COMPENDIUM OF TECHNOLOGIES FOR USED WATER MANAGEMENT IN HILLY AREAS

A guide to approach and technology selection

This technology compendium is a reference guide for local bodies and practitioners in effectively managing used water in the hilly settlements. Used water management (UWM) includes safe handling and management of greywater, blackwater including faecal sludge and septage disposal generated in the cities/towns and villages.

DECEMBER 2024

About **DRSTUAoA**

Dr. Raghunandan Singh Tolia Uttarakhand Academy of Administration (DRSTUAoA), Nainital is a distinguished academic and research institution located in the picturesque hill station of Nainital, Uttarakhand, India. Established as a premier center for administrative training and research, the academy plays a crucial role in developing and enhancing the capabilities of civil servants, government officials, and public administration professionals.

The academy is dedicated to providing comprehensive training programs, conducting in-depth research, and offering strategic insights into various aspects of public administration, governance, and developmental challenges. DRSTUAoA, Nainital focuses on building the institutional capacity of government functionaries through innovative training methodologies, knowledge sharing, and continuous learning opportunities.

The training programs at DRSTUAoA cover a wide spectrum of administrative and developmental domains, including public policy, governance reforms, rural and urban development, financial management, leadership skills, and emerging technological interventions in public service delivery. The academy employs a multi-disciplinary approach, bringing together experienced academicians, seasoned administrators, subject matter experts, and practitioners to design and deliver high-quality training interventions.

A significant aspect of DRSTUAoA's work involves preparing civil servants to address complex administrative challenges, promote effective governance, and implement transformative development strategies. The academy also undertakes research projects, organizes workshops, seminars, and conferences, and collaborates with various national and international institutions to foster knowledge exchange and innovative solutions in public administration.

About **USAID**

United States Agency for International Development (USAID) is a prominent independent federal agency of the United States government, dedicated to implementing and administering civilian foreign aid and development assistance worldwide. Established in 1961 by President John F. Kennedy through an executive order, USAID has been at the forefront of global development efforts, working in over 100 countries to support economic growth, agriculture, global health, democracy, conflict prevention, and humanitarian assistance.

USAID's mission is to promote and demonstrate democratic values abroad and advance a free, peaceful, and prosperous world. The agency plays a critical role in implementing U.S. foreign policy by extending financial support, technical assistance, and humanitarian aid to countries in need. USAID collaborates with a diverse range of partners, including governments, non-governmental organizations, academic institutions, private sector entities, and international organizations to address complex global challenges.

The agency has a significant focus on several key development areas: global health (including combating infectious diseases, improving maternal and child health, and strengthening health systems), food security and agricultural development, water and sanitation infrastructure, economic resilience, education, gender equality, and climate change adaptation. USAID has been instrumental in supporting numerous initiatives that promote sustainable development, poverty reduction, and improved quality of life in developing countries.

In India, USAID has been a strategic partner in various developmental programs, focusing on areas such as health, clean energy, agriculture, education, and water, sanitation, and hygiene (WASH). The agency has consistently supported innovative solutions and partnerships that address critical socio-economic challenges and contribute to India's developmental goals.

About **Water, Sanitation and Hygiene Institute (WASH Institute)**

Water, Sanitation and Hygiene Institute (WASH Institute) is a registered non-profit organization established in Kodaikanal, Tamil Nadu, India, in the year 2008. WASH Institute provides technical, training, research and development services to a wide range of stakeholders - Governments, Industry, DFIs, philanthropic organizations, and other NGOs. WASH Institute is dedicated to providing practical solutions to a wide range of water, sanitation, hygiene and environmental issues. It operates from 14 locations spread across nine states and one Union Territory in India. WASH Institute has a multi-disciplinary team of over 180 employees with expertise in engineering, urban planning, policy and business models, capacity building, communication and behaviour change.

WASH Institute is a sector partner for Ministry of Jal Shakti that provided skill and capacity building trainings to Government Officials across the country. WASH Institute regularly undertakes training programs for government functionaries (technical staff, decision makers, elected representatives, and policy makers), frontline community workers (Swachhta Doots, volunteers supporting cleanliness efforts) and sanitation workers (masons, operators). The training programs cover the entire spectrum - water security and water management, integrated water supply, water quality, water and sanitation during emergency, ECOSAN, Citywide Inclusive Sanitation (CWIS), Fecal Sludge Management (FSM) and Decentralized Wastewater Management. So far WASH Institute has trained more than 13,000 professionals across the country - Engineers/Govt. officials, NGO/INGO professionals, over Master Masons – as well as school children.

Technical Assistance:
Provides Technical Assistance (TA) to Ministry of Housing and Urban Affairs (MoHUA) on Swachh Bharat Mission Urban (SBM Urban), since 2015
I. As part of TA, WASH Institute has also been providing dedicated support to Central Public Health & Environmental Engineering Organization (CPHEEO), MoHUA, since 2017
II. Provides Technical Assistance to Department of Drinking Water and Sanitation (DDWS), Ministry of Jal Shakti on Swachh Bharat Mission Grameen, since 2016
III. Provides Technical Assistance to Department of Drinking Water and Sanitation (DDWS), Ministry of Jal Shakti on Jal Jeevan Mission, since 2019

About **Hashtag PerCapita**

Hashtag PerCapita Private Limited is an engineering & planning advisory firm established in 2021 between a group of like-minded planners, engineers and public health professionals working in the intersection of water and sanitation.

The mission of Hashtag PerCapita Pvt. Ltd. (HPC in short) is to use livelihood and lifestyle analytics to inform collective societal decisions. Central to this approach of ours is to evaluate the unit-level impact of social, economic and environmental variables on settlement planning and policy advisory.The team at HPC captures such evidence, by undertaking research, technical assistance and providing training support to leadership within the sector of water and sanitation.

About the **Program** and **Compendium Document**

The program represents a collaborative initiative led by the Deen Dayal Research Society of Uttarakhand Academy of Administration (DRSTUAoA), with WASH Institute serving as the knowledge partner and USAID providing financial support. This strategic partnership was established to develop a comprehensive compendium addressing used water management challenges in the unique hilly terrain of Uttarakhand.

