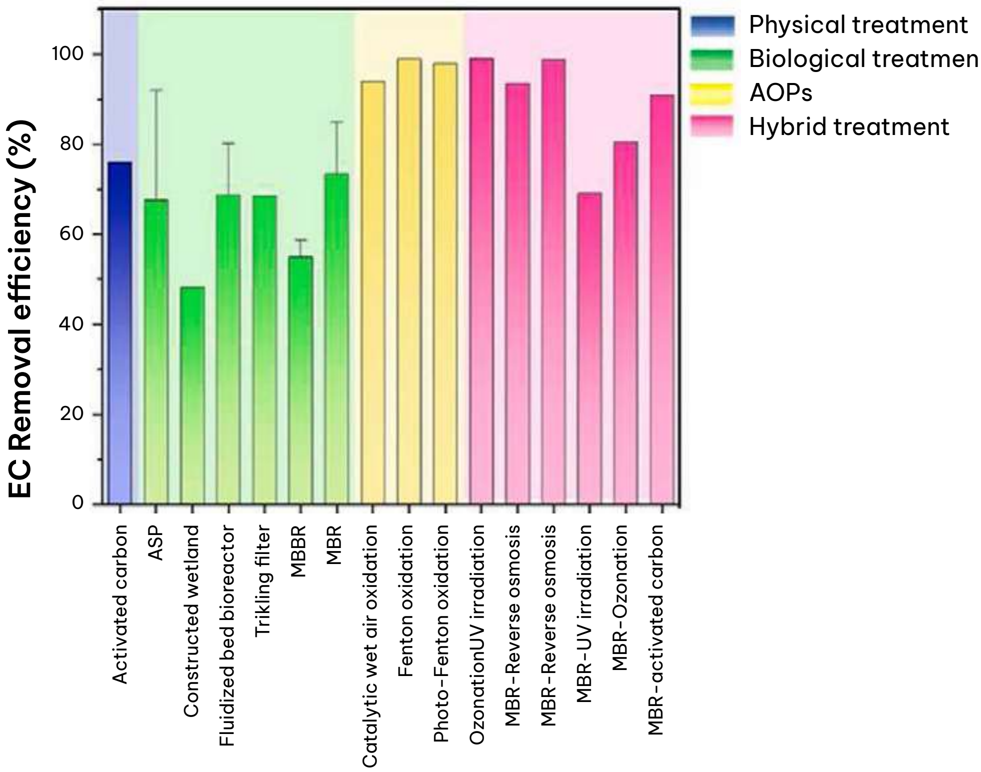


Figure 7.4. Different wastewater treatment technologies and their EC removal efficiency. BLUE – physical treatment, GREEN – biological treatment, YELLOW – advanced oxidation process, RED – hybrid treatment.

(Source: Parida, 2022)

Parida and his team (2022) have compiled published data to illustrate the efficiency of various treatment technologies in removing ECs, as depicted in Figure 7.4. On the basis of the available data, it can be deduced that classical aerobic biological treatment systems exhibit a relatively low EC removal rate. Although anaerobic biological systems are not specifically listed, it can be inferred that their EC removal rate may be even lower. In contrast, AOPs theoretically offer the highest removal rates for ECs. However, it is important to note that AOPs typically require effective primary, secondary and sometimes tertiary treatment stages and they may not function optimally as standalone processes. In contrast, hybrid systems represent multi-stage treatment systems that incorporate primary and secondary treatment processes. These systems are known for their robustness and consistent performance, making them a promising option for addressing ECs in wastewater treatment.

However, the following needs to be considered:

- Not all ECs can be removed with the same efficiency by using the same technology.
- Oxidation processes are required to remove ECs.
- AOPs are required to remove ECs with the greatest efficiency.
- Filtration processes such as membrane bio-reactors (micro and ultra-filtration) or constructed wetlands have only a 50%–60 % EC removal rate.
- Activated carbon functioning based on adsorption has a EC removal rate of 70–80%.
- Multi-stage systems are required to provide sufficient and robust treatment efficiency.

Several other treatment technologies for EC removal are analysed as follows:

(1) Use of aerated constructed wetlands

A study was conducted at a Belgian hospital with a daily wastewater flow rate of 300 L. The system was operated at 50% and 100% aeration. The findings revealed that atenolol and bisoprolol were efficiently removed (>75% and >50%, respectively); however, other pharmaceuticals such as carbamazepine, diclofenac, gabapentin and sulfamethoxazole were only removed up to 50%. Intermittent ventilation did not produce results different from that of complete ventilation. The hydraulic retention time (HRT) for the system was 2 days (Auvinen et al., 2017).

(2) Oxidation Ditch (OD)

Some hospitals in Thailand have implemented OD as a treatment system and it was found to have a removal efficiency of 32%–79% of 14 types of antibiotics. The anoxic conditions created in the system also helped in the removal of amoxicillin and ampicillin. However, OD showed a lower removal rate for some antibiotics (Chiemchaisri et al., 2022).

(3) Aerated Fixed-Bed Reactor (AFBR)

Some studies have shown that AFBR, similar to submerged fixed or moving bio-bed reactor, has better efficiency in removing components such as fluoroquinolones with an efficiency rate of approximately 80%–90%. However, AFBR showed a negligent removal rate for some antibiotics (Chiemchaisri et al., 2022).

(4) Anaerobic Fixed-Bed Reactor or Anaerobic Filter (AF)

An anaerobic system followed by AFBR was studied; it showed a removal in the range of 34–100%. A removal of 80–100% was observed for fluoroquinolones. Mostly, the main phenomenon for removal was perceived to be the adsorption on the attached growth (Chiemchaisri et al., 2022).

(5) Constructed Wetlands (pond system)

Two ponds were constructed concurrently and it was observed that several antibiotics, including ciprofloxacin, norfloxacin, tetracycline, levofloxacin, ofloxacin, doxycycline, trimethoprim and colistin, were present in higher concentrations in the effluent of the first pond as compared to that in the influent. Nevertheless, the second pond exhibited better removal efficiency, achieving removal rates ranging from 51–99%. Notably, antibiotics such as ampicillin, ciprofloxacin, oxytetracycline and doxycycline were removed to a significant extent, exceeding 90% removal rates. Similarly, ofloxacin, levofloxacin, norfloxacin and sulfamethoxazole were removed at rates between 89–90% (Chiemchaisri et al., 2022).

(6) Activated Sludge Process (ASP)

In Saudi Arabia, ASP has been successfully applied for the treatment of hospital wastewater. This method has demonstrated impressive results, with an average removal efficiency exceeding 90%. Notably, the rate of removal of specific contaminants such as paracetamol, sulfamethoxazole, N-acetylcysteine (NACS), ciprofloxacin and caffeine via ASP ranged from over 95% to greater than 99%. Additionally, atenolol, carbamazepine and clarithromycin were effectively eliminated with an average removal rate exceeding 86% (Qarni et al., 2016).

7.3. Microplastic removal at wastewater treatment plants

MP pollution is a topic of increasing concern to society. Many research studies have reported the existence of MPs in nearly all environmental compartments, such as the air, aquatic environments, soil and sediments, flora and fauna and organisms. The effluent of WWTPs has been identified as a potential source of MPs in marine and freshwater environments. However, recent studies have shown that WWTPs significantly contribute to the reduction of MPs in the environment by removing MPs from influent waters.

MPs such as microbeads in wastewater are typically from hundreds of products and are often used as abrasive scrubbers, including face washes, body washes, cosmetics and cleaning supplies discarded down the drain. MP particles (microbeads) have replaced natural exfoliating materials such as pumice, oatmeal, apricot, and walnut husks (Fendall and Sewell, 2009). Microbeads in wastewater may pass through the treatment plant unfiltered; therefore, millions or billions of them end up in waterways, including marine and freshwater environments.

Several scientific studies have demonstrated the limited capacity of WWTPs to remove microbeads effectively. WWTPs are designed to treat wastewater and break down human waste; however, they have not been designed to filter microbeads. Primary treatment processes in plants can only capture particles up to a size of 5 mm. Although they are effective at removing larger plastic items, they may not be effective at removing most MPs such as microbeads.

An MP with a positive buoyancy value will float and its fate will be determined by the currents (Maximenko et al., 2012; Wardrop et al., 2016). Most MPs are initially buoyant because of the type of polymers commonly used. The source of microbeads and other MPs may help determine their fate. During wastewater treatment, many microbeads may end up in clarifier solids or scum. In the US, these solids are generally incinerated, landfilled or land-applied. Non-biodegradable microbeads remaining in land-applied bio-solids can enter agricultural environments and natural waterways through run-off. However, physical processes (e.g. currents) may concentrate plastics elsewhere to remote open oceans, beaches and estuaries (Wardrop et al., 2016).

WWTPs are recognized as a significant point source of microplastic (MP) pollution. However, they have been demonstrated to effectively remove up to 99% of MPs from wastewater during conventional treatment processes (Talvitie, 2017). However, since large amounts of effluents are continuously discharged into aquatic environments due to population growth and urbanisation, the resulting MP pollution is significant.

There are emerging technologies that could enhance the removal of MPs from wastewater (Table 7.1). Among these are MBR or Membrane Bioreactor with a 99.9% MP removal efficiency; RSF or rapid sand filter with a 97% MP removal efficiency; DAF or dissolved air flotation with a 95% MP removal efficiency; and disc filter with a 40%–98.5% MP removal efficiency (Talvitie, 2017). In large cities, technologies used for wastewater treatment facilities are selected on the basis of environmental/health requirements, statutory requirements and economics (cost efficiency).

Table 7.1. Treatment technologies for the removal of microplastics (MPs)

Treatment technologies	Removal of MPs	Potential release into the environment
Activated sludge system	The activated sludge system is a wastewater treatment technology that includes several necessary steps, such as sedimentation, aeration and return sludge system, to effectively remove contaminants. In this technology, most MPs are removed during sedimentation and are trapped in the sludge. There is an issue with the compaction of sludge in the secondary clarification process. Lightly compacted solids will result in higher turbidity of the supernatant (Genesis Water Tech, 2019), thus affecting the trapping of MPs in the sludge. These suspended MPs could be carried to the final effluent discharge.	MPs are removed after they are trapped in the sludge. If handled improperly, scattered MPs in land environments, such as landfills and agricultural lands, could threaten flora and fauna. Not all MPs are removed by this system. Final effluents containing MPs are released into receiving water bodies and could impact aquatic organisms. The aeration system used by the WWTP may release MPs into the atmosphere (Sol, Laca, Laca, & Diaz, 2021).
Coagulation	By introducing coagulants, suspended MPs are destabilised and aggregated during the coagulation process, which subsequently form large flocs and are removed from the water. The most commonly used types of coagulants are aluminium salts and iron salts. This process is simple and inexpensive. However, coagulant residuals contribute to potential secondary pollution and may induce ecological toxicity (Gao et al., 2022).	MPs are formed into large flocs, together with other contaminants. MPs in coagulant residuals could leak into the environment if not handled appropriately.

Treatment technologies	Removal of MPs	Potential release into the environment
Rapid sand filtration (RSF)	RSF is a physical treatment process that is usually applied in the tertiary treatment stage (Ngo, Pramanik, Shah, & Roychand, 2019). Water passes through an RSF chamber filled with layers of sand and gravel to efficiently remove larger suspended particles. The disadvantage of this technology is the fragmentation of MP particles (Sol, Laca, Laca, & Diaz, 2021).	The filter media needs to be cleaned frequently by backwashing. The rejected water goes back either to the primary treatment or sludge holding tank. MP particles from backwashing in the primary treatment zone may continue to be carried through final effluent discharge and be released into the aquatic environment, whereas MP particles from backwashing in the sludge holding tank may be released into the land environment due to improper sludge handling and disposal.
Reverse osmosis (RO)	RO is a water treatment technology that forces water through a semi-permeable membrane to remove contaminants such as MPs. RO is highly effective in removing contaminants; however it is expensive and wastes significant amount of water.	Retained MP particles in the final effluent continue being released into marine and freshwater environments. The RO system drains water with the rejected contaminants. Upon discharge, it may carry MP particles and be released into the environment through disposal or other applications.

Treatment technologies	Removal of MPs	Potential release into the environment
Membrane bioreactor (MBR)	MBR is a high-strength wastewater treatment because of its bio-degradation and membrane filtration, which allow only extremely small particles of contaminants, such as MPs, to pass through. Its filters have the smallest pore size (around 0.08 µm) compared with that of other filters used in treating wastewater (Ngo, Pramanik, Shah, & Roychand, 2019). Although MBR yields the highest removal efficiency, it has some disadvantages including maintenance issues, high energy demand, high membrane costs and low flux (Sol, Laca, Laca, & Diaz, 2021).	Larger MP particles are removed with sludge. If handled improperly, scattered MPs in land environments, such as landfills and agricultural lands, could threaten flora and fauna. Although studies have reported MP removal efficiencies > 99% by using MBR, some particles smaller that its pore size continue being released into marine and freshwater environments through final effluent discharge.
Air flotation	Air flotation is a wastewater treatment technology that introduces microscopic air bubbles and helps contaminants float on the surface. Floating low-density MPs are removed during grease or surface skimming (Ngo, Pramanik, Shah, & Roychand, 2019). The system's disadvantages include high energy usage and cost.	High-density MPs that settle with the sludge may be incorrectly discarded and released into the land environment. Scraped solids containing MP particles may also be released if improperly handled.

Treatment technologies	Removal of MPs	Potential release into the environment
Electrooxidation (EO)	The EO process is based on the in situ generation of oxidising radicals by direct and indirect electrochemical processes and has been developed to degrade pollutants found in effluents. Kiendrebogo et al. (2021) was first study to be conducted regarding treating MPs in water by anodic oxidation by using polystyrene. This is a promising technology that could degrade MPs into non-toxic molecules such as water and carbon dioxide.	The treatment process requires no chemicals; thus, no additional sludge is produced. The results also showed that there was no increase in liquid by-products formed throughout the process. Moreover, analyses obtained through dynamic light scattering (DLS) suggested that MPs did not degrade into smaller particles but transformed into gaseous products such as CO2 (Kiendrebeogo, Estahbanati, Mostafazadeh, Drogui, & Tyagi, 2021).

The handling and disposal practices of sewage sludge vary by country. Common practices include disposal into landfills and being used as fertilisers after processing in agricultural lands. If mismanaged, MPs trapped in sludge, and other harmful contaminants, could entail a potential threat to fauna and flora. Another practice is the incineration of sludge to generate energy. However, while this could help to further fragment and degrade MPs, it contributes to greenhouse gas (GHG) emissions (Sol, Laca, Laca, & Diaz, 2021).

The characteristics of MPs (abundance, morphology and nature) affect chemical treatment processes by inhibiting the denitrification process. The physical treatment processes are also influenced by MP characteristics; therefore, the dose of chemicals used for removing suspended solids is increased owing to the large surface area of MPs with negative charge (Cluzard et al., 2015). Regarding biological processes, the presence of MPs reduce the abundance of functional microorganisms (Zhang and Chen, 2020).

A compilation of recent studies on MP removal from WWTPs in various countries is shown in Table 7.2. Le et al. (2023) evaluated the MP removal efficiency of four WWTPs in Vietnam. They observed that the removal efficiency of the treatment plants ranged from 68.8%–99.9%. The MP removal efficiency was the highest in the Da Lat WWTP, which is a tertiary treatment plant using trickling filters followed by an aerated lagoon and maturation ponds for BOD and nitrogen removal. The lowest MP removal efficiency was observed in the Binh Hung WWTP, a combined sewer system which uses conventional ASPs as secondary treatment. This study demonstrated that MPs could not be adequately removed by the physical and biological processes used in the above-mentioned four domestic WWTPs. It was suggested that MPs should be placed in the priority pollutant list to be monitored in WWTPs to control their release into the environment and adapt the setting parameters of each step to improve the MP removal efficiency (Le, T.M.T, et al., 2023).

Few studies have been undertaken in the Philippines to assess the MP removal efficiency of various sewage treatment plants (STPs). The World Bank Group investigated five STPs and discovered that STPs adopting CAS systems showed the highest and lowest MP removal efficiency, at 94.40% and 21.57%, respectively (World Bank, 2021). Moreover, most MPs discovered in these STPs were filaments that may have originated from textiles. IGES (2022, 2023) has been conducting a similar study, which includes two phases: Phase I and Phase II. As indicated by their Phase I findings, an STP located within the Marikina River Basin successfully removed 82% of the MPs identified in the influent during the final discharge. During Phase II, eight STPs from various institutions were studied and it was discovered that the DEWATS using anaerobic treatment had the highest MP removal efficiency at 98% (IGES, 2022), whereas the STP that used advanced oxidation had the lowest MP removal efficiency at 55% (IGES, 2022). Variations in findings could be attributed to the MP load in the influent, operational issues, technology used in the tertiary stage and other considerations.