DRSTUAoA initiated the project with a clear objective of creating a definitive knowledge resource that could enhance understanding and management of used water systems in hilly regions. Recognizing the need for specialized expertise, the organization engaged WASH Institute as the knowledge partner, leveraging their extensive experience in water, sanitation, and hygiene research.

The research methodology was implemented through a meticulously planned two-phase field study covering diverse urban and rural settlements.

Phase I focused on:

- Urban area: Champawat Urban Local Body (ULB)
- Rural areas: Mudiyani and Khark Kharkee

Phase II expanded the research scope to include:

- Urban areas: Mussoorie ULB and Barkot ULB
- Rural areas: Kolukhet and Kharsali

Location selection was strategically designed to capture the diverse demographic, topographic, and environmental characteristics of Uttarakhand's hilly regions. This approach ensured a comprehensive understanding of used water management challenges across different settlement types and geographical contexts.

The research approach was fundamentally participatory, involving:

- Extensive stakeholder consultations
- In-depth field investigations
- Multi-level engagement with local officials, community members, and service providers
- Comprehensive documentation of existing practices, challenges, and potential solutions

This compendium is more than a technical document which serves as a comprehensive resource, systematically documenting UWM challenges, context-specific solutions, and a replicable framework for hilly regions. Beyond Uttarakhand, it is a valuable reference for researchers, policymakers, WASH professionals, and development practitioners addressing water management in mountainous terrains.

Abbreviations

WASHi	Water, Sanitation and Hygiene (WASH) Institute
USAID	United States Agency for International Development
DRSTUAoA	Dr. Raghunandan Singh Tolia Uttarakhand Academy of Administration
FSM	Faecal Sludge Management
FSSM	Faecal Sludge & Septage Management
ULB	Urban Local Body
GP	Gram Panchayat
D (D1, D2, D3, D4)	Deliverables
GW	Greywater
BW	Blackwater
UW	Usedwater
UWM	Usedwater Management
sq.km.	Square Kilometer
km	Kilometer
ft.	Feet
m	Meter
%	Percentage
yrs	Years
STP	Sewage Treatment Plant
°N	Degree North
°E	Degree East
°W	Degree West
°S	Degree South
HH	Household
FS	Faecal Sludge
O&M	Operation & Maintenance

Key Definitions

Used Water Management (UWM): Includes the safe handling and management of greywater, blackwater, including faecal sludge, and septage disposal generated in urban and rural settlements.

Blackwater: Wastewater originating from toilets, typically containing human waste and requiring higher levels of treatment.

Greywater: Wastewater from sinks, showers, washing machines, and other non-toilet sources, generally less contaminated than blackwater.

Faecal Sludge Management (FSM): The collection, transport, treatment, and safe disposal or reuse of faecal sludge from onsite sanitation systems like septic tanks or pit latrines.

Decentralized Wastewater Treatment System (DEWATS): A small-scale treatment system that integrates multiple technologies to manage wastewater locally, suitable for communities, institutions, and small industries.

Constructed Wetland Systems: Engineered systems that mimic natural wetlands to treat wastewater by utilizing vegetation, soils, and microbial processes.

Simplified Sewer System (SSS): A cost-effective sewerage solution using small-diameter pipes and shallow excavation to collect and transport wastewater for centralized treatment.

EcoSan Toilets: Ecological sanitation systems that separate urine and feces for resource recovery, converting waste into compost and fertilizer without requiring water.

Mobile Treatment Unit (MTU): A portable facility for onsite treatment of faecal sludge and septage, particularly useful in remote or disaster-affected areas.

Pyrolysis: A thermal treatment process for faecal sludge that decomposes organic material at high temperatures under oxygen-deficient conditions, producing biochar, bio-oil, and syngas.

Septic Tank with Soak Pit: A decentralized sanitation solution where wastewater is partially treated in a septic tank and further filtered through a soak pit for safe soil absorption.

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Section 1: **Introduction**

1.1 Background

The situation of sanitation awareness and practices improved in India because of the Swachh Bharat Mission. A lot of emphasis was given on sanitation services and infrastructure including toilets. But, management of the used water and fecal sludge and septage remains a challenge, especially in the hilly regions of the country.

Water, Sanitation and Hygiene (WASH) Institute with USAID[1] support and in coordination with Dr. Raghunandan Singh Tolia Uttarakhand Academy of Administration (DRSTUAoA), Nainital proposed a research study project to identify the WASH Challenges in the hilly regions of Uttarakhand. As part of this project, select towns and villages from Uttarakhand were identified to document the challenges, issues and proposing solutions pertaining to these challenges.

One of the key outputs of the above-mentioned study is developing a technology compendium as a guide for administrators, local body officials (ULBs and GPs) and WASH practitioners in hilly areas.

This compendium is a result of the same.

1.2 Methodology

The methodology adopted for developing this compendium for used water management in hilly areas includes the following key steps:

1. Secondary research on key issues related to WASH in hilly areas (in Uttarakhand)
2. Consultations with key stakeholders from both urban and rural areas for selecting towns and villages that the a representative sample
3. Field visits to selected towns and villages to document the key challenges

1.3 Key challenges in hilly areas

1.3.1 A snapshot of existing UWM systems

The field level assessments conducted in all the study towns and villages captured observations noted at each segment of the service chain pertaining to how usedwater was being collected, conveyed, treated (if any), reused (if any) and disposed. From amongst these segments, wherever certain stages of usedwater management were not prevalent on the ground, say like reuse or treatment.

The below images illustrate the different potential segments that make up the usedwater value chain. These systems would be found in different specifications across the different range of urban and rural areas selected in Uttarakhand:

[1] United States Agency for International Development

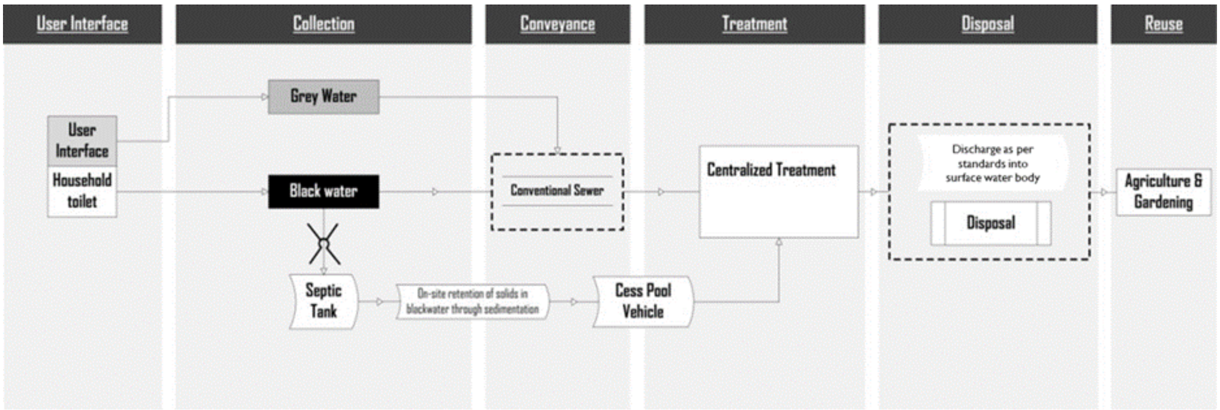


Figure 1: The flow chart illustrating the usedwater management in networked systems

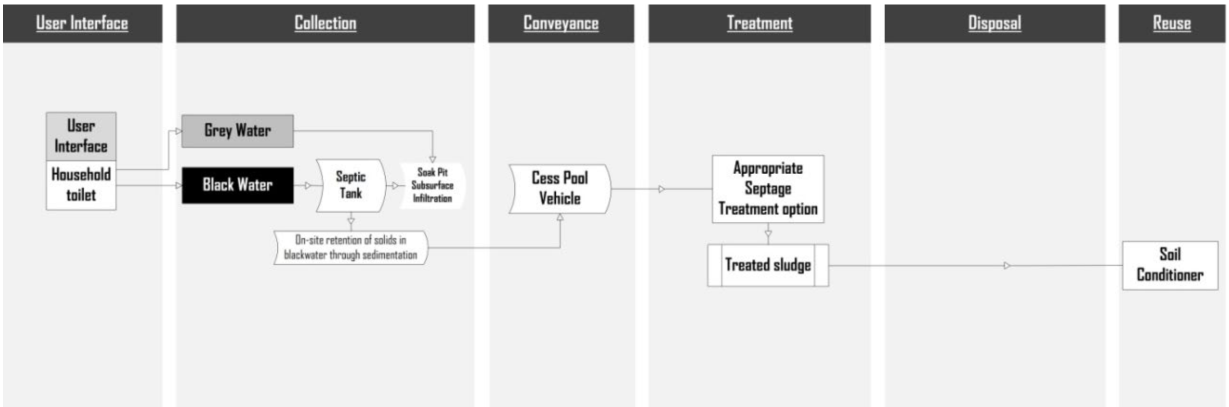


Figure 2: The flow chart illustrating the usedwater management in non-networked systems

1.3.2 Gravity of the current situation

Based on the study conducted in towns, the management of used water reveals significant environmental risks. In Champawat (non-networked town), 67% of used water flows directly into rivers, with gaps in faecal sludge management. Mussoorie (networked town) channels 69% of greywater to surface drains, treating only 14% of blackwater at its STP, leading to contamination risks. Barkot (non-networked town) discharges 67% of greywater into natural drains and rivers, and only 2% of blackwater is treated as faecal sludge. Across towns, heavy reliance on natural drains, insufficient sewage treatment, and open discharge indicate critical gaps in sanitation infrastructure and severe threats to environmental health.

In villages, 80% of used water is greywater, with 60% discharged into open areas and 20% into surface drains, posing risks to hygiene and local water quality. Blackwater management relies on on-site systems (20%), supernatant (18%), and faecal sludge (2%), with 20% infiltrating the ground. The lack of comprehensive treatment facilities and reliance on natural drains threaten groundwater quality, particularly in high water table zones. Insufficient funding and resources severely hinder the development and maintenance of sanitation infrastructure, perpetuating health and environmental vulnerabilities in these rural settings.

The Sankey diagrams presented below depict the gravity of the issues related to used water management in hilly towns and villages:

- *It is to be noted that the data used for the preparation of the San-key diagram is based on consultations organized during the course of the field-work. It is expected to only provide an indicative understanding of effluent generation in the town.*

- *With regard to the villages, the San-key Diagram illustration is developed for the observations captured for the Gram Panchayats of Khark Kharki, Mudiyani, Kolukheth and Kharsali altogether. Considering the minor scale and similarity between these settlements, a single San-key diagram has been developed for all the villages that were visited.*

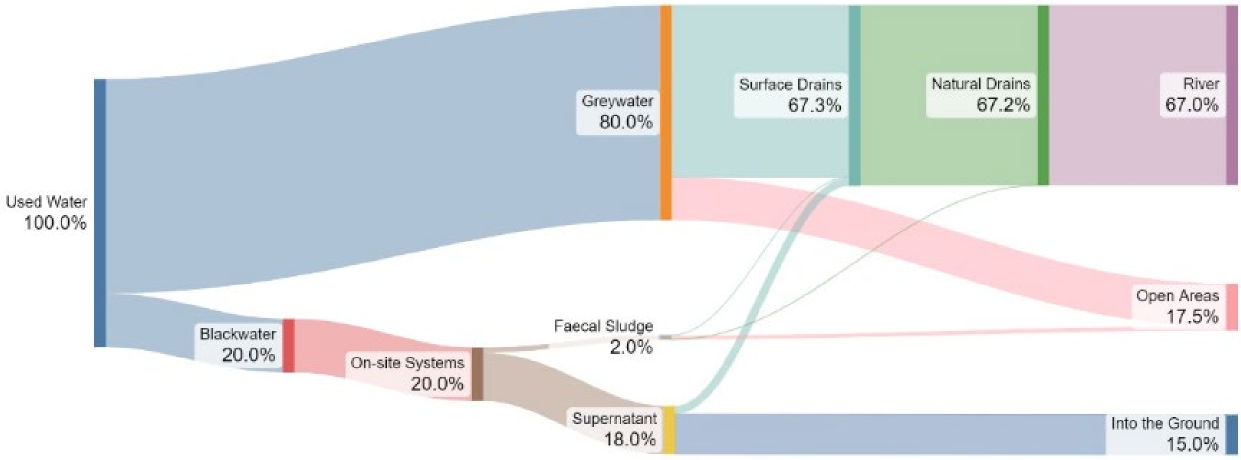


Figure 3: San-key Diagram illustrating usedwater flows across the service chain for the town of Champawat