Understanding the performance of MP removal or retention during the main treatment processes of WWTPs is crucial for identifying the fate of MPs in the treatment plants. There is also a need to investigate the fate of MPs which have been removed in the treatment plant that is, MPs that are trapped in the sludge.

Table 7.2. Removal of microplastics in WWTPs

Country	Capacity (m^3/day)	Treatment technology	MP concentration: Influent (particles/m^3)	MP concentration: Effluent (particles/m^3)	Average removal efficiency	Reference
Australia	48,000	RO	Not specified	210	> 90.0%	(Ziajahromi, Neale, Rintoul, & Leusch, 2017)
China	50,000	ASP	280	130	53.6%	(Lv, et al., 2019)
	70,000	MBR	280	50	82.1%	
	1,000,000	Advanced activated sludge (A_2O) process + ultra-filtration and ozonation	12,000	590	95.2%	(Yang, et al., 2019)
Finland	10,000	ASP	57,600	1,000	98.3%	(Lares, Ncibi, Sillanpää, & Sillanpää, 2018)
	3,000,000	MBR	57,600	400	99.4%	
	Not specified	Dissolved air flotation (DAF)	2,000	100	95.0%	(Talvitie, Mikola, Koistinen, & Setälä, 2017)
	310,000	Disc filter (DF)	2,000	30	98.5%	
France	240,000	ASP	290,000	32,000	94.0%	(Dris, et al., 2015)
Morocco	30,000	Infiltration-percolation	519,000	86,000	81.0%	Hajji, S., Ben-Haddad, M., Abelouah, MR., De-la-Torre, GE., Alla, AA. (2023)

Country	Capacity (m^3/day)	Treatment technology	MP concentration		Average removal efficiency	Reference
			Influent (particles/ m^3)	Effluent (particles/ m^3)		
Philippines	Not specified	ASP	4,370	1,100	74.8%	(World Bank, 2021) Ongoing publication
	Not specified	ASP	2,500	140	94.4%	
	10,400	SBR	1,000	200	80.0%	
	15,400	Activated sludge system	510	400	21.6%	
	567	SBR	3,860	760	80.3%	
	100,000	SBR	1,750	315	82.0%	(IGES, 2022) Unpublished
	40	Anaerobic treatment	4,930	790	97.5%	(IGES, 2023) Unpublished
	10	Anaerobic treatment	2,920	828	71.6%	
	50	Anaerobic treatment	4,130	989	76.00%	
	60	Anaerobic treatment	1,330	430	65.13%	
	10,000	Conventional activated sludge system	3,900	235	92.66%	
	500	Advanced oxidation	475	213	55.15%	
	200	Conventional activated sludge system	1,670	402	75.82%	
	110	Anaerobic treatment	475	143	67.36%	

Country	Capacity (m^3/day)	Treatment technology	MP concentration		Average removal efficiency	Reference
			Influent (particles/ m^3)	Effluent (particles/ m^3)		
Thailand	200,000	SBR	12,200	2,000	83.6%	(Hongprasith, et al., 2020)
UK	260,954	Aerobic treatment	15,700	250	73.5%	(Murphy, Ewins, Carbonnier, & Quinn, 2016)
US	2,500,000	Activated sludge system	133,000	5,900	98.5%	(Michielssen, Michielssen, Ni, & Duhaime, 2016)
	Not specified	Electro-coagulation	Not specified	1,000	96.5%	(Elkhatib, Oyanedel-Craver, & Carissimi, 2021)
Vietnam	17,000	ASP	24,300	810	96.7%	(Le, et al., 2023)
	7,500	Aerobic treatment	125,250	140	99.9%	

Chapter 8
Planning guide for municipal wastewater projects

8.1. General considerations

The objective of this chapter is to outline the most essential planning steps for designing a municipal and sewer-based decentralised wastewater infrastructure and provide the further associated detailed information by referring to existing guidebooks and manuals.

8.2. Defining the service area

Defining the service areas and project boundaries is one of the initial steps in planning a wastewater project. It is typically carried out during the project development phase. This process aims to clearly delineate the specific area or community that will be served by the project and the geographical project boundaries.

Such boundaries are usually defined by relevant project-specific aspects such as:

- A specific target population or area to be served;
- Administrative boundary;
- Implementation funds available.

If the budget serves as the guiding aspect, the geographical boundaries and population targets are determined after conducting a comprehensive assessment of the local conditions and specific investment requirements, typically through a feasibility study. This assessment considers the financial limitations and evaluates the feasibility of the project within the given constraints. It provides crucial information for defining the project's geographical boundaries and setting realistic population targets to be served based on the available funds and local context.

Depending on the scale or nature of the project, the project area may need to be sub-divided into individual clusters, each serving a specific sub-area with its unique community and urban activities. Each cluster would encompass a collection system, sewer network and WWTP with effluent discharge. The decision to target sub-areas and establish individual clusters is typically considered in certain conditions; these conditions include the following:

- When the number of pumping stations shall be minimised or only a gravity-based sewer system shall be applied;
- When the urban areas are scattered and not connected to each other;
- When only small land areas are available for the installation of the WWTP;
- When reuse of the effluent of the decentralised wastewater unit is intended.

If pumping stations are eliminated from the DWM system, each cluster can be defined as a hydraulic catchment area served by an individual gravity-based sewer network with treatment plant.

In the context of a specific project implemented in a secondary city along the Mekong River, Figure 8.1 and Figure 8.2 visualise the defined project boundaries. In this project, the hydraulic catchment areas were identified through the utilisation of digital contour maps, which enabled the investigation of the existing stormwater drainage systems and transect walks.

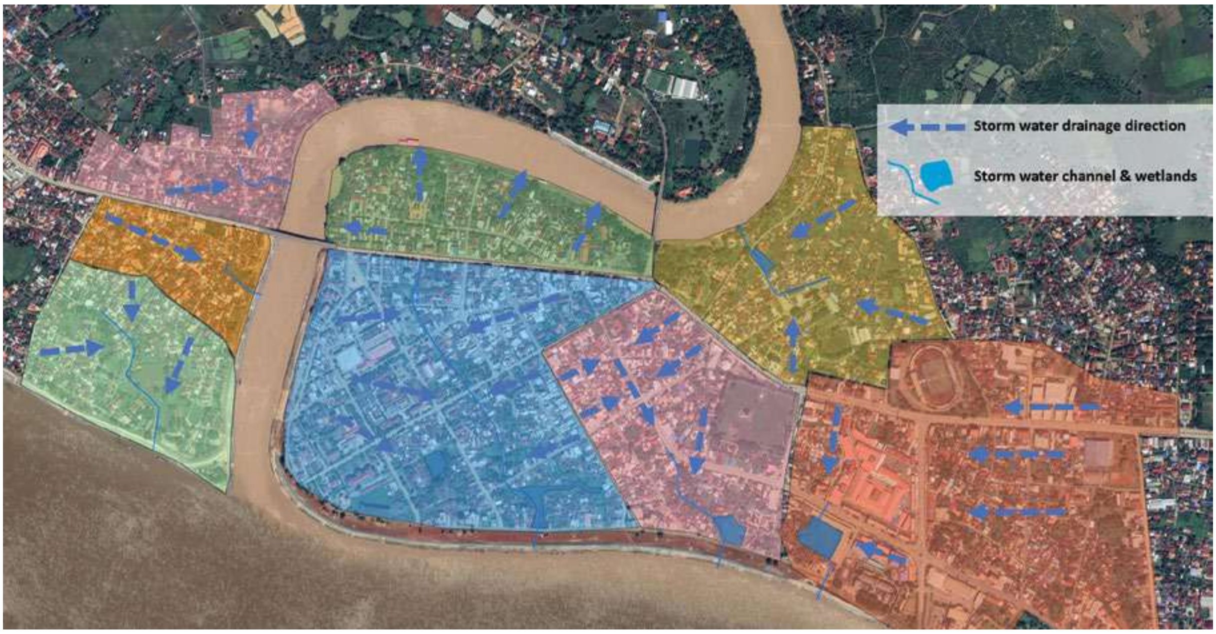


Figure 8.1. Mapping the entire project area (coloured areas) and identification of hydraulic catchment areas.
(Source: UrbanWaters Consulting GmbH)

Upon analysing the local conditions, it was determined that the seven clusters were suitable for implementing purely gravity-based sewer networks with decentralised wastewater treatment. However, for the remaining urban areas located between these seven clusters, it was found necessary to involve lifting stations equipped with pumps to provide wastewater services.

Figure 8.2. Mapping of the selected clusters (white line) that can be severed by a gravity sewer system and possible locations for the installation of WWTPs with the effluent discharge option (yellow points) into stormwater channels and/or wetlands (blue). *(Source: UrbanWaters Consulting GmbH)*

The local conditions were analysed based on the following:

- Land availability for the construction of a WWTP;
- Impact of the WWTP infrastructure on the sanitary condition of the community;
- Feasibility for gravity-based sewer systems;
- Available project budget.

Additionally, the following assumptions were made for these initial analyses:

- Average sewer pipe slope was 2%;
- Minimum soil cover of sewer pipe was 50 cm;
- Final gravity outlet level of the treatment plant into the public stormwater channel was at least 20 cm above the average maximum water level in the stormwater line during the rainy season;

- Specific area requirements were met for different treatment options such as 0.5 m^3/capita for ABR, 1.5–2.5 m^2/capita for constructed wetlands and 0.15–0.3 m^2/capita for package plants.

8.3. Site selection for treatment plants and effluent discharge/reuse

Identifying suitable public land for wastewater treatment installations is a challenging and often resource-intensive task, especially for decentralised wastewater projects. This challenge is particularly prominent in urban areas where treatment plants need to be located in or near residential areas. Usually, the most common questions that occur and which need to be resolved include the following:

- Is an updated cadastral map available for demarcating the boundaries of public and private land?
- Is an updated land use plan available for the current and planned land use allocations of open areas?
- Are the underground conditions and distance of the intended WWTP to buildings suitable for its construction?
- Can the treatment plant and the overflow point for the discharge of the effluent be located at a level suitable to operate a gravity-based system or is a lifting pump before or after the treatment plant required?
- How close is the next suitable discharge point and what are the potential risks involved?
- Can the identified location be affected by high groundwater or flooding events? If so, what are the risk mitigation measures?
- What will be the social and environmental impact and potential hazards of constructing a WWTP at this location?

To answer these questions, which will enable determining the overall feasibility of the site or even the entire project, the following actions are required:

- Using Google Earth maps or other platforms to analyse contour, land use and cadastral maps.
- Conducting community consultation meetings and transect walks with the local government and community representatives.
- Conducting land surveying to measure the construction areas and/or to obtain an orientation of the hydraulic levels of the canals and pipes.

- Conducting a geotechnical survey.
- Carrying out a formal land acquisition process of the identified and most suitable public or private land.

During the site selection process for decentralised WWTPs, project teams around the world have often been faced with the need to find creative solutions. These solutions include locating treatment plants under roads, parking lots, playgrounds, recreational areas and even within existing wetlands. It is rare to find an ideal location, especially in unplanned or densely populated urban areas. Particularly for gravity-based systems, the construction site is typically chosen at the lowest point in the hydraulic catchment area, where stormwater also flows naturally and where wetlands and swamps are often found. These areas may also be prone to flooding. In such locations, the project team must carefully consider the most appropriate treatment technology and construction method and evaluate the feasibility of incorporating a lift pump to reduce complexity.

Selection of the point of discharge or reuse of the treated effluent is the next step; the following options and comments need to be considered in this regard.

Table 8.1. Criteria for selecting the point of discharge
(Source: Authors)

Discharge	To be considered
Bigger rivers	Avoiding direct public access to the point (pipe) of discharge. Considering the prevention of backflow and animals entering the outlet pipe.
Smaller rivers or water courses, natural wetlands and open stormwater channels (natural and public)	It is important to consider the possibility of treatment failure or design limitations of the system, especially if high effluent quality is required. In such cases, it is advisable to install a constructed wetland as an additional treatment measure. Constructed wetlands can provide further treatment and help mitigate potential risks associated with direct human exposure to the effluent discharge point. By incorporating a constructed wetland into the wastewater treatment system, the overall treatment performance can be improved, ensuring a higher level of water quality and reducing potential health hazards.
Closed public stormwater drains	Maintaining updated as-built documents that indicate the exact location the outlet pipe.

Discharge	To be considered
Underground infiltration	The ability to infiltrate wastewater underground is subject to limitations related to infiltration capacity and the volume of wastewater to be infiltrated. In urban areas, it is recommended to consider flow rates of less than 10 m^3/d for infiltration purposes. In order to avoid potential groundwater pollution, it is recommended to avoid the use of soak pits and instead to opt for shallow infiltration areas with a depth of 0.5–1.0 m. It is important to note that specific requirements may exist in certain countries, such as the need for hydraulic proof or the establishment of maximum allowable water infiltration rates per square meter per day (l/m^2*d). Compliance with these requirements will ensure the appropriate functioning and environmental safety of the infiltration system.
Reuse	See Chapter 6

8.4. Defining baseline data

The design parameters mentioned below are crucial for designing wastewater infrastructures. In this Guidebook, only a brief overview shall be provided with references to more detailed documents that specifically address each parameter in-depth. This approach ensures that readers can access comprehensive information regarding each design parameter, while maintaining the focus and brevity of the Guidebook.

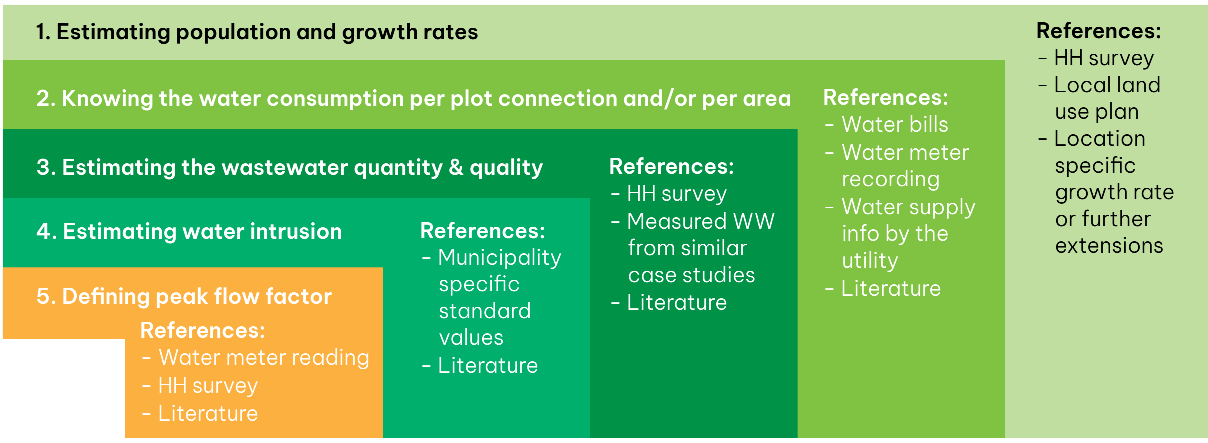


Figure 8.3. References for estimating different design parameters of wastewater infrastructure *(Source: Authors)*

Estimation of the population and growth rate

Defining the population to be served by the wastewater infrastructure is a crucial step in determining its capacity and any necessary capacity reserves. This involves investigating the current and projected future population, taking into account local census data, household surveys and consultation with urban planners and community representatives. It is important to consider not only the residential population, but also the population of facilities such as schools, office buildings, marketplaces and commercial areas.

For future projects, it is common to project a city-relevant population growth rate over a period of 20 - to 40 -year period. However, in decentralised projects with smaller service areas, it is essential to carefully analyse the potential urban development specific to the project area. The population in these areas may experience disproportionate increases or declines compared to the overall city population growth rate. Additionally, considering project periods longer than 20 years in decentralised approaches may not be practical due to the rapid urban development commonly observed in many ASEAN cities.

Water consumption

It is highly advisable to conduct an investigation and map the water consumption patterns within the project areas and the plots that will be served by the planned wastewater infrastructure. This applies not only to existing urban areas but also to greenfield projects. Analysing the specific water consumption of similar urban areas, institutions or human activities can provide valuable insights.

In contrast to data from literature, which can serve as references but remains secondary information, household surveys, water bill readings and consultation with water suppliers provide real and primary data. Such data is important, because in smaller service areas, the fluctuation in water consumption is often significant. The water consumption and its relation to the wastewater return factor have a substantial impact on the design, size, cost and treatment performance of the wastewater infrastructure.

Wastewater generation (quantity) – secondary data

Table 8.2. Communal water consumption and wastewater production per country and community type

Location	Water consumption [L/cap*d]	Wastewater Production [L/cap*d]	Description	References
Global/ General	90–140	–	Rural settlement (<5,000 inhab.); HH connection; no severe water shortage	(IWA, 2007)
	100–160	–	Village (5,000–10,000 inhab.); HH connection; no severe water shortage	(IWA, 2007)
	110–180	–	Small town (10,000–50,000 inhab.); household (HH) connection; no severe water shortage	(IWA, 2007)
	120–220	–	Average town (50,000 – 250,000 inhab.); HH connection; no severe water shortage	(IWA, 2007)
Indonesia	–	80	Average of 9 low income–upper/medium income communities in Java	(Reynaud, 2014)
	135		Jakarta; Residential (HH + institutions)	(UNEP, 2000)
	–	88	1 Low-income community in Java	(Reynaud, 2014)
	–	62–88	5 Medium income communities in Java	(Reynaud, 2014)
	–	81–91	3 upper/medium income community in Java	(Reynaud, 2014)
Philippines	202		Manila; Residential (HH + institutions)	(UNEP, 2000)
Thailand	–	204–212	Min: pour flush; Max: full flush	(AIT, 2013)
	–	74	Estimated through water usage data for toilet, bathroom, laundry and kitchen	(Tsuzuki et al., 2010)
	265	–	Bangkok; Residential (HH + institutions)	(UNEP, 2000)

Location	Water consumption [L/cap*d]	Wastewater Production [L/cap*d]	Description	References
Vietnam	104–136	–	Urban (Hanoi metropolitan area)	(Montangero, 2007)
	–	125	Mega-cities (3,000,000)	(UNEP, 2000)
	–	69	Large cities (1,000,000 –3,000,000)	(UNEP, 2000)
	–	39	Cities (<1,000,000)	(UNEP, 2000)
	180	150	Water supply demand based for utilities	(UNEP, 2000)

Table 8.2. serves as an attempt to outline available data for different ASEAN countries and community groups. Its purpose is to demonstrate the diversity of data sources and highlight the limited information values of the data. The table underscores the importance of conducting project-specific investigations to gather primary data.

Very helpful secondary data on water consumption and wastewater generation, especially for institutions and commercial buildings, is provided by the classical wastewater book → *Wastewater Engineering: Treatment and Resource Recovery, edited by Metcalf & Eddy (2003) or Wastewater Characteristics, Treatment and Disposal, edited by Marcos von Sperling (IWA, 2007) and other relevant publications.*

Wastewater generation (quantity) – primary data

The wastewater generation data based on primary data is the product of the wastewater return factor multiplied with the primary water consumption data, as shown below:

The amount of daily wastewater generated = the daily water consumption x return factor

Metcalf & Eddy *(D EDDY,2003. Wastewater Engineering Treatment, Disposal, Reuse)* recommend a return factor between 0.65–0.85; the EPA *(2. Wastewater Treatment/Disposal for Small Communities. EPA/625/R-92/005, Washington DC.)* suggested a return factor of 0.75. Based on their practical experience, the authors of this Guidebook recommend a return factor of 0.8, which is appropriate for most decentralised wastewater applications. In cases where water is used extensively for gardening or other purposes and where this used water is not discharged to the sewer system, a lower return factor should be selected.

Wastewater characteristics (quality)

Table 8.3. Per capita pollutant and nutrient loads depending on region, country and income group.

Location	COD [g/cap*d]	BOD_5 [g/cap*d]	TSS [g/cap*d]	TKN [g/cap*d]	TP [g/cap*d]	References
General	130	60	–	14	2.4	(Henze and Comeau, 2008)
	70–150	30–60	40–80	8–12	1–3	(WHO and UNEP, 1997)
Developing countries	80–120	40–60	35–70	6–10	0.7–2.5	(IWA, 2007)
	–	20–40	–	5.6	0.8	(Reynaud, 2014)
Indonesia	56–95	20–40	–	5.5–6.8	0.5–1.0	(Reynaud, 2014)
Thailand	81	46.4	–	11.5	1.9	(Tsuzuki *et al.*, 2013
	–	49	–	15.6	6.3	(Tsuzuki *et al.*, 2007)

Determination of the wastewater concentration (c) is the product of pollution load (PL) multiplied with the wastewater flow rate (q).

Example:

Wastewater flow rate: q = 150 m^3/d *1,000 = 150,000 L/d

Number of people = 1,364 (based 110 L/capita/d)

Specific COD pollution load (L_{COD}): 100 g_{COD} /cap*d (assumed based on Table 8.3.)

Daily COD load (PL) = L_{COD} x Number of people = 100 g_{COD} /cap*d x 1,364 capita = 136,364 g_{COD}/d x 1,000 = 136,363,636 mg_{COD}/d

Wastewater concentration: c = PL / q = 136,363,636 mg_{COD}/d / 150,000 L/d = 909 mg_{COD}/L

Table 8.4 presents an overview of common and average wastewater concentrations. However, it should be noted that the literature data ranges are often broad and may not be suitable for accurately defining the design parameters of a WWTP. It is recommended to calculate the average and peak parameters based on the specific project and available primary data. This approach ensures that the design of the WWTP aligns with the actual characteristics of the wastewater being treated, leading to more accurate and effective treatment processes.

Table 8.4. Comparison of different municipal wastewater streams

Parameter	Municipal wastewater	Municipal greywater	Municipal FS
TS [mg/l]	300–1,200	20–200	5,000–120,000
VS [mg/l]	100–300	5–60	3,000–80,000
COD [mg/l]	600–2,000	100–300	5,000–100,000
BOD [mg/l]	300–1,000	50–150	2,000–30,000
COD/BOD	1.9–2.1	1.9–2.1	3–5
NH_4-N [mg/l]	10–50	0–5	600–1,500
Phosphors [mg/l]	5–20	2–8	100–500
Nitrogen [mg/l]	20–90	10–30	500–2,000
Solid waste [g/l]	<0.01		10–100
E.coli [MPN/100 ml]	106–1,012	104–106	108–1,010

(Source: Authors)

In the example above, the 'number of persons' was used as the unit of population. This approach is appropriate when designing a wastewater project which only serves a residential area with no commercial or institutional activity. However, for non-residential activities such as schools, offices, hotels, hospitals, restaurants and others, it is recommended that the term 'person' or 'population equivalent' (PE) be used to determine the load and wastewater generation.

PE is a parameter used to characterize non-residential wastewater. It compares the pollution potential of an industry, measured in terms of biodegradable organic matter, with the equivalent load produced by a population or a specific number of people.

In the worldwide literature, a commonly cited value for PE ranges from 40–60 gm of BOD per person per day. Many countries have adopted this value for design purposes. However, alternative values are also used. For example, in Europe, one PE is equivalent to 60 grams of BOD per person per day and 200 litres of wastewater per day. In the US, the measure of 80 grams of BOD per person per day is commonly used.

In the case of a community served by a decentralised wastewater infrastructure that includes both residential and non-residential areas, it is recommended that the average daily load and wastewater generation be calculated separately for each area. Additionally, it may be beneficial to further break down the calculations for each individual non-residential lot.

Very helpful data for 'Population Equivalent' for various applications can be found in → *Wastewater Engineering: Treatment and Resource Recovery by Metcalf & Eddy (2003) or Wastewater Characteristics, Treatment and Disposal from Marcos von Sperling IWA 2007 and other standard publications.*

Peak flow

Hydraulic peak flow is another critical design factor that requires the attention of designers and permitting authorities. Different treatment plants have different capacities to handle peak flows, which can be significantly higher than the average design flow. Figure 8.4 provides a general understanding of the different flow patterns observed in decentralised wastewater projects.

In Figure 8.4, the orange line represents the wastewater flow in a communal sanitation centre, while the green and blue lines represent communal wastewater projects with a sewer network. The main difference between the GREEN and BLUE projects, aside from their location and type of community, is the length of the sewer pipes. The GREEN projects have a longer sewer network, resulting in a more equalized wastewater flow pattern.

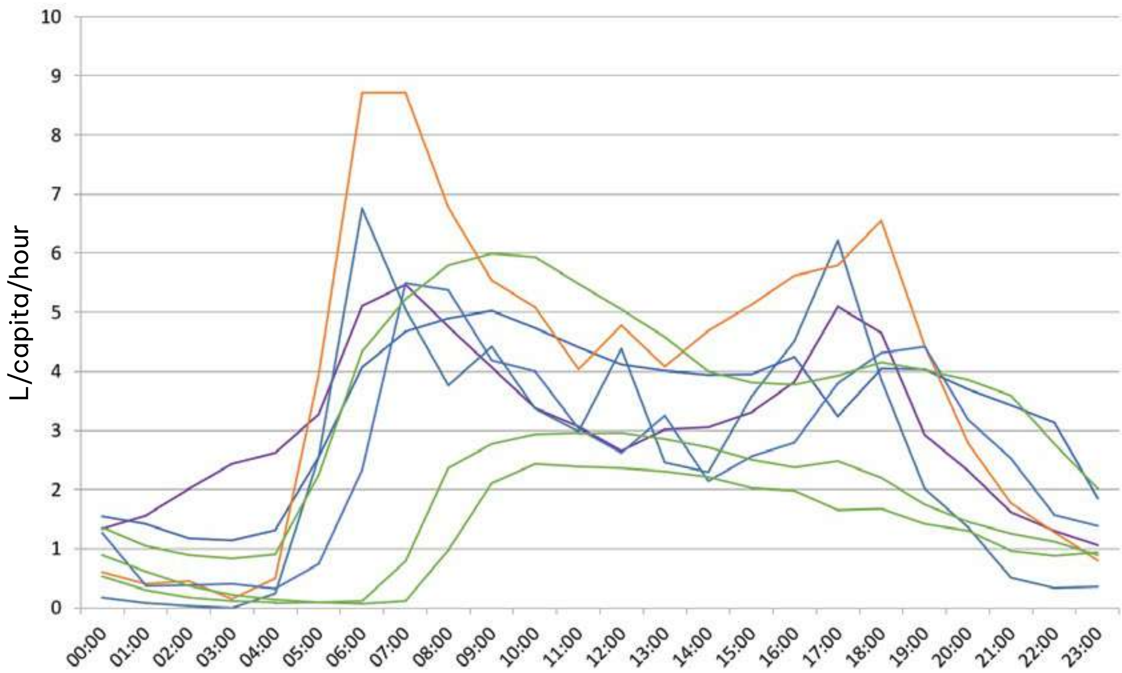


Figure 8.4. Wastewater flow patterns measured at different decentralised wastewater projects *(Source: Renyaud 2014 and UrbanWaters Consulting GmbH)*

It is observed that as the service area size, population and sewer pipe length increases, the peak flows in wastewater systems become more equalized; smaller service areas typically containing decentralised wastewater systems are more sensitive towards peak flows. While constructed wetlands have a high technical capacity to buffer peak flow events, treatment plants such as ABRs, activated sludge bed systems and RDCs have a smaller capacity and tolerance in this regard. Hence, these hydraulic-sensitive systems need to be designed to accommodate a reasonable peak flow. It is recommended to set the design flow at 80% of the maximum hourly peak flow for such hydraulic-sensitive systems. Hence, such treatment plants should be designed and selected based on their hourly treatment capacity [m^3/ hour] and not only on the daily capacity [m^3/ day].

For sewer design calculations in Brazil (LEEDS, 2001), based on experiences outlined in the Guidebook, a daily peak flow factor of 1.8 is recommended for simplified sewer projects. For decentralised WWTPs serving up to 2,000 people, the authors of this Guidebook suggest a factor of 1.8–2.4 for residential areas and for non-residential activities, a factor of 2.5–3.0 is recommended. Alternatively, an on-site investigation can be conducted to determine specific peak flow factors for individual buildings if necessary.

Mathematically, the peak flow factor can be represented as:

Daily Peak Flow Factor = Expected Peak Flow / Average Daily Wastewater Flow

For example, if the average daily wastewater flow is 1,000 cubic meters per day and the expected peak flow is estimated to be 2,500 cubic meters per day, the daily peak flow factor would be:

Daily Peak Flow Factor = 2,500 / 1,000 = 2.5

This means that the peak flow is 2.5 times higher than the average daily flow and the wastewater treatment system needs to be designed and operated to handle this maximum flow during peak periods.

8.5. Climate resilient design

In the ASEAN context, climate changes can impact DWM at city and project (plot) level as follows:

Table 8.5. Potential impacts to DWM infrastructure at city and project level

Changes	Impact	
	City level	Project level
Heavy rain events	Flooding due to: • water level rising in rivers; • limited stormwater drainage capacity.	a) Stormwater intrusion and/or backflow into the wastewater system, creating: • Risk of washout of FS and polluted wastewater into the public area; • Damaging filter systems and engines; • Electrical issues; • Washing out of bio-sludge, resulting in the biological system becoming non-functioning; • A block, resulting in no wastewater being discharged into the system. b) Flooding or rising groundwater table may damage the foundation of tanks or bedding (position) of sewer pipes and manhole chambers due settling and buoyancy.
Short term or long-term water shortage	Reduced water supply and wastewater generation	Reduced water in the sewer system may lead to solid accumulation and increase maintenance demand.

Assessing the location situation and designing a wastewater system that prevents or minimises climate change impacts (as listed in Table 8.4) by considering all possible scenarios falls under the purview of project management and engineering tasks. It is also important to design for short term (few hours) and long-terms events (couple of days or weeks), for example, in case of flooding. Common technical options that can be employed into the construction design of the WWTP are listed below:

- Suitable pipe bedding classes to prevent settling and floating of gravity-based sewer (Chapter 4.2.5);
- Application of pressure pipes in high groundwater or flooding area;
- Raising of the entire wastewater system (pipes, manholes, treatment plant);
- Building retaining walls to protect the surface water from entering the system;
- Flap valve at the outlet which closes once the outside water attempts to enter the system;
- Overflow or inflow facilities (out/inlet) for controlling the water flows.


Planted Gravel Filter (PGF)
Biological treatment of the effluent


REACTOR
SEPARATION
DISINFECTION
EFFLUEN

Chapter 9
Planning guide for the establishment of city-wide sanitation masterplan and regulation of DWM at municipality level

Starting point:	**A municipality sees a necessity or has been directed by central government to develop and implement a city-wide wastewater or sanitation strategy or master plan.**
Objective:	To outline the essential steps for planning and formulating the necessary enabling community framework for implementing a DWM project.
Main target group:	Municipal urban planners, public water and sanitation/ wastewater service providers, government bodies responsible for environmental compliance control, and government bodies responsible for public tariff setting.

9.1. Setting city-wide sanitation masterplan

Leading questions

- *What are the short-, medium- and long-term goals, milestones and interventions of the proposed DWM project?*
- *What are the priority or stress areas?*
- *What types of intervention are applied where in the DWM project?*
- *What are the financial requirements for implementing the DWM project?*

9.1.1. A Vision for the City

Designing a sanitation masterplan is a crucial step in the planning of DWM systems due to the several reasons listed below:

(i) Understanding existing and planned levels and coverage of sanitation services, identifying gaps and establishing priorities.

(ii) Aligning individual implementation projects with the masterplan, ensuring their goals and priorities are in line with other relevant sectors such as urban planning, water resources management, stormwater management, solid waste management and water supply.

(iii) Understanding and applying the existing and planned institutional, regulatory and financial frameworks.

(iv) Considering city-specific technical and social project requirements, including standards for technical designs and planning processes.

Among the various approaches to sanitation planning, City-wide Inclusive Sanitation (CWIS) planning is a comprehensive approach that aims to develop and implement sanitation services that are accessible and equitable for all members of a city's population.

A sanitation plan is developed to align national and state-level sanitation targets, such as improving access to sanitation facilities or reducing open defecation. It also serves as a basis for coordination among different government agencies and external partners, including NGOs and private sector entities involved in the city. Collaboration among these stakeholders is crucial in DWM, as ownership and maintenance responsibilities are often distributed among different groups. Therefore, the sanitation masterplan acts as both a visionary document and a mandate for collaborative action in wastewater management.

9.1.2. Preparing a City-wide Inclusive Sanitation (CWIS) Plan

The CWIS planning follows the following fundamental steps:

- Situation Assessment: This includes baseline data collection and identification of existing gaps in service delivery through assessment of both infrastructure and the enabling environment.
- Capacity Assessment: This includes assessing the existing and required public institutional and financial capacity to close the identified service gaps.
- Stakeholder Engagement: This includes a consultative process with all stakeholders as a basis for visioning and prioritizing interventions.