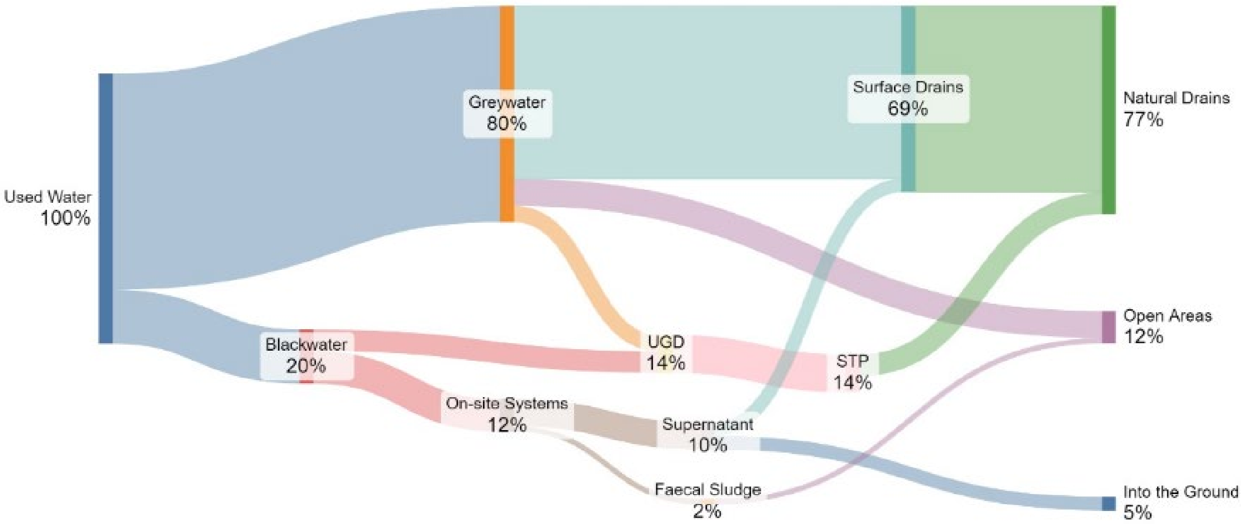


Figure 4: San-key Diagram illustrating usedwater flows across the service chain for the town of Mussoorie

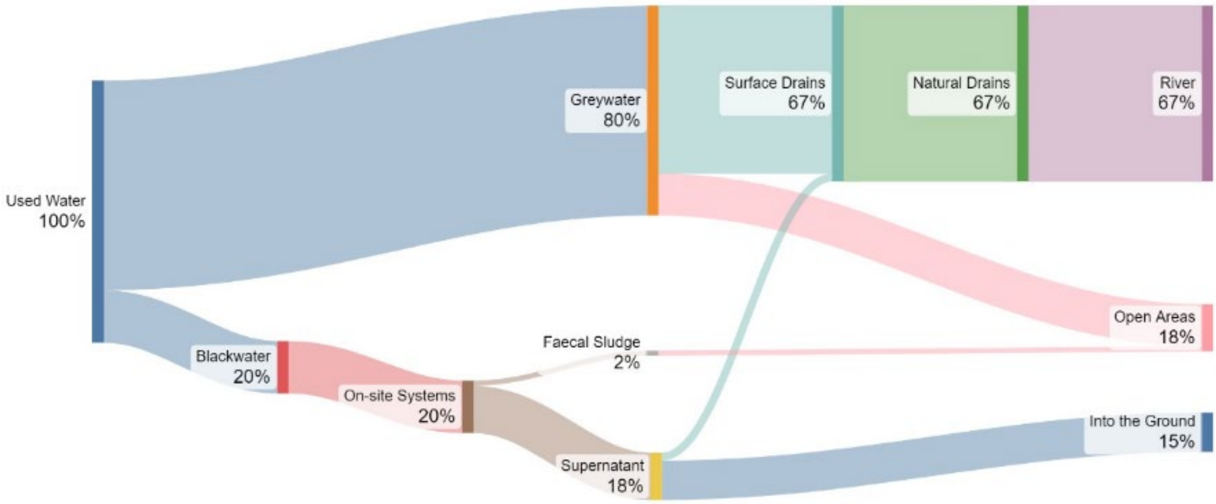


Figure 5: San-key Diagram illustrating usedwater flows across the service chain for the town of Barkot