- Setting Goals and Objectives: Based on the situational analysis and stakeholder input, goals and objectives are set for the CWIS plan.
- Phasing and Identifying Sanitation Solutions: The selection of appropriate sanitation solutions based on the set goals and objectives, including the use of centralised and/or decentralised systems.
- Monitoring and Evaluation: Appropriate monitoring systems and impact evaluation methods are also defined while the implementation plan is conceptualised.

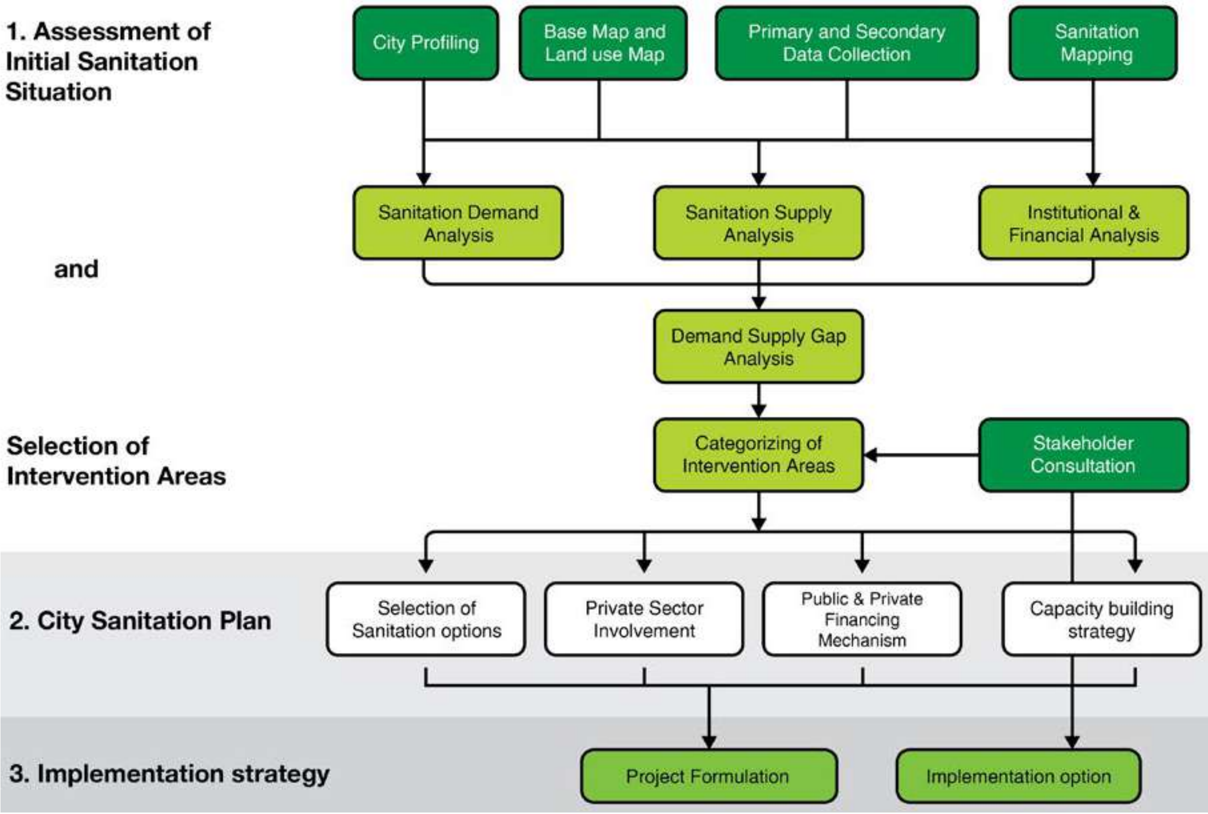


Figure 9.1. Process flow chart for developing a city-wide sanitation plan
(Source: CDD Society)

A well-prepared CWIS plan should ensure adequate capacity building for relevant institutions, promote safe and reliable solutions through the application of diverse technical options, prioritise equity and affordability in service delivery and strive for financial and environmental sustainability of the implemented solutions (ADB, 2021).

DWM has been recognized as a priority in several ASEAN countries to meet sanitation targets. Some examples include:

(i) The Philippines: The Philippines has identified DWM as a priority in its National Sanitation Roadmap. The roadmap emphasizes the need for decentralised wastewater treatment systems to address the lack of access to centralised sewage systems in rural and peri-urban areas.

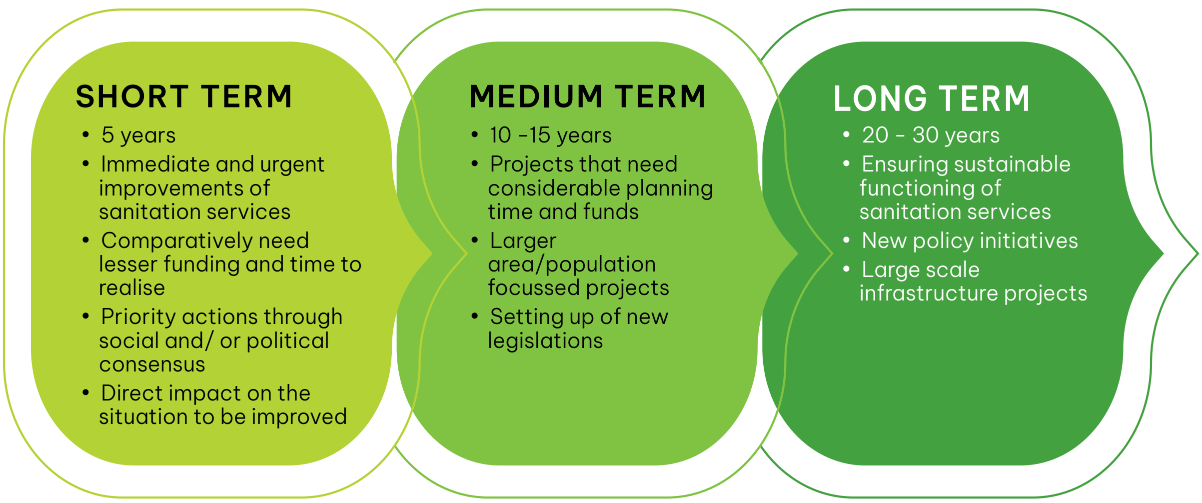
(ii) Thailand: Thailand has also recognised the importance of DWM and has developed a policy framework to promote decentralised wastewater management in urban and rural areas. The policy aims to incentivise private and public sector investments in decentralised systems.

(iii) Indonesia: Indonesia set a target of achieving universal access to sanitation by 2019; it has acknowledged the role of DWM in reaching this goal. The government has initiated several programmes to promote DWM, particularly in rural areas.

(iv) Vietnam: Vietnam considers DWM as a vital strategy to improve sanitation access in rural and peri-urban areas. The government has launched various programmes to encourage the adoption of DWM, including providing financial incentives for households to install their own systems.

Given the existing infrastructure gaps and weaknesses in the enabling environment for water and sanitation management in the ASEAN regional context, CWIS plans prioritise decentralised wastewater treatment systems.

9.1.3.Prioritising Actions



Prioritising actions is a critical step in sanitation planning. As depicted in the figure above, during the preparation of the sanitation plan, actions are categorized into short-, medium- and long-term interventions. FSM and DWM systems often require less time and funding as compared to that for a centralised approach. Therefore, they can be utilised to address service delivery gaps in priority areas of the city within a short or medium-term timeframe. However, this does not imply that they are not a potential long-term solution. With a strengthened enabling environment for monitoring and management, this system can also fulfil the long-term targets set within the framework of CWIS.

9.1.4. Stakeholder Engagement

Stakeholder engagement plays a crucial role in the preparation of a CWIS plan. The stakeholder participation matrix depicted in Figure 9.2. serves as a tool to assess the level of involvement and engagement of various stakeholders in a project or decision-making process. It categorises stakeholder participation into five forms: informing, consulting, collaborating, deciding and controlling. The 'inform' level entails providing stakeholders with project- or decision-related information. 'Consult' involves seeking feedback and input from stakeholders. 'Collaborate' entails working closely with stakeholders to develop solutions. 'Decide' grants stakeholders a voice in the final decision. Lastly, 'control' empowers stakeholders to implement and manage the decision or project.

Diferent forms of Involvement

	INFORM	CONSULT	COLLABORATE	DECIDE	CONTROL
Public's role	Provide Informa-tion and get Informed	Influence the decision	Take over responsibility	Influence Decision making	Control the implemen-tation Process
Process objectives	Improve awareness and under-standing	Input before decision, two way dialogue	Broad Ownership	Broad Ownership	Make use of transparency
Some tools & technique	Hearing briefings worshops	Public meetings, Focus groups, Workshops, formal hearings	Joint manage-ment commitee	Steering boards, Committes	Monitoring and evaluation of work-shops

Figure 9.2. Stakeholder participation matrix
(Source: Walther, D. et al (2016))

Categorising stakeholders in this manner can assist in determining the appropriate channels and frequency of engagement with each stakeholder. Manila Water's stakeholder engagement processes, as outlined in their annual integrated reports, provide a concrete example of systematic stakeholder engagement. In the context of DWM systems, stakeholder engagement holds significant importance since the infrastructure must be constructed and maintained in close proximity to communities, often with their support in management.

9.1.5. Recommended tools for sanitation planning

CWIS Planning tools World bank–Available at https://www.worldbank.org/en/topic/sanitation/brief/citywide-inclusive-sanitation#3

Walther, D. et al. (2016); Preparing City Sanitation Plan - SNUSP II - Trainer's Manual; Available at https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/2706

SANIKit Available at https://www.cseindia.org/sanikit/index.html

A CWIS plan is a great starting point towards improving the sanitation service delivery in any city. The CWIS plan highlights the existing gaps and challenges for establishing and regulating decentralised wastewater treatment systems at a municipality level. Among these, the regulatory, institutional, financial and capacity-related aspects—often brought under an overarching term 'enabling environment' are crucial in the success and sustainability of the DWM project. The rest of this chapter attempts to provide a roadmap for establishing such an enabling environment for implementing and operating DWM projects. It is to be noted that a CWIS plan also highlights several other aspects such as areas for sanitation service delivery through centralised wastewater management or FSM as well as systemic initiatives required for ensuring inclusion and accessibility to sanitation services. However, the specific focus of this chapter is on decentralised wastewater treatment. The chapter guides through the leading questions that need to be answered by the municipal officials at the time of planning decentralised wastewater treatment systems.

Following the logic provided in Chapter 3, decentralised projects can be assessed based on asset ownership and operations.

Table 9.1. Ownership model types for DWM systems

Q1: What type of ownership model fits your project?	Reference
A: Privately owned and managed on-site DWM project	This ideally consists of an on-site decentralised wastewater treatment facility owned and operated by the landowner (probably) with an off-site system for sludge management (FSM). Refer to Section 3.2 for a detailed description of these systems.
B: Publicly owned and managed DWM project	This ideally consists of an off-site decentralised wastewater treatment facility connecting to a smaller network owned, operated and managed by the public utility provider. Refer to Section 3.3 for a detailed description of these systems.

The following section details the checklist of aspects that need to be well-defined while setting up the enabling environment for DWM projects.

9.2. Enabling regulatory and institutional framework at the city level

The following section aims to present basic questions that arise during the implementation of a DWM project. These questions are intended to be addressed by a sanitation masterplan and the required enabling framework. Hence, the objective of this section is not to provide a detailed guide on how to develop a sanitation masterplan, as that information can be found in references.

The outlined questions serve as a means to evaluate and enhance the existing enabling framework at the city level. It is important to note that the sanitation and wastewater sectors in ASEAN countries vary significantly in terms of development and the specific system in place may provide answers to the questions presented here.

Additionally, it is important to acknowledge the importance to differentiate between the following:

- Privately owned and managed DWM project (on-site sanitation), and
- Publicly owned and managed DWM project (off-site sewer-based sanitation).

9.3. The regulatory and institutional framework at the city level

A: Privately owned and managed (on-site DWM project)	Reference/Note
For building permit: Are all technologies permissible or do any restrictions apply? Are certain technologies required to be certified or registered?	Certification systems are described in Section 3.2.
If so, which institute or department is in charge of certification and/or registration?	For instance, the Pollution Control Department (PCD) in Thailand and the Environmental Management Bureau (EMB) in the Philippines are examples of such systems.
Which government agency or department is responsible for issuing building permits?	The department responsible for these tasks can vary by city. For instance, in Manila, the Department of Engineering and Public Works (DEPW) is in charge, while in Vietnam, the Construction Permit Office at the provincial or city level generally assumes this responsibility.
What are the regulatory standards for effluent from on-site systems?	Effluent standards are typically established at a national or regional level. The adoption of international standards may also be an option.
What standard information is required for a building permit application?	The required information can vary by location. For DWM projects, typical information includes the site plan, technical design, capacity, effluent discharge details, construction plan and in certain cases, an environmental impact assessment.
Is there a need to consult any other government department before issuing the building permit? (This could be due to geographical limitations for on-site systems or special technical requirements.)	

A: Privately owned and managed (on-site DWM project)	Reference/Note
Is an Environmental and Social Impact Assessment (ESIA) required for the on-site domestic wastewater treatment system?	For a brief overview regarding EIA requirements in the Southeast Asian countries, please see the following document: Environmental Impact Assessment: Regulations and Strategic Environmental Assessment Requirements - Practices and Lessons Learned in East and Southeast Asia (UNEP, 2004).
Is there a system in place for monitoring and enforcing operational compliance?	The compliance monitoring system implemented by San Fernando City, the Philippines, in 2010 provides a good template for the regulatory system for DWM projects. Since DWM projects are implemented in diverse contexts, the system calls for larger-scale monitoring, adaptable regulations and benchmarks and positive measures for achieving compliances. This includes building capacities and authority for city engineers to review and approve DWM projects so that the national agency is not required to review every single WWTP; making exceptions for pre-existing conditions such as lack of space for construction; social and economic incentives for compliance; and organising regular discussions with non-compliant users to help them develop and implement measures to achieve compliance (Robbins, 2011)
Which government department is responsible for external compliance monitoring and how is this monitoring financed?	
Is there a requirement for the owners of on-site systems to submit and file their self-monitoring reports?	

A: Privately owned and managed (on-site DWM project)	Reference/Note
How is the monitoring of sludge collection services conducted?	Business models for FSM (www.iwmi.cgiar.org) provides different approaches for monitoring and managing sludge collection operators.
Is there a registration system for private bio-solids collectors? If so, which department oversees this registration?	
Do service quality standards exist for FS collection services? If so, how are these standards monitored and by whom?	
Who is allowed to operate FSTPs?	
Are there specific regulations for the disposal and reuse of untreated and treated FS?	
B: Publicly owned and managed DWM projects	**References/Notes**
Are regulations regarding user connections clearly defined?	For standards regarding user interface, please refer to Section 3.3 for a detailed description.
Which department or unit holds responsibility for asset management (ownership)?	The responsible department at the municipality with a capacity for asset management needs to be integrated in the department monitoring the DWM project.
Which department/unit is allowed to operate?	
Which department/unit is monitoring the operation?	
Are there established policies and standards for contracting or outsourcing the operation of assets and services to another government or private entity?	
What does the approval process entail? To what extent is an EISA required?	A brief overview on EIA requirements of the Southeast Asia countries are available at Environmental Impact Assessment: Regulations and Strategic Environmental Assessment Requirements - Practices and Lessons Learned in East and Southeast Asia (UNEP, 2004).
Is there a standard planning process?	Chapter 10

9.4. The financial framework at the city level

A: Privately owned and managed (on-site DWM projects)	Reference/Note
Are there financial schemes or subsidies available to private owners for the implementation of DEWATS?	ADB publication on financing mechanisms for wastewater and sanitation provides several case studies (ADB, 2016)
Does a cost-recovery concept exist for regular compliance monitoring?	Business models for FSM (www.iwmi.cgiar.org) provides different approaches for cost recovery in the context of FSM. They are applicable in setting up decentralised WWTPs as well.
B: Publicly owned and managed DWM projects	**References/Notes**
What are the options and procedures for securing initial investment funding?	Chapter 3.5
Is there a tariff system in place for wastewater service fees? (How much fee can be levied?)	Wastewater service fees separate from water tariff could help to ring fence the funds required to invest in the wastewater systems. 'Wastewater Tariff' in Indonesia and 'sewerage charges' in the Philippines are examples from sewered areas which can be replicated while implementing decentralised WWTPs.
Can the wastewater service fee be included in the water bill? If not, what other billing options are available?	
What is the procedure for applying for funding to cover the cost of significant repairs or reinvestments?	
How can capacity building regarding wastewater management for a project manager, administration, social facilitators, engineers and technicians be financed?	International NGOs, multilateral aid agencies, as well as national bodies such as the Philippine Centre for Water and Sanitation (PCWS) could play a dedicated role in long-term capacity building.