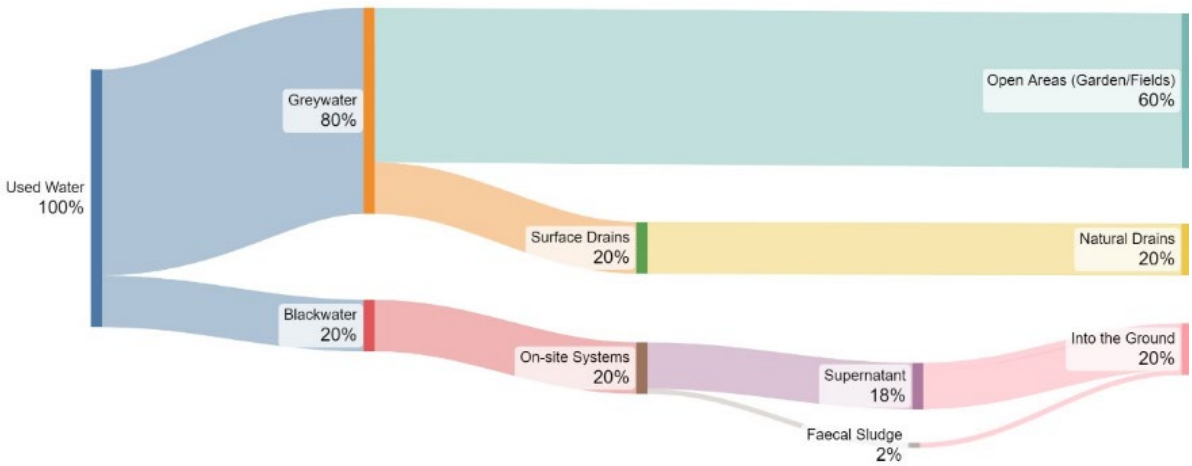


Figure 6: San-key Diagram illustrating usedwater flows across the service chain for the villages of Khark Kharki (GP), Mudiyani (GP), Kolukheth (GP) and Kharsali (GP)

1.3.3 Key challenges identified

Hilly areas face critical challenges in managing blackwater due to inadequate infrastructure and geographical constraints. Containment systems, often unscientific, contribute to groundwater contamination through effluent seepage and supernatant discharge into open drains. Practices such as valve-controlled effluent release during heavy rains worsen public health risks, especially as these untreated discharges eventually pollute downstream water sources. Dense settlements on steep slopes limit sewer connectivity, leaving many households reliant on septic tanks inaccessible for emptying services. The high cost of desludging further deters households, leading to unsanitary practices like open defecation and unmanaged waste disposal, exacerbating environmental and health hazards.

Greywater management in hilly regions is equally fraught with issues due to the absence of dedicated infrastructure. Most greywater is discharged untreated into stormwater drains or open areas, causing sanitation concerns, particularly in dense settlements where stagnation worsens environmental degradation. Informal practices, such as channeling greywater through natural stormwater pathways, offer partial treatment but fail to address pollution risks adequately. Additionally, untreated greywater from households located at higher altitudes flows downstream, impacting lower-lying areas. The lack of systematic treatment and reuse mechanisms underscores the need for tailored solutions to mitigate these environmental and health impacts.

A detailed summary on the key challenges w.r.t. used water management have been presented in the table below:

Table 1: Issues and challenges across segments of sanitation service chain

Segments of the Usedwater Service Chain	Challenges across segments of the service chain
	Blackwater Management
Collection	• **Effluent permeation into the ground:** The containment systems built in hilly towns are mostly unscientific (holding tanks/pits with bottom unlined and side walls lined). **There is risk of groundwater contamination due to the effluent permeating into the ground** in cases where the tanks are not plastered at the bottom but earthen. **The risk is higher when the water table is closer than 1.5 meters to the bottom of the tank.** This potential case of groundwater contamination (in the form of traces of faecal coliform) was noted in one of five samples collected from hand pumps to test for water quality. • **Supernatant discharge into open drains/areas:** The containment systems (the holding tanks/pits) at certain households have outlets where the effluent/supernatant gets discharged into the open environment **thus leading to pollution of water bodies** that act as a sink for these untreated effluents. • **Valve controlled blackwater discharge:** It was noticed in certain households in Champawat town have a **valve-controlled outlets for discharging effluent** from holding tanks/pits into the stormwater channels, these households located next to the drains which carry stormwater, open these valves during heavy rains to avoid the nuisance of smell and being noticed by authorities**. This creates a huge public health issue as these stormwater drains eventually merge with rivers,** which are the source of drinking water for the towns and villages located downstream. • **Effluent permeation in Barkot**: Many Containment systems (mostly holding tanks) allow effluent to permeate through the earthen bottom, leading to the risk of groundwater contamination. This is noted from the consultations with local residents from this region • **Pressure due to floating population**: Barkot being a pilgrim town (leading to Yamunotri), the demand for wastewater/usedwater management services are high, but the infrastructure is inadequate, especially during the heavy footfall periods of April and June (when most of the hotel establishments in Barkot are at maximum occupancy). In addition to this, the issue of managing horse excreta also emerged as a potential area of crisis as pointed by the District Magistrate who mentioned about the potential pollution from the same, especially during the peak season. • **Risk of Overflow:** In a case in Kolukheth, the household members resorted to open defecation as there containment system started to fill and overflow within a span of two years. This was due to water seepage into the system from the uphill due to heavy rains, due to high costs and risk of overflow. The cost of desludging was very high due to which households restored to open defecation.

Segments of the Usedwater Service Chain	Challenges across segments of the service chain
	Greywater Management • Greywater is discharged into open spaces or stormwater drains, which exacerbates sanitation concerns when stagnant. • Greywater from households located in the central part of the town directly discharged into nearby open areas or stormwater drains. There is no dedicated infrastructure for greywater separation at the household level, and collection practices are informal. • Greywater is conveyed via natural stormwater drains and surface drains, often without treatment. These open drains are the primary pathways for greywater, contributing to environmental degradation, especially during periods of stagnation.
Conveyance/Emptying	**Blackwater Management** • **Dense settlement pattern over a slopy topography making last mile connectivity and sewer coverage cumbersome**. In Mussoorie, despite having a sewer network, only 25% of households are connected to it, leaving the rest dependent on large septic tanks that are inaccessible to emptying services. • **Location of containment systems:** The inaccessibility of septic tanks in certain zones of Mussoorie, the difficulty in accessing containment systems that are located as much as 100 ft below the ground level. • **Limited access to emptying services:** Due to narrow pathways and dense settlement patterns, mechanical emptying is difficult for containment systems of dwelling units, particularly in the city center (close to the mall road). • **Challenges with inaccessible areas:** 80% of households and establishments in hilly areas inaccessible to mechanical emptying services due to the town's terrain. The narrow pathways, steep slopes and density localities make it difficult for emptying trucks to provide desludging services. • **Prohibitively High Emptying Costs:** The cost of accessing emptying services for faecal sludge is very high (due to the distance for the trucks to arrive to these areas as well as the steepness and narrow nature of the pathways here), discouraging households from utilizing such services.
	Greywater Management • Greywater is conveyed either into concretized drains, separate pits or through natural stormwater drains and channels.
Treatment	**Blackwater Management** • **Sealed Soak Pits:** In villages, households rely on sealed soak pits for blackwater containment. When these pits fill up, new ones are constructed, but there is no mechanism for managing or treating the waste, posing risks to the local environment. • **Lack of Septage and Faecal Sludge Management:** In villages, the sparse characteristic spread of the settlement and the difficulty for trucks to enter these undulating zones which are located along kutcha walkways impedes the possibility for access to FSSM[2] services. Due to the available land, households tend to dig new pits when existing ones fill up. Septage and faecal sludge are not managed, and households never seek emptying services.