9.5. Technical aspects

A: Privately owned and managed on-site DWM projects	Reference/Note
Do general technical standards for design and operation exist?	For example: The Philippine National Standards for On-site Wastewater Systems (PNS DWMS 1:2017) by the Department of Public Works and Highways (DPWH). Indonesia: Technical Guidelines for Decentralised Wastewater Treatment System (PUB 2017) by the Ministry of Public Works and Housing. Vietnam: Guidelines on Design, Construction, Operation and Maintenance of Domestic Wastewater Treatment Systems (QCVN 40:2011/BTNMT) by the Ministry of Natural Resources and Environment.
Are there city-specific technical or operational requirements or geographical restrictions?	For instance, are there any restrictions against locating systems in or near drinking water catchment areas or areas with high water tables? Are there set intervals for desludging?
How is the sludge from on-site systems managed?	A detailed concept for sludge collection and management is necessary with the associated business plan for FSM at the city level.
How is the effluent from on-site systems managed?	Where is discharge permitted (e.g. infiltration, stormwater channels, etc.) and what quality standards must be met?
B: Publicly owned and managed DWM projects	**Reference/Note**
How is the choice of technology determined? What are the guiding parameters and approval processes?	Several factors may influence the choice of technology. It is crucial that these factors are thoroughly analysed during the selection process.
Are there general or city-specific requirements and specifications for the WWTP construction design?	Please refer to Chapter 3.2.
How are effluent and sludge managed?	Strategies for effluent and sludge management need to be clearly defined and incorporated.

9.6. Capacity development strategy

A: Privately owned & managed on-site DWM projects	Reference/Note
Does the responsible department or unit possess the necessary expertise and capacity (either in-house or external) to assess technologies used in DWM projects for the issuance of building permits?	The availability, skills and expertise of the staff should be considered. Please refer to Chapters 3 and 4.
Does the responsible department or unit have the necessary expertise and capacity (either in-house or external) to monitor DWM projects?	The availability, skills and expertise of the staff should be considered. Please refer to Chapters 3, 4, 5.
Are there accredited water laboratories capable of performing wastewater analytics at a distance of within a half-day's reach from the WWTP?	
B: Publicly owned and managed DWM projects	**Reference/Note**
Does the responsible department or unit possess the necessary expertise and capacity to manage assets, including planning, procurement and funding?	The availability, skills and expertise of the staff should be considered. Please refer to Chapter 3.5
Does the responsible department or unit possess the necessary expertise and capacity for operation?	The availability, skills and expertise of the staff should be considered. Please refer to Chapter 3.3
Is there a programme or institute that provides capacity-building measures and training regarding wastewater management for project managers, administrators, social facilitators, engineers and technicians?	Is there a strategy for staff capacity building and access to regular programmes to enhance the understanding of DWM projects?

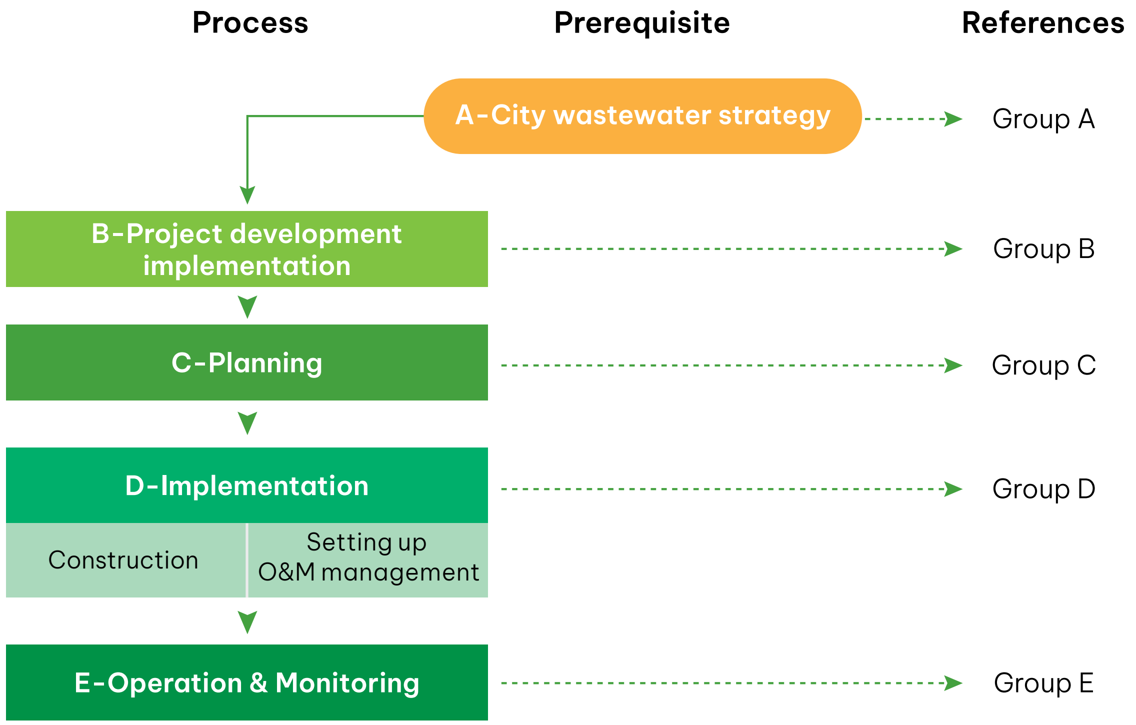
Chapter 10
Planning guide for implementing and operating DWM infrastructure

Starting point Existing wastewater strategy of the city or the decision of the municipality to install and operate a DWM infrastructure.

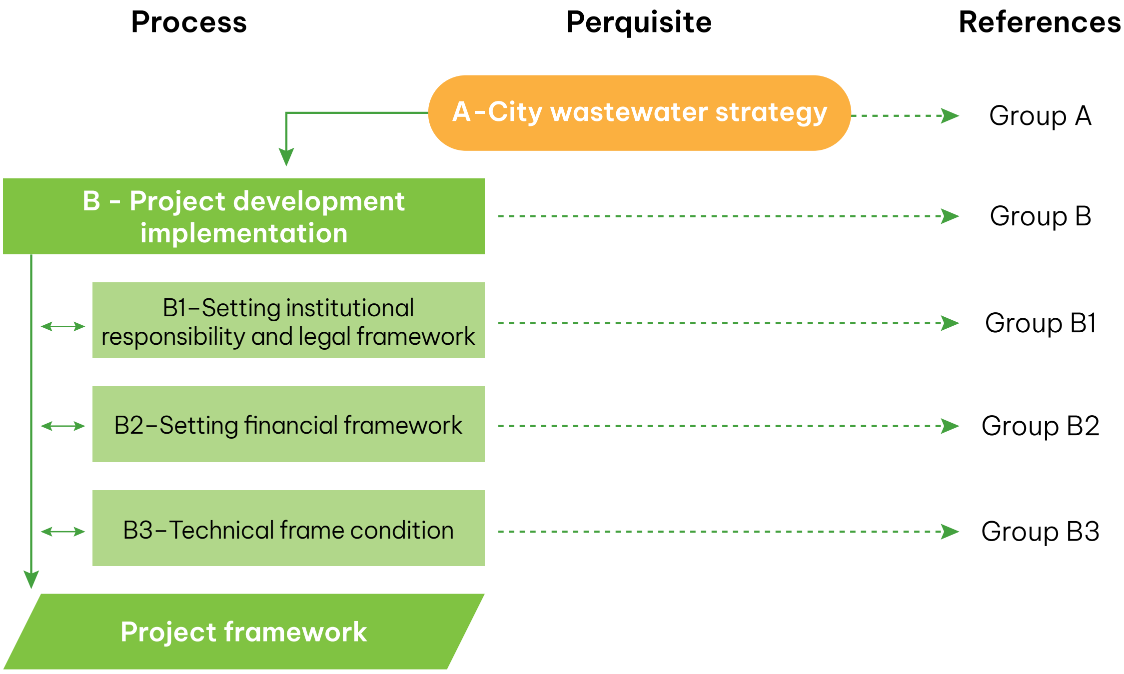
Objectives To outline the essential process steps for preparation, planning, implementation and operation of DWM projects; their sequencing; and, links to practical references such as tools and knowledge boxes which are specifically useful for DWM infrastructure.

Main target groups Project managers and their implementation team, including consultants.

10.1. Overall overview of the main process steps



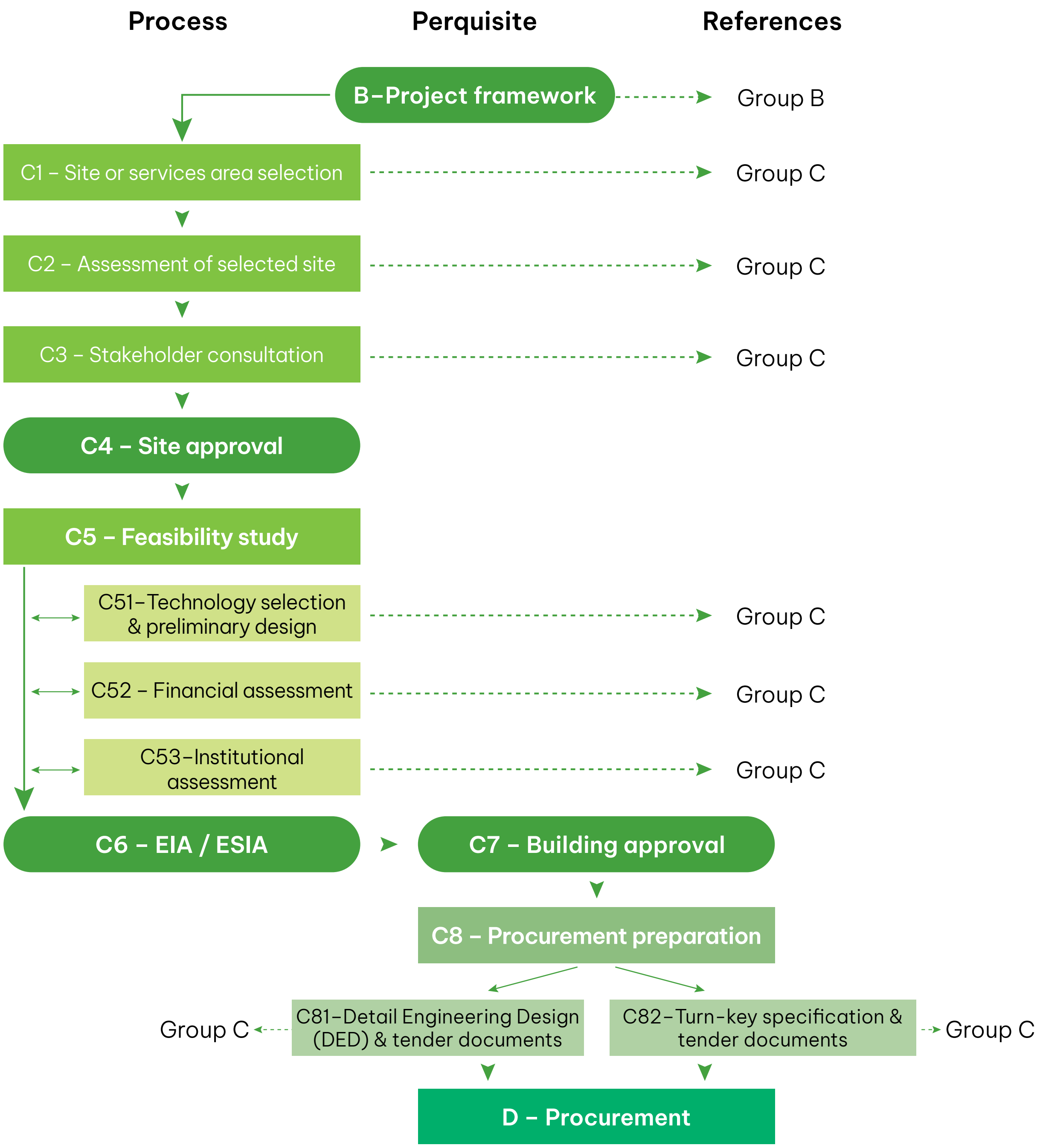
10.2. Step 1 – Project development



Process steps		Explanations	Reference
B	**Project development**	The objective and outcome of the project development step is to enable a project implementation unit (PIU) to prepare the project in the most effective and sustainable manner by clarifying all enabling conditions and approvals. This step can be a single meeting for smaller single facilities or a larger pre-feasibility study with a series of meetings for constructing new infrastructure (assets) in larger or multiple service areas.	Chapters 3, 4, 5.
B1	**Setting the institutional and legal framework**	Identifying the institutions involved and defining their roles and responsibilities along the existing legal government framework and project cycle through to operation. Some simple guiding questions are: • *Who owns and manages the facility?* • *Who will operate it?* • *Who and how will the CAPEX & OPEX be paid?* • *Who oversees or monitors the facility?*	Chapters 3 and 4.

Process steps		Explanations	Reference
B2	**Setting financial framework**	Setting financial boundaries for: • Project implementation; • Operation, maintenance and monitoring; • Cost for capacity-building measures; • Cost for stakeholder/community engagement activities, if required. The financial boundaries can be lump sum budgets or specific investment or operating costs, such as the maximum cost per beneficiary or per m^3 of wastewater treated. Either such cost limits are given or the financial capacity of the project needs to be assessed. Cost limits may also be provided by the municipal sanitation strategy/policy. Additionally, it is important at this early stage to establish the principles for the cash flow and cost-recovery mechanism. This means developing a common understanding of the costs (CAPEX and OPEX) and how the costs will be recovered. The recovery mechanism can be: • Any type of public or private budget; • Service fees to be collected; • Water tariffs; • Taxes (e.g., property tax).	Section 3.5.
B3	**Technical frame conditions**	The technical objectives, special requirements and public standards, as well as regulations, shall be identified and their project relevance defined as following: • **The objective,** for example, sanitation services, resource recovery (biogas or water reuse), treatment target and water body protection, etc. • **Special requirements,** for example, limited land area, high groundwater level, flooding, etc. • **Standards and regulations,** for example, national or municipality-specific design and/or construction standards, registration or certification requirements for technical equipment and system.	Chapters 4, 5, 6.

10.3. Step 2 – Planning



Process steps		Explanations	Reference
C1	**Site and service area selection**	The selection of a specific site or service area for installation of a DWM system is guided by the following questions. • *What are the priority areas?* • *Where is the greatest need? (Wastewater Service Supply/Gap Analysis)* • *Land availability;* • *Availability of wastewater discharge/reuse options.*	Chapters 4, 8.
C2	**Assessment of the selected site**	The objective of the site assessment is to verify its feasibility and to gather all required technical and non-technical site-specific information to prepare for implementation.	Chapters 4, 8.
C3	**Stakeholder consultations**	Once a specific site has been selected and evaluated, the stakeholders involved need to be consulted and, if necessary, engaged. Consultation involves providing the stakeholder group with all necessary and available technical and non-technical information to obtain their consent and, where appropriate, their support throughout the project. The information provided shall be specific and relevant to the legal and institutional roles and responsibilities of each stakeholder group. Stakeholders involved can be: • Local government authorities; • End-beneficiaries; • Civil society organizations; • Private sector representatives. Stakeholders and their responsibilities should be identified at the project development stage (B). Especially in community-based projects, intensive consultation and additional education are often required before the objective of project approval and support can be achieved. The consultation process should continue throughout the project with a liaison process and be detailed in a stakeholder engagement plan. The goal is to keep stakeholders informed of progress and changes and to receive requests and inquiries. This is a key project element for gaining project support and ensuring sustainability.	Chapter 3.

Process steps		Explanations	Reference
C4	**Site approval**	It is recommended to secure land ownership and obtain site-specific project acceptance from the relevant stakeholders before proceeding with the preparation of a feasibility study or implementation.	
C5	**Feasibility study**	The objectives of the feasibility study are: • Assessing technical requirements and options including technology selection; • Assessing the financial requirement for the implementation of the selected technical option against the project or site-specific financial capacity to cover CAPEX and OPEX; • Assessing the technology and site-specific institutional responsibilities and required implementation and operation capacities.	Chapters 3.5, 4, 5.
C51	**Technology selection and preliminary design**	The selection of technology should be guided by the following factors: • The project/treatment objectives set during the project development phase (B) and the outcomes of the site assessment (C2); • Site-specific financial boundaries (B); • Availability of locally sourced parts and services; • Implementation timeline; • Applicable certifications. The preliminary design should adhere to state-of-the-art design processes and calculations. For prefabricated package plants, this information is often explicitly requested from the system supplier. In addition to the international common code of practice developed by numerous municipalities worldwide, technical standard specifications and designs for public sewers, sewer household connections and the required framework for public WWTPs are available.	Chapters 4, 5.

<table>
<tr><th colspan="2">Process steps</th><th>Explanations</th><th>Reference</th></tr>
<tr><td>C52</td><td>Financial assessment</td><td>Assessing the financial requirements of the selected decentralised wastewater solution or concept involves evaluating its compatibility with the project or site-specific financial capacity to cover both capital expenditures (CAPEX) and operational expenditures (OPEX). Key questions include:
• What are the total project costs, covering planning, implementation, commissioning operation, stakeholder liaison and capacity development?
• Does this project cost fit within the available budget?
• What are the total operation costs, covering operation, maintenance, O&M management, monitoring and user liaison?
• How will the operation evolve over the next 20 years (20-year lifecycle cost analysis)?
• Is the cost-recovery mechanism sufficiently robust?
• What is the solution if 100% of the operation cost cannot be recovered?
• How should the cost be recovered through:
(i) State budgets?
(ii) Property tax?
(iii) An independent service fee?
(iv) Water tariffs?</td><td>Chapters 3.5, 4, 5.</td></tr>
<tr><td>C53</td><td>Institutional assessment</td><td>Along the sanitation service chain for the specific project, the assessment includes:
• The stakeholders involved;
• Their roles and responsibilities;
• The definition of the required execution capacity.
It is important to note that high effluent standards and complex technical solutions require a higher level of implementation and operational capacity. Larger sewer networks within a community require more O&M capacity compared to a shorter pipe network for a decentralised WWTP in a hospital. When selecting the technology concept, it is crucial to consider the existing implementation and operational capacity available locally. Accordingly, a stakeholder engagement and capacity-building plan should be prepared and executed before, during and after the physical implementation.</td><td>Chapter 3.</td></tr>
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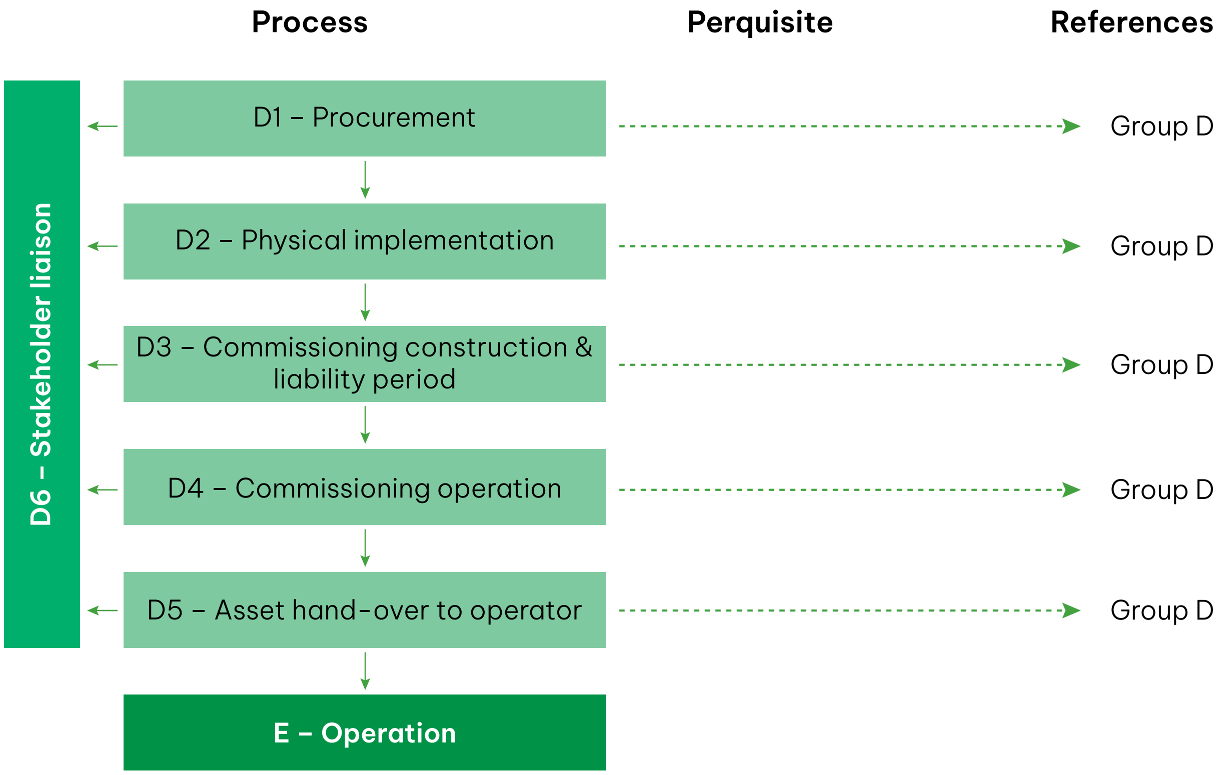
Process steps		Explanations	Reference
C6	EIA / ESIA	In the EISA, a certified independent agency assesses the project concept and verifies its soundness. The requirements and associated costs of conducting EIA/ESIAs have significantly increased over the past decade.	
C7	Building approval	This final approval step is conducted by the respective government authorities before starting implementation.	
C8	Procurement preparation	This step is the final stage before commencing the physical implementation. It is advisable to make decisions regarding the procurement process, whether it be a single-source or tender process, during the project development phase (B). Additionally, the PIU can choose to implement the construction as a civil engineering design and construction project (C81) or opt for a 'Turn-key' or Design and Build project.	
C81	Detail engineering design and tender documents	Under C81, the engineer is responsible for preparing execution drawings, technical specifications, bills of quantities and tender documents in accordance with government standards or the standards specified by the project owner. This process is also elaborated in detail in the RED FIDIC book. Implementation approaches for technologies such as nature-based WWTPs, such as constructed wetlands, typically follow this civil engineering implementation approach.	
C82	Turn-key specification and tender documents	Turn-key or Design and Build contracts often adhere to the YELLOW FIDIC book. In this scenario, a specification is prepared based on which private contractors offer their Design and Build services or supply specific treatment plant components. This approach is commonly applied, particularly for prefabricated package plants. However, it is important to emphasise that purchasing a WWTP is more complex than buying a car. The framework specifications and scope of delivery need to include: • System interfaces (pipe connections, etc.); • Site-specific requirements (foundations, electricity, etc.). This is necessary to prevent unforeseen surprises or additional costs.	

10.4. Step 3 – Physical implementation

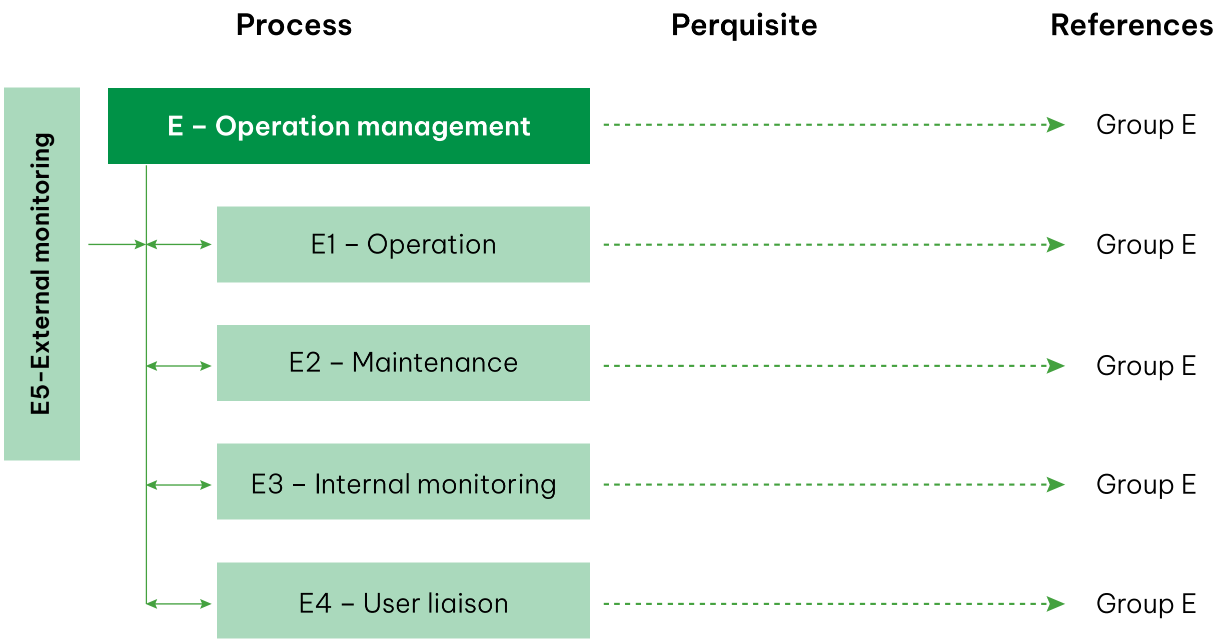


Process step		Explanation	Reference
D1	**Procurement**	This step involves legally engaging a contractor to provide the necessary services or supplies.	
D2	**Physical implementation**	This step encompasses all physical measures of project implementation, commonly referred to as construction. It is crucial to accompany this step with stakeholder liaison measures as outlined in the stakeholder engagement plan. Specifically, working in and with communities requires skilled community facilitation to ensure effective communication and support activities.	
D3	**Acceptance of construction and liability period**	Acceptance of the construction involves verifying that all installations, supplies and services align with the design specifications outlined in the tender document and that the as-built documentation is provided. Once this verification is complete, the defect and liability period of the contractor begins. For civil engineering works, this period typically lasts 6–12 months, whereas for engineers, it can range from 2–5 years based on national regulations.	

Process step		Explanation	Reference
D4	Commissioning	Commissioning is an important step that often does not receive sufficient attention. The procuring party must ensure that: c) the contractor, design engineer or supplier initiates the operation of the WWTP, and d) a trained O&M management is in place to take over the responsibility of operation. This consists of the following steps: a) O&M documentation: Ensuring that all O&M manuals, SoPs, logbooks, and/or documents for sub-components such as pumps, controllers, etc., are handed over and in a language that the operator understands. b) Ensuring that the O&M management is in place, meaning the person, department or entity assigned with the job description and budget is informed and trained if required. c) Ensuring that O&M equipment is procured and available for operation and monitoring. d) Ensuring that operators (technicians or external operation service providers) are assigned job descriptions and trained if required. Once all these components of this step are established, the operation can be officially handed over to the asset owner. The commissioning period should be a minimum of 6 months for a single installation, such as a decentralised WWTP for institutions. For a system serving a community with a sewer network, the commissioning period should be at least 12 months. Unfortunately, many wastewater systems fail to properly complete this essential step and never go into full operation. In a wastewater system that includes household connections, a sewer network and a treatment plant, the construction of the treatment plant often begins before the sewer connections are completed and wastewater can be received. This can create a challenge where the treatment plant is constructed but cannot be immediately put into operation due to the lack of wastewater flow.	

Process step		Explanation	Reference
D4	**Commissioning**	To address this issue, the overall project management needs to collaborate with the design engineer or technology supplier to develop an implementation plan. This plan should ensure that the phase of commissioning starts only when the WWTP receives sufficient wastewater flow. It is recommended that the full commissioning period is included in the scope of services during the procurement process	
D5	**Asset handover to the operator**	Once the system is commissioned, that is, when the system is operational as per the design specifications, all relevant documents are filed and an O&M management system is established, the WWTP can be officially handed over to the asset owner or the responsible institution/entity for operation.	
D6	**Stakeholder liaison**	As mentioned earlier under D2, it is often crucial to ensure that stakeholders receive regular updates regarding the progress and changes throughout the project implementation. For smaller or simpler projects, this can be accomplished through a single meeting or an information letter. However, for more complex projects, an intensive stakeholder engagement process may be necessary, as outlined in a project-specific stakeholder engagement plan facilitated by a community facilitator. Many municipalities and water and wastewater utilities involve their community liaison office to implement water and sanitation services in communities. It is recommended to conduct an inauguration event for the infrastructure, allowing stakeholders to personally be introduced to the project, services and operators. This measure can significantly contribute to the stakeholder liaison process during the operation phase.	Chapter 3.3.

10.5. Step 4 – Operation



Process step		Explanation	References
E	Operation management	The operations management team is tasked with executing all technical, non-technical and commercial duties necessary to ensure that the decentralised wastewater treatment infrastructure delivers the intended service to the asset owner and/or beneficiaries. Asset owners include an institution, landowner, municipality or public utility provider, while beneficiaries include end users such as communities or recipients of reused wastewater. It is recommended to identify the entity or stakeholder responsible for O&M management during the project development stage (B1) or, at the latest, during the feasibility study phase (C52). This ensures that O&M management responsibilities are clearly defined and assigned early in the project lifecycle. The scope of the service of O&M management includes the following activities:	Chapters 3.3, 5.

Process step		Explanation	References
E	**Operation management**	a) Technical operation of the infrastructure and services (E1); b) Operation of a user liaison (E5); c) Maintenance management of the physical structure and equipment of a WWTP (E2); d) Internal performance monitoring of E1, E2 and E5; e) External compliance monitoring management (E4); f) Human resource management and capacity development; g) Financial management. The scope of work of O&M management regarding financial management depends on the assigned responsibilities and job description of the responsible entity or stakeholder. It can range from simply receiving and spending the O&M budget to more extensive tasks such as invoicing, collecting service fees or generating revenue from the sale of by-products. The specific financial management responsibilities will be determined based on the project's requirements and objectives, as well as the agreements and arrangements made with the asset owner or beneficiaries The scope of work of O&M management regarding financial management depends on the assigned responsibilities and job description of the responsible entity or stakeholder. It can range from simply receiving and spending the O&M budget to more extensive tasks such as invoicing, collecting service fees or generating revenue from the sale of by-products. The specific financial management responsibilities will be determined based on the project's requirements and objectives, as well as the agreements and arrangements made with the asset owner or beneficiaries	Chapters 3.3, 5.

Process step		Explanation	References
E1	**Operation**	Operation is an ongoing and continuous activity that ensures the technical functionality of the decentralised WWTP system. The nature and frequency of these operational tasks may vary depending on the complexity and operational demands of the wastewater system. It can involve daily or periodic activities aimed at maintaining the system's performance and efficiency. Additionally, operators should be prepared to respond promptly and effectively to emergencies to mitigate any potential disruptions or issues. The operational tasks are crucial to ensure the smooth and uninterrupted functioning of the treatment plant. Especially, community sewer infrastructures require the operator to be able to: • Receive inquiries or notifications through the user liaison office; • dispatch a technical response team. In case of an emergency, which can be: • Any type of damage; • Overflows; • Odours; • Other issues that interfere with the system's functionality. The O&M management needs to ensure that: • The operator staff is trained; • They have access to the necessary tools; • They follow the Standard Operating Procedures (SOPs), including the health and safety instructions.	Chapter 5.

Process step		Explanation	References
E1	**Operation**	Nature-based WWTPs typically require simple periodic tasks or functionality checks, while systems with biological, mechanical and chemical treatment systems, including electro-mechanical devices, require continuous process control and monitoring. Advanced wastewater systems or prefabricated package systems often come equipped with integrated automation systems and many technology suppliers offer remote control and response services. If the O&M management or asset owner prefers not to be directly involved in the technical operation of the system, they have the option to outsource the operation to a professional service provider through a service-level contract. Outsourcing of operation services, especially for smaller wastewater systems, may prove to be a cost-effective solution, rather than holding the required in-house capacity. Service providers typically operate multiple wastewater systems with a professionally trained and equipped team, which helps reduce specific operational costs. When selecting the technology and procuring its supply for a decentralised wastewater project, it is important to consider the availability of local operation service providers and ensure that their services can be procured. This helps ensure that there is a reliable and capable service provider available to handle the ongoing O&M of the system. The removal and disposal of by-products such as scum or sludge is considered an operational task and not a maintenance task.	Chapter 5.