[2] Faecal Sludge & Septage Management

Segments of the Usedwater Service Chain	Challenges across segments of the service chain
	Greywater Management • There is minimal treatment of greywater. The town and village's lacks specific greywater treatment infrastructure, and most of the greywater flows untreated into the environment. • While this may contribute to water pollution at settlements which are at the foothills of a slope and located in dense settings. • However, in other areas which are located at a higher topography, greywater that is discharged can tend to get reduced and partially treated while moving from higher to lower topographies through the natural slopy pathways and stormwater channels.
End use/Safe disposal	**Blackwater Management** • No reuse mechanisms were pointed out or noted for blackwater based on interactions and consultations. The current management practices focus solely on containment and disposal, without exploring reuse opportunities like biogas production or treated water for non-potable uses. • Blackwater disposal is informal and hazardous. Supernatant from (holding tanks/pits) is often discharged directly into stormwater drains, contributing to river pollution. In cases where tanks are unlined, effluent permeates into the ground, increasing the risk of groundwater contamination, especially in areas with a high-water table. **Greywater Management** • Greywater is mostly disposed of in open areas or pits, with no systematic management in place. The practice of directing greywater to separate pits is unique, but it still lacks treatment, contributing to environmental risks when greywater seeps into the ground or is left stagnant in open areas. • The households located on the fringe of the city and in villages, disposed/reused greywater without any treatment in their kitchen garden to grow vegetables, flowering plants and other food crops.

1.4 How to use the compendium

This compendium is designed as a step-by-step guide to assist practitioners, planners, and decision-makers in implementing effective used water management systems, particularly in hilly areas. The key steps are outlined below:

Step 1: Develop a Comprehensive Understanding of Existing Systems

- Conduct a detailed assessment of the current used water management systems and their operational status.
- Analyze the physical, institutional, and environmental conditions in the selected hilly area, which may include a city, town, or village.

Step 2: Finalize the Approach and Methodology

- Refer to the framework outlined in **Section 2** to design a tailored approach for used water management.
- Ensure that the methodology aligns with the specific challenges and opportunities of the selected settlement.

Step 3: Identify the Most Suitable Technology Options

Select technologies that are compatible with the local context, including factors such as:

- **Topography**: Steep slopes, elevation, and terrain characteristics.
- **Climate**: Precipitation patterns, temperature variations, and seasonality.
- **Settlement Pattern**: Urban density, layout, and connectivity.
- **Resource Availability**: Water supply, energy, and financial resources.
- **Cultural Practices**: Local preferences, habits, and traditions.

Refer to **Section 3** for detailed descriptions of available technologies and their applicability.

By following these steps, users can systematically design and implement robust used water management strategies that are sustainable, efficient, and contextually appropriate for hilly areas.

Section 2: **Approach & Methodology for UWM**

Developing an effective approach for wastewater management in hilly settlements is crucial before identifying technologies, as it provides a structured foundation that aligns with local environmental, social, and technical contexts. The approach detailed in the framework emphasizes the following:

1. **Categorization of Solutions Based on Settlement Characteristics**: Interventions must align with the unique physical and socio-economic conditions of hilly settlements. The categorization ensures solutions are context-specific, balancing factors like population density, land availability, and ecological sensitivity.
2. **Integration of Decentralized and Centralized Systems**: For scattered settlements or small clusters, decentralized systems may be more effective, while centralized systems can be considered for larger urban centers. This dual focus ensures adaptability and efficiency.
3. **Resource Optimization and Local Adaptability**: Understanding topography, soil type, and climatic factors guides the selection of technologies that are resilient and resource-efficient. For instance, gravity-based systems might be preferred in steep terrains to reduce energy consumption.
4. **Ecological and Environmental Safeguards**: Hilly areas are often environmentally fragile. The approach integrates nature-based solutions and green technologies to mitigate risks such as soil erosion, water pollution, and biodiversity loss.
5. **Community-Centered Planning**: Local participation is critical for ownership and long-term success. Solutions should reflect community needs, cultural practices, and willingness to adopt new systems.
6. **Iterative Feedback and Continuous Improvement**: The approach encourages regular monitoring, evaluation, and learning to adapt strategies based on emerging challenges and insights during implementation phases.

This structured framework ensures that wastewater management in hilly settlements is technically viable, environmentally sustainable, and socially inclusive. By finalizing a context-driven approach, stakeholders can effectively prioritize and implement technologies tailored to local needs, promoting long-term success and resilience.