Process step		Explanation	References
E2	**Maintenance**	Maintenance tasks aim to ensure that the infrastructure's physical condition enables its functionality and does not cause harm to people or the environment. These tasks can include: • Repairs (tanks, pipes, wire, walls, cover, etc.); • Replacement (filter, UV lamp, sensors, bearings, etc.); • Cleaning (pipes, filter, etc.); • Readjustment (connections, levels, sensors, etc.); • Greasing (bearings of air blower, the gearbox of RDC, etc.). In the O&M budget plan, the system-specific maintenance interval and cost need to be outlined. The maintenance can be performed by the in-house staff or procured from external service providers.	Chapter 5
E3	**Internal monitoring**	Internal monitoring is an O&M management task that ensures: • The assigned service and performance standards are met, including those of external service providers; • The in-house staff is following the given instructions and regulations, including: a) Reporting and documentation; b) Standard Operation Procedures (SoPs) for system operation, health and safety; c) Self-monitoring of the WWTP performance. For self-monitoring, specific regulations may vary from country to country. The frequency and intervals of reporting to the national environmental compliance authority depend on the national regulations in place. Typically, larger plants are required to report quarterly, while smaller wastewater systems may report once per year. In terms of self-monitoring, the O&M management has the option to either maintain in-house analytic capacity or outsource the tasks of sampling, analysing and reporting to a private service provider. This decision can be based on factors such as available resources, expertise and cost considerations.	Chapter 5

Process step		Explanation	References
E3	**Internal monitoring**	By adhering to the self-monitoring requirements and ensuring accurate and timely reporting, the O&M management can demonstrate compliance with environmental regulations and contribute to the effective management and operation of the WWTP.	Chapter 5
E4	**External monitoring**	External monitoring adheres to national environmental compliance regulations and is typically conducted by an independent agency or the responsible environmental authority.	
E5	**User liaison**	The operation performance of a WWTP can be influenced by the receiving wastewater as follows: • Quantity of wastewater: This can be affected by too few or too many household connections, changes in water consumption and wastewater discharge and the connection of roof rainwater or stormwater run-off. • Quality of wastewater: This can be influenced by the disposal of non-municipal waste components (solid waste, chemicals, industrial wastewater, etc.) The quantity and quality of wastewater depends on the user/beneficiary and their activities and can potentially change daily. This makes it particularly challenging to continuously monitor the incoming wastewater, especially for decentralised WWTPs. Deviations from the defined design parameters in terms of quantity and quality can significantly impact the functionality and performance of the treatment plant, potentially leading to complete breakdowns. To prevent such incidents and ensure proper control, the O&M management or its user liaison office must communicate to the users what is permissible and what should not be disposed of into the wastewater system. It is crucial to establish clear guidelines and regulations regarding the acceptable wastewater constituents. Additionally, efforts should be made to identify and control the sources of non-compliant discharges.	Chapter 3.3

Process step		Explanation	References
E5	**User liaison**	In the case of sewer-based wastewater systems serving communities and commercial activities, it is advisable to implement by-laws that include a penalty structure to regulate non-compliance. These regulations help maintain the integrity of the wastewater system and promote responsible wastewater management practices among users. Another function of the user liaison is to provide a contact point for the community or user to report the following: • Malfunctions of any components of the system or odours; • Inquiries for repairs and other services for their on-plot installations (septic tank, clogs, broken sewer pipe, etc.). In cases where the cost-recovery mechanism is based on household fee collection, the responsibility for this task is assigned to the user liaison office. The user liaison office takes charge of collecting the fees from households, whether on a monthly, quarterly or annual basis. It plays a crucial role in facilitating the fee collection process, addressing any inquiries or concerns from users and ensuring compliance with the established payment structure.	Chapter 3.3

Chapter11
Conclusions and policy recommendations

11.1. Concluding remarks

Game changer

The DWM approach has the potential to revolutionise urban wastewater management. The true potential of this approach becomes evident when wastewater management integrates source separation and resource recovery solutions. This leads to the closing of smaller nutrient and water loops, ensuring that wastewater is not simply treated at the end of the pipe and discharged into larger water bodies or oceans. The industry has also responded to the potential of this approach by offering various technical solutions and services tailored to the specific demands and opportunities presented by decentralised wastewater projects.

However, unlocking the potential of this approach heavily relies on the presence of feasible regulations and self-sustaining financial frameworks. It is the government's responsibility to establish enabling frameworks through effective regulation, law enforcement and financial incentives to drive this game-changing shift. In response, the private sector and communities will actively engage and contribute to the implementation of DWM approaches.

Enabling framework

Having an effective enabling framework is crucial for the successful large-scale implementation of DWM, which has significant benefits for public health, environmental protection and job creation. This Guidebook aims to provide guidance on the diverse range of technical and institutional options available within the decentralised approach.

One important aspect highlighted in the Guidebook is the legal differentiation between on-site (privately owned and managed) and off-site (publicly owned and managed) systems. It emphasizes the need for a universal understanding of these two basic components of decentralised sanitation and wastewater management.

From the government's perspective, strong and effective regulation and law enforcement are essential for the on-site sanitation component. This means that the government regulates privately owned and managed wastewater infrastructures. However, when the government decides to take over wastewater management and implement sewer infrastructure (off-site), their role changes from regulating to managing and they become the service provider. Consequently, the enabling framework for each component differs. Unfortunately, this fundamental differentiation is often overlooked by development partners, leading to overly ambitious projects that overwhelm the capacity of local government partners during implementation.

By understanding and adhering to these distinctions, stakeholders can ensure that DWM projects are appropriately aligned with the capabilities and responsibilities of the involved parties. This approach fosters more realistic and sustainable project outcomes while maximising the potential benefits of DWM.

Do it right

DWM should not be viewed solely as a 'low cost' or innovative alternative to the centralised wastewater management approach. Regrettably, when decentralised wastewater projects are driven exclusively by the desire to be 'low cost' or innovative, they often suffer from poor quality and lack long-term sustainability. These projects can also become burdened with excessive technical and managerial complexity, leading to failure within a few years of operation.

To ensure the effectiveness of decentralised wastewater projects, it is crucial to adopt a holistic approach that includes dedicated social and technical field engineering. This approach considers the specific context and requirements of the project. It also involves implementing technical standards that reflect state-of-the-art practices in the field.

Simplification of processes and systems is another key driver for success in DWM. By prioritizing these factors, projects can achieve higher effectiveness, long-term sustainability and successful operation.

11.2. Key policy recommendations

Regulation, law enforcement and financial frameworks

In municipal areas where wastewater management is realised through the on-site sanitation approach, it is crucial for the government to invest in effective regulation and law enforcement. Additionally, the implementation of an efficient FSM system is necessary. These investments are essential to ensure the implementation of overarching national environmental policies and to encourage private sector involvement in the development of technical solutions and services.

In contrast, in municipal areas where the local government is responsible for providing wastewater services through smaller or larger sewer networks and infrastructure, the key elements for success lie in the institutional capacity of the operator, the establishment of a self-sustaining financial framework, the implementation of appropriate by-laws to regulate the interaction between users and the service provider and technical implementation standards for sewer and treatment infrastructure as well as for planning processes.

By focusing on these key aspects, the government can create an enabling environment for effective wastewater management in municipal areas. This includes promoting private sector participation, ensuring appropriate regulatory oversight, establishing sustainable financing mechanisms and fostering strong institutional capacities. Such measures contribute to the overall success and sustainability of wastewater management systems in urban areas.

The 5% principle

According to the recommendation from the UN and WHO, the cost for water and sanitation services should not exceed 5% of the household income. It is crucial to establish wastewater service tariffs that adequately cover the full O&M costs of the infrastructure for public wastewater services. Many projects worldwide have demonstrated that sustainable sewer-based sanitation services can be provided for a cost of less than 3% of the household income, including various cross subsidy options. However, in many countries, the wastewater tariffs lag behind the local water supply tariffs. In European countries, the ratio between water fees and wastewater fees is approximately 1:1.5–2.0; in Japan, it is approximately 1:1, while in many ASEAN countries, the ratio of water to wastewater fees is 1: < 0.5. In reality, wastewater management costs more than water supply; however, many governments are hesitant to establish sustainable wastewater tariffs due to political reasons. This leads to underfinanced wastewater service providers that rely on government budget subsidies and lack sufficient funds to invest in appropriate asset maintenance and service expansion.

Prioritisation

The rapid urbanisation of cities in the ASEAN region and around the world presents a significant challenge for sanitation services and other essential public services. To effectively address this challenge, it becomes crucial to prioritise and set clear objectives. Prioritisation can be based on various factors such as political considerations, geographical factors and institutional capacities.

Geographical prioritisation involves identifying areas with specific needs, such as water-protected areas or areas experiencing frequent outbreaks of water-borne diseases. These areas require immediate attention and allocation of resources to ensure the provision of adequate sanitation services.

Institutional prioritisation focuses on building the necessary capacity within government institutions to effectively manage and deliver sanitation services. This includes developing the skills, knowledge and expertise of personnel involved in planning, implementing and operating sanitation infrastructure. Without the requisite institutional capacity, any sanitation project, especially those involving public wastewater infrastructure, is at risk of failure.

Decentralised wastewater infrastructure projects offer an opportunity for learning and capacity development in the context of sewer-based public sanitation services. These projects have shorter implementation cycles and lower initial investment requirements as compared to that of centralised systems. They provide an ideal platform for governments to develop and enhance their institutional capacity while delivering essential sanitation services to communities. However, it needs to be stated that any capacity-building project requires a significant accompanying budget. This fact is often underestimated.

Integrated thinking and acting

Wastewater flow crosses boundaries and interacts with other urban water bodies, stormwater, water supply, urban activities and developments and even solid waste that may end up in the wastewater. Therefore, it is essential that regulation, urban planning and project implementation are developed with an integrated and aligned mind-set.

Technical standards

It is highly recommended for local governments to establish technical standards for the planning and implementation processes of both on-site and off-site sanitation systems. These standards have a significant impact on the effectiveness of the infrastructure and services, as well as the operation costs. For instance, the use of low-quality sewer pipes and inspection chambers as well as improper joining and/or pipe bedding systems can lead to unforeseen high O&M costs. Similarly, the proliferation of various package wastewater treatment technologies offered by the private sector can create challenges. It becomes difficult for users and approving authorities to assess functionality and obtaining professional operation services for such technologies.

By setting technical standards for implementing agencies and suppliers to adhere to and sometimes limiting the number of technical options through local policies, quality assurance and sustainability can be ensured.

Research demand

The authors of the Guidebook acknowledge that there is no significant research demand in the area of DWM specifically aimed at providing improved sanitation services at scale to meet SDGs. To effectively achieve SDGs, it is crucial to have effective regulation and appropriate financial instruments in place, as well as to ensure quality implementation of already existing knowledge and technologies. However, when it comes to emerging aspects such as resource recovery and ECs, there continues to be a need for applied research in the following areas:

a. Scalable technologies and technical concepts for:

(i) *Source separation (blackwater, greywater, urine separation) and processing to generate marketable products;*

(ii) *Nitrogen and phosphate recovery from small WWTPs;*

(iii) *Reuse of treated wastewater or greywater for integrated urban greening and/or urban cooling;*

(iv) *Removal and elimination of ECs such as MPs and pharmaceutical components in decentralised WWTPs.*

b. A comprehensive database for wastewater quantity and quality characteristics specific to smaller wastewater catchment areas in diverse geographical and socio-economic contexts: existing municipal wastewater data primarily focus on larger catchment areas, overlooking the unique characteristics of decentralised systems. In decentralised settings, wastewater characteristics such as concentrations, specific production rates and peak flows can vary significantly depending on the local context. By establishing a more differentiated and localised database, it would be possible to optimise wastewater system designs both technically and economically.

c. Marketing strategies and business development concepts for recovered resources.

d. Integrated financial concepts that demonstrate the monetary valuation of source separation and resource recovery concepts at the city level: for example, eliminating nitrogen and/or reducing wastewater at the source can result in cost savings for investments and operations at the public WWTP. By implementing such decentralised concepts at scale, the financial burden associated with the installation and operation of public wastewater infrastructure can be reduced significantly.

Staggered effluent standards

In the past decade, countries worldwide have made efforts to improve wastewater discharge standards to enhance the quality of aquatic water bodies. However, certain parameters such as total nitrogen, nitrate or phosphate can only be effectively eliminated through advanced and well-functioning multi-stage wastewater treatment technologies. Unfortunately, these technologies are often not economically feasible for the majority of individuals and municipalities. It is estimated that by 2030, approximately 70% of the global population will still rely on simple on-site sanitation systems such as septic tanks and pit latrines.

A wastewater system that incorporates a tertiary treatment stage typically entails investment costs that are 30%–50 % higher as compared to a system with only a secondary treatment stage. Additionally, the operational costs of a wastewater system with tertiary treatment can increase by up to 100% when compared to a system with only secondary treatment. Furthermore, many countries yet do not have a sufficient number of accredited water laboratories to apply effective compliance monitoring.

Furthermore, the current national wastewater discharge standards tend to treat small polluters, such as individual households and large polluters, such as industries or municipal WWTPs, as equivalent. It would be more effective and impactful to adopt a staggered effluent standard based on the discharged pollution load. This approach would allow for more moderate and cost-effective standards for smaller polluters, while imposing higher standards for larger polluters. This concept is followed by the European Water Directive and also implemented in countries such as South Africa, leading to a more practical and scalable approach to wastewater regulation.

Recommended reading documents

1. City-wide Inclusive Sanitation (CWIS) Planning tools World bank – Available at https://www.worldbank.org/en/topic/sanitation/brief/citywide-inclusive-sanitation#3
2. Walther, D. et al. (2016); Preparing City Sanitation Plan - SNUSP II – Trainer's Manual; Available at https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/2706
3. SANIKit Available at https://www.cseindia.org/sanikit/index.html
4. Guidelines for City-wide Inclusive Sanitation (CWIS) Planning, March 2020, ESAWAS Regulators Association.
5. Sanitation potpourri: Criteria for planning mix of sanitation systems for City-wide Inclusive Sanitation; May 2022 Environmental and Planning B Urban Analytics and City Science
6. Andersson, K., Rosemarin, A., Lamizana, B., Kvarnström, E., McConville, J., Seidu, R., Dickin, S. and Trimmer, C. (2020). Sanitation, Wastewater Management and Sustainability: from Waste Disposal to Resource Recovery. 2nd edition. Nairobi and Stockholm: United Nations Environment Programme and Stockholm Environment Institute.
7. Urban Wastewater Treatment Directive (91/271/EEC): This EU directive sets standards for urban wastewater treatment, including the monitoring of small-scale wastewater treatment systems. It provides a framework for water quality protection and pollution prevention.
8. Wastewater Charges Act (Abwasserabgabengesetz - AbwAG): AbwAG regulates charges and fees related to wastewater discharge. It includes provisions for monitoring and reporting on wastewater parameters.
9. 'Cost-Benefit Analysis: Concepts and Practice' by Anthony Boardman, David Greenberg, Aidan Vining and David Weimer: This book focuses on cost-benefit analysis, which is a fundamental tool for evaluating wastewater infrastructure projects. It provides a comprehensive overview of the concepts, methods and applications of cost-benefit analysis, including practical examples.
10. 'Life Cycle Costing for Engineers' by B. S. Dhillon: This book focuses on lifecycle costing, which is an essential component of evaluating the financial feasibility and long-term costs of wastewater infrastructure projects. It provides insights into the methodologies, techniques and considerations involved in conducting lifecycle cost analysis.

11. 'Water and Wastewater Finance and Pricing: A Comprehensive Guide' by George A. Raftelis: This book addresses the financial aspects of water and wastewater infrastructure projects, including financing options, pricing strategies and economic analysis. It offers guidance on the financial management and sustainability of water and wastewater utilities.
12. Environmental Impact Assessment: Regulations and Strategic Environmental Assessment Requirements: Practices and Lessons Learned in East and Southeast Asia (UNEP, 2004).
13. Business models for faecal sludge management (www.iwmi.cgiar.org) provides different approaches for monitoring and managing sludge collection operators.
14. "Financing mechanisms for wastewater and sanitation" provides several case studies (ADB, 2016). Available at: https://www.adb.org/sites/default/files/publication/215956/mechanisms-wastewater-sanitation.pdf
15. Business models for faecal sludge management (www.iwmi.cgiar.org) provides different approaches for cost recovery in the context of FSM. Available at: https://www.iwmi.cgiar.org/publications/resource-recovery-reuse/resource-recovery-reuse-6/
16. IS 2470 (Part 1): 2002 - Design and Construction of Sewage and Drainage Systems - Part 1: Recommendations - This standard provides guidelines for the design and construction of sewage and drainage systems, including septic tanks.
17. 'Specification on the institutional system and technologies related to Johkasou operation and maintenance (draft)' available at: https://www.env.go.jp/recycle/jokaso/en/pdf/operation_and_maintenance.pdf
18. 'Design Manual: Small Sewerage Systems' by the Water Research Commission (WRC): This manual provides practical guidelines for the design of small sewerage systems, including sewer network layout, pipe sizing, hydraulic design and construction considerations. It covers both gravity and pressure sewer systems and offers guidance specific to smaller-scale applications (WRC 2009).
19. 'Small-Diameter Gravity Sewers' by the Water Environment Federation (WEF): This publication focuses on the design and construction of small-diameter gravity sewer systems. It provides guidance on the material selection, trenchless installation techniques, maintenance considerations and relevant design standards.
20. 'Sewers for Adoption' by Water UK: Sewers for Adoption is a comprehensive guidance document produced by Water UK that provides design and construction specifications for sewerage infrastructure. While primarily intended for larger-scale developments, it includes information and requirements applicable to smaller sewer networks as well (Water UK 2028).
21. 'Manual on Sewerage and Sewage Treatment' by the Central Public Health and Environmental Engineering Organisation (CPHEEO): This manual, published by the Government of India, offers guidelines for the design, construction and operation of sewerage systems. It provides detailed information on various aspects, including sewer network design, pipe materials, construction techniques and maintenance practices (GoI 2012).