2.1 Approach for Conceptualizing Solutions

To guide the local bodies in finalizing the approach to used water management in their respective hilly settlements, the following framework can be used as an approach to conceptualize the interventions. For the same, solutions can be categorized in relation to the categories presented below:

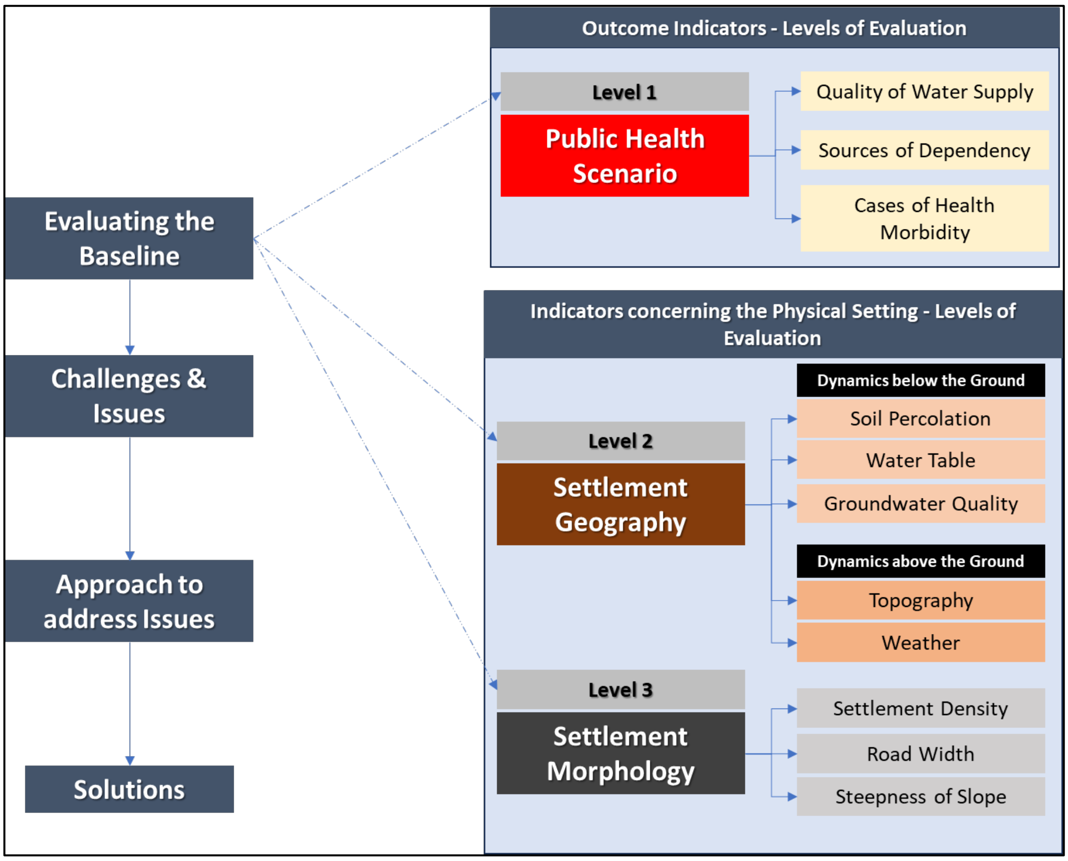


Figure 7: Approach to conceptualize interventions for Usedwater management

2.2 Methodology for identifying Technology Options

The methodology for used water management in hilly areas is shaped by several critical factors, including the unique topography, climatic conditions, population density, and accessibility challenges of these regions. These considerations influence the selection, design, and implementation of appropriate technologies that prioritize sustainability, cost-effectiveness, and resilience. Given the physical and environmental constraints, decentralized systems are often preferred, ensuring adaptability to the terrain and local community needs. Additionally, the methodology emphasizes integrating solutions that address environmental stressors, align with social and economic contexts, and facilitate efficient resource utilization, aiming for a balance between ecological preservation and practical implementation.

2.2.1 Blackwater management

Blackwater management prioritizes environmental safety by evaluating groundwater distance and space availability for On-Site Sanitation (OSS). If space allows and soil percolation is high, OSS with percolation is implemented, managing supernatant through infiltration and sludge via vehicles. In areas with low percolation rates, lined OSS systems are employed, requiring external management for both supernatant and sludge. Where space is insufficient, community sanitation systems are the solution. Integration with Faecal Sludge Management ensures safe sludge treatment and disposal. This approach combines decentralized solutions with site-specific considerations, including soil characteristics and space constraints, fostering sustainable sanitation practices tailored to local needs.

The flowchart presented below on blackwater management outlines a systematic approach to treating and reusing wastewater. It emphasizes on adaptability to site-specific conditions, ensuring compliance with environmental standards while maximizing resource recovery and sustainability in blackwater management.