22. Night Soil Treatment and Decentralised Wastewater Treatment Systems in Japan, by the Ministry of the Environment (https://www.env.go.jp/recycle/jokaso/en/pamph/pdf/wts_full.pdf).

23. https://sswm.info/content/onsite-sanitation. Knowledge platform for water management.

24. Small-Scale Sanitation Scaling-Up (4S) in South Asia. Available at: http://www.sandec.ch/4S, Expert organisation for decentralised water and sanitation management

25. German Water Association (DWA, https://en.dwa.de/en/), U.S. Environmental Protection Agency (EPA, https://www.epa.gov/) and Central Public Health & Environmental Engineering Organisation (CPHEEO, https://cpheeo.gov.in/) developed and updated technical guidelines that became compulsory for the approval process; they were also mandatory considerations that practitioners needed to incorporate in their design; the documentation of the design of the wastewater treatment system also needed to be carried out in line with these guidelines.

26. 'Wastewater Engineering: Treatment and Resource Recovery' by Metcalf & Eddy, Inc., George Tchobanoglous, Franklin L. Burton, H. David Stensel, Ryujiro Tsuchihashi and Franklin L. Burton: This comprehensive textbook covers various aspects of wastewater treatment and infrastructure, including selection, design and evaluation. It provides a detailed understanding of the principles and practices involved in wastewater engineering.

27. 'Wastewater Treatment and Reuse: Theory and Design Examples' by Syed R. Qasim: This book presents a detailed exploration of wastewater treatment and reuse, including the design and selection of treatment processes and systems. It offers design examples and case studies that illustrate the application of different wastewater treatment technologies.

References

Asian Development Bank. (2015). Investment needs in urban wastewater management in Southeast Asia. Asian Development Bank.

Asian Development Bank. (2016). Financing mechanisms for wastewater and sanitation. Asian Development Bank.

Asian Development Bank. (2021). CWIS Guidance Notes - What Is Citywide Inclusive Sanitation and Why Is It Needed? Available on: http://doi.org/10.22617/TIM210395-2

Asian Institute of Technology. (2013). Sustainable decentralized wastewater management in developing countries (1st progress report). Asian Institute of Technology.

ASEAN Secretariat. (2022). ASEAN Statistical Yearbook. ASEAN Secretariat.

Boardman, A., Greenberg, D., Vining, A., & Weimer, D. (2001). Cost-benefit analysis: Concepts and practice (2nd ed.). Prentice Hall.

Capodaglio, A. G. (2017). Integrated, decentralised wastewater management for resource recovery in rural and peri-urban areas. Resources, 6(2). https://doi.org/10.3390/resources6020022

CDD India. (2021). Mahadevpura Lake – Reimagining lake rejuvenation through natural solutions. Retrieved from https://cddindia.org

Chiemchaisri, W., et al. (2022). Surveillance of antibiotic persistence adaptation of emerging antibiotic-resistant bacteria in wastewater treatment processes: Comparison between domestic and hospital wastewaters. Environmental Technology & Innovation, 31, 102410. https://doi.org/10.1016/j.eti.2022.102410

China Geological Survey. (2012). Groundwater serial maps of Asia. Sinomaps Press.

Central Public Health and Environmental Engineering Organisation (CPHEEO). (2006). Manual on sewerage and sewage treatment. Ministry of Urban Development, India.

Elkhatib, D., Oyanedel-Craver, V., & Carissimi, E. (2021). Electrocoagulation applied for the removal of microplastics from wastewater treatment facilities. Separation and Purification Technology, 274, 118877. https://doi.org/10.1016/j.seppur.2021.118877

Danyluk, A. (2008). Wastewater treatment systems: An assessment of sustainability (Master's thesis). University of Cincinnati.

Dhillon, B. S. (2017). Life cycle costing for engineers. CRC Press.

Dris, R., Gasperi, J., Saad, M., Mirande, C., & Tassin, B. (2015). Synthetic fibers in atmospheric fallout: A source of microplastics in the environment? Marine Pollution Bulletin, 104(1-2), 290-293.

Government of India. (2012). Manual on sewerage and sewage treatment. Central Public Health and Environment Engineering Organization, Ministry of Urban Development.

Hajji, S., Ben-Haddad, M., Abelouah, M. R., De-la-Torre, G. E., & Alla, A. A. (2023). Occurrence, characteristics, and removal of microplastics in wastewater treatment plants located on the Moroccan Atlantic: The case of Agadir metropolis. Science of the Total Environment, 862, 160815. https://doi.org/10.1016/j.scitotenv.2023.160815

Henze, M., & Comeau, Y. (2008). Wastewater characterization. In Biological wastewater treatment: Principles, modelling, and design (pp. 33-52). IWA Publishing.

Hongprasith, N., Kittimethawong, C., Lertluksanaporn, R., Eamchotchawalit, T., Kittipongvises, S., & Lohwacharin, J. (2020). IR microspectroscopic identification of microplastics in municipal wastewater treatment plants. Environmental Science and Pollution Research International, 27(15), 18557-18564. https://doi.org/10.1007/s11356-020-08184-8

Imhof, B., & Muhlemann, J. (2005). Greywater treatment on household level in developing countries: A state of the art review (Supervised by Antoine Morel). EAWAG-SANDEC. Retrieved from https://www.uvm.edu/~ewb/Documents/Grey%20Water%20in%20Developing%20 Countries.pdf

International Water Association. (2007). Wastewater characteristics, treatment and disposal (Vol. 1). IWA Publishing. Retrieved from https://www.iwapublishing.com/sites/default/files/ ebooks/9781780402086.pdf

Japan Education Centre of Environmental Sanitation (JECES). (2012). Guidance of the Johkasou development project 2012 (Johkasou seibizhigyo no tebiki 2012 - in Japanese). JECES.

Parkinson, J., & Tayler, K. (2003). Decentralised wastewater management in peri-urban areas in low-income countries. Environment & Urbanization, 8(1), 75-88.

Lares, M., Ncibi, M. C., Sillanpää, M., & Sillanpää, M. (2018). Occurrence, identification and removal of microplastic particles and fibers in conventional activated sludge process and advanced MBR technology. Water Research, 133, 236-246.

Le, T. M. T., et al. (2023). Evaluation of microplastic removal efficiency of wastewater-treatment plants in a developing country, Vietnam. Environmental Technology & Innovation, 29, 102994. https://doi.org/10.1016/j.eti.2022.102994

Lee, E., et al. (2018). Assessment of transboundary aquifer resources in Asia: Status and progress towards sustainable groundwater management. Journal of Hydrology: Regional Studies, 20, 103-115.

LEEDS (2001). PC-based simplified sewer design. Retrieved from https://www.ircwash.org/sites/ default/files/332-01PC-16418.pdf

Lv, X., Dong, Q., Zuo, Z., Liu, Y., Huang, X., & Wu, W. M. (2019). Microplastics in a municipal wastewater treatment plant: Fate, dynamic distribution, removal efficiencies, and control strategies. Journal of Cleaner Production, 225, 579-586.

Meinzinger, F., & Oldenburg, M. (2009). Characteristics of source-separated household wastewater flows: A statistical assessment. Water Science & Technology, 59(9), 1785-1791.

Metcalf & Eddy, Inc., Tchobanoglous, G., Stensel, H. D., Burton, F. L., Tsuchihashi, R., & Burton, F. L. (2014). Wastewater engineering: Treatment and resource recovery (5th ed.). McGraw-Hill Education.

Michielssen, M. R., Michielssen, E. R., Ni, J., & Duhaime, M. B. (2016). Fate of microplastics and other small anthropogenic litter (SAL) in wastewater treatment plants depends on unit processes employed. Environmental Science: Water Research & Technology, 2(6), 1064-1073. https://doi.org/10.1039/C6EW00207B

Milou, M. L. D. (2020). Responsible water reuse needs an interdisciplinary approach to balance risks and benefits. Water, 12(4), 1003.

Ministry of Construction, Vietnam. (2020). Vietnam – Water supply and sanitation. Retrieved from https://www.gfdrr.org/sites/default/files/publication/VIETNAM-water-supply-sanitation.pdf

Montangero, A., Cau, L. N., Anh, N. V., Tuan, V. D., & Belevi, H. (2007). Optimising water and phosphorus management in the urban environmental sanitation system of Hanoi, Vietnam. Science of the Total Environment, 384(1-3), 55-66.

Murphy, F., Ewins, C., Carbonnier, F., & Quinn, B. (2016). Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment. Environmental Science & Technology, 50(11), 5800-5808. https://doi.org/10.1021/acs.est.5b05416

Nashwan, S. M., Mizzouri, S. A., Kochary, N. S. A., & Barwari, N. (2022). Decentralised sanitation solutions for temporal internally displaced people (IDPs) and refugee camps and residential complexes in Duhok Province: A case study. Ain Shams Engineering Journal, 13(2), 185-193.

Odindo, A. O., Bame, I. B., Musazura, W., Hughes, J. C., & Buckley, C. A. (2016). Integrating agriculture in designing on-site, low-cost sanitation technologies in social housing schemes. Water Research Commission. Available from https://www.wrc.org.za/wp-content/uploads/mdocs/TT%20700-18.pdf

Ogawa, H. (2015). Domestic wastewater treatment by Johkasou systems in Japan. Presentation, Japan Educational Centre of Environmental Sanitation, Tokyo.

Oteng-Peprah, M., Acheampong, M. A., & Mofokeng, D. C. (2018). Greywater characteristics, treatment systems, reuse strategies and user perception—A review. Water, Air, & Soil Pollution, 229(8), 255. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6133124/

Parida, V., Sikarwar, D., Majumder, A., & Gupta, A. K. (2022). An assessment of hospital wastewater and biomedical waste generation, existing legislations, risk assessment, treatment processes, and scenario during COVID-19. Ain Shams Engineering Journal, 13(2), 245-259. https://doi.org/10.1016/j.asej.2021.10.008

Philippine Statistics Authority. (2020). Water supply and sanitation survey: 2020 final results. Retrieved from https://psa.gov.ph/content/water-supply-and-sanitation-survey-2020-final-results

Qarni, H. A., Collier, P., O'Keeffe, J., & Akunna, J. (2016). Investigating the removal of some pharmaceutical compounds in hospital wastewater treatment plants operating in Saudi Arabia. Environmental Science and Pollution Research, 23(15), 14994-15007.

Raftelis, G. A. (2005). Water and wastewater finance and pricing: A comprehensive guide. CRC Press.

Rajan, R., et al. (2019). Financial sustainability of small-scale sanitation in India: Life cycle cost analysis and policy recommendations. 4S Project Report Vol. III.

Reynaud, N. (2014). Operation of decentralised wastewater treatment systems (DEWATS) under tropical field conditions (PhD thesis). Technical University, Dresden.

Robbins, D. (2011). Developing guidance policies for the management of decentralised wastewater treatment systems (DEWATS) by local governments. In Conference on Decentralised Wastewater Treatment Systems (DEWATS) for Urban Environments in Asia, Manila, Philippines, May 25–28, 2011.

Sasse, L. (1998). DEWATS: Decentralised wastewater treatment in developing countries. Bremen Overseas Research and Development Association (BORDA). Retrieved from https://www.susana.org/_resources/documents/default/3-1933-7-1522145573.pdf

Schmidt, A., Edathoot, A., Camargo, J., & Hodgson, A. (2022). Cluster approach for scaling up decentralised sanitation. Trialog, 142, 40-45.

Strande, L., Ronteltap, M., & Brdjanovic, D. (Eds.). (2014). Faecal sludge management: Systems approach for implementation and operation. IWA Publishing. https://doi.org/10.2166/9781780404738

Syed, R. Q. (2010). Wastewater treatment and reuse: Theory and design examples. CRC Press.

Talvitie, J., Mikola, A., Koistinen, A., & Setälä, O. (2017). Solutions to microplastic pollution – Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies. Water Research, 123, 401-407. https://doi.org/10.1016/j.watres.2017.07.005

Tchobanoglous, G., Burton, F. L., & Stensel, H. D. (2003). Wastewater engineering, treatment and reuse (4th ed.). McGraw-Hill.

Tsuzuki, Y., & Koottatep, T. (2010). Water pollutant discharge indicator estimation and water quality prediction in Pak Kret district, Bangkok, Thailand. Journal of Water and Environment Technology, 8(1), 51-75.

Tsuzuki, Y., Koottatep, T., Sinsupan, T., Jiawkok, S., Wongburana, C., Wattanachira, S., & Sarathai, Y. (2013). A concept for planning and management of on-site and centralised municipal wastewater treatment systems: A case study in Bangkok, Thailand. Water Science and Technology, 67(9), 1934-1944.

United Nations. (2003). General Comment No. 15: The Right to Water (Arts. 11 and 12 of the Covenant). E/C.12/2002/11.

United Nations Human Settlements Programme (UN-Habitat) & World Health Organization (WHO). (2021). Progress on wastewater treatment – Global status and acceleration needs for SDG indicator 6.3.1. UN-Habitat and WHO.

United Nations Water. (2021). Dashboard: Data for Eastern and South-Eastern Asia. Retrieved from https://sdg6data.org

United Nations Environment Programme (UNEP). (2000). International source book on environmentally sound technologies for wastewater and stormwater management. Retrieved from http://www.gdrc.org/uem/usan/ecourse/documents/SourceBook.pdf

United Nations Environment Programme (UNEP). (2004). Environmental impact assessment and strategic environmental assessment: Towards an integrated approach. Hussein Abaza, Ron Bisset, Barry Sadler. UNEP.

United Nations Human Settlements Programme (UN-HABITAT). (2008). Constructed wetlands manual. UN-HABITAT Water for Asian Cities Programme Nepal. Retrieved from https://unhabitat.org/sites/default/files/download-manager-files/Constructed%20 Wetlands%20Manual.pdf

UNICEF & World Health Organization (WHO). (2020). Joint monitoring programme – Online dashboard. Retrieved from https://washdata.org

Verlicchi, P. (Ed.). (2018). Hospital wastewater: Characteristics, management, treatment, and environmental risks. Springer.

Walther, D., et al. (2016). Preparing city sanitation plan – SNUSP II – Trainer's manual. Retrieved from https://www.susana.org/en/knowledge-hub/resources-and-publications/library/ details/2706

Water UK. (2018). Sewers for adoption: A design and construction guide for developers (8th ed.). WRc plc.

Water Environment Federation (WEF). (2010). Small diameter gravity sewers. WEF.

World Health Organization (WHO). (2014). Blue book for safe management of waste from healthcare activities. WHO.

World Bank. (2013). Review of community-managed decentralised wastewater treatment systems in Indonesia (Technical paper). Water and Sanitation Program.

World Bank. (2018). Cambodia – Water and sanitation. Retrieved from https://data.worldbank. org/indicator/SH.STA.ACSN?locations=KH

World Bank. (2019). Meeting the challenges of wastewater management in the Greater Mekong Subregion. Retrieved from https://openknowledge.worldbank.org/handle/10986/31416

World Health Organization (WHO) & United Nations Environment Programme (UNEP). (1997). Water pollution control - A guide to the use of water quality management principles. WHO/ UNEP.

Water Research Commission (WRC). (2009). Process design manual for small wastewater works (WRC Report No. TT 389/09). Water Research Commission.

Water Research Commission (WRC). (2010). Process design guide for small wastewater works (WRC Report No. TT 389/09). Water Research Commission.

World Bank Water and Sanitation Program (WSP). (2013). Review of community-managed decentralised wastewater treatment systems in Indonesia (Technical paper). World Bank.

Yang, L., Li, K., Cui, S., Kang, Y., & An, L. (2019). Removal of microplastics in municipal sewage from China's largest water reclamation plant. Water Research, 155, 175-181.

Yoshitaka, N., Masud, M. A., & Hanaki, K. (2018). Benchmarking of operational costs and performance of wastewater treatment plants in Southeast Asia. United Nations University Institute for the Advanced Study of Sustainability.

Ziajahromi, S., Neale, P. A., Rintoul, L., & Leusch, F. D. L. (2017). Wastewater treatment plants as a pathway for microplastics: Development of a new approach to sample wastewater-based microplastics. Water Research, 112, 93-99

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