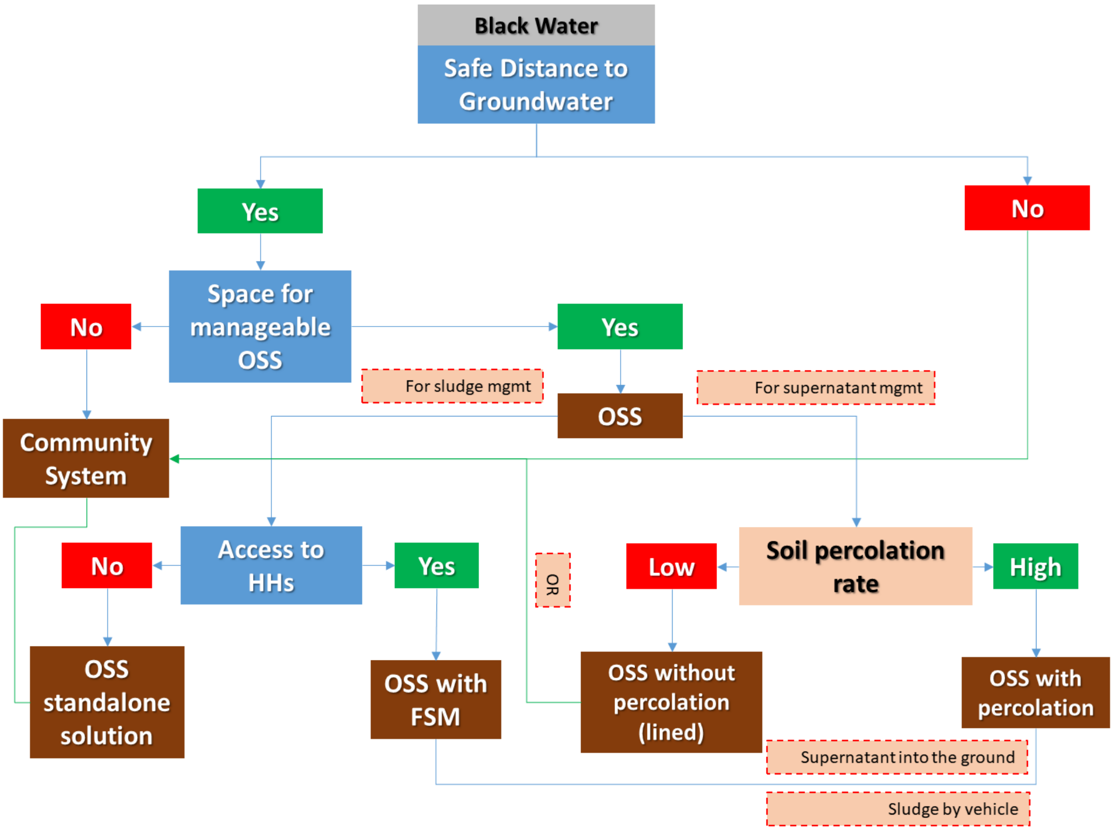


Figure 8: Methodology for choosing the suitable technology options for blackwater management

2.2.2 Greywater management

Greywater management ensures environmental safety by assessing groundwater distance and available space for On-Site Sanitation (OSS). Where space permits, OSS with soil percolation infiltrates greywater, supporting kitchen gardens. In low-percolation areas, lined OSS systems manage greywater, often connecting to surface drains. For limited space, community systems handle greywater collectively. Surface drain coverage further guides interventions; high coverage employs inline or Interception and Diversion (I&D) systems with Nature-based Solutions (NbS), while low coverage uses small bore or Settled Sewer Systems (SSS) with NbS. This approach adapts to local soil, space, and infrastructure conditions, fostering sustainable greywater management tailored to specific needs.

The flowchart presented below on greywater management outlines a systematic approach to treating and reusing wastewater. It emphasizes on adaptability to site-specific conditions.

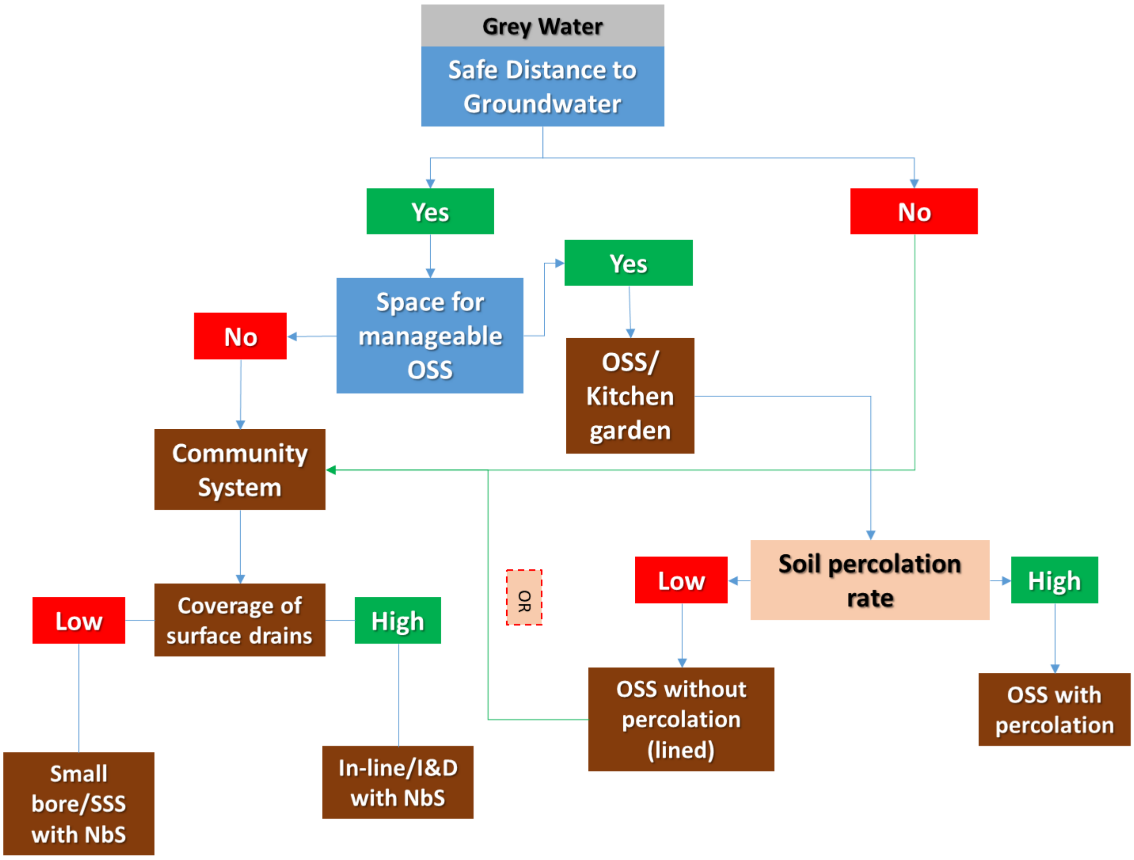


Figure 9: Methodology for choosing the suitable technology options for greywater management

3.1 Collection

a. **Scientific septic tank with a soak pit system**: A scientific septic tank with a soak pit system is a decentralized sanitation solution designed to manage and treat domestic wastewater efficiently. It utilizes natural processes for primary and secondary treatment, ensuring safe disposal of wastewater into the environment.

<u>How it Works:</u>

Septic Tank:

- Collection: Wastewater flows into the septic tank, a sealed underground chamber.
- Separation: Solid waste settles at the bottom as sludge. Oils and grease rise to the top as scum. The liquid layer (effluent) remains in the middle.
- Decomposition: Anaerobic bacteria break down organic matter, reducing the volume of sludge and scum.
- Effluent Discharge: Partially treated effluent exits through an outlet for further treatment in the soak pit.

Soak Pit:

- Percolation: Effluent enters a porous pit where it seeps into the surrounding soil.
- Filtration: The soil acts as a natural filter, trapping particles and impurities. Microbial activity in the soil further treats the wastewater.
- Safe Disposal: Treated effluent replenishes groundwater or safely integrates into the soil without pollution.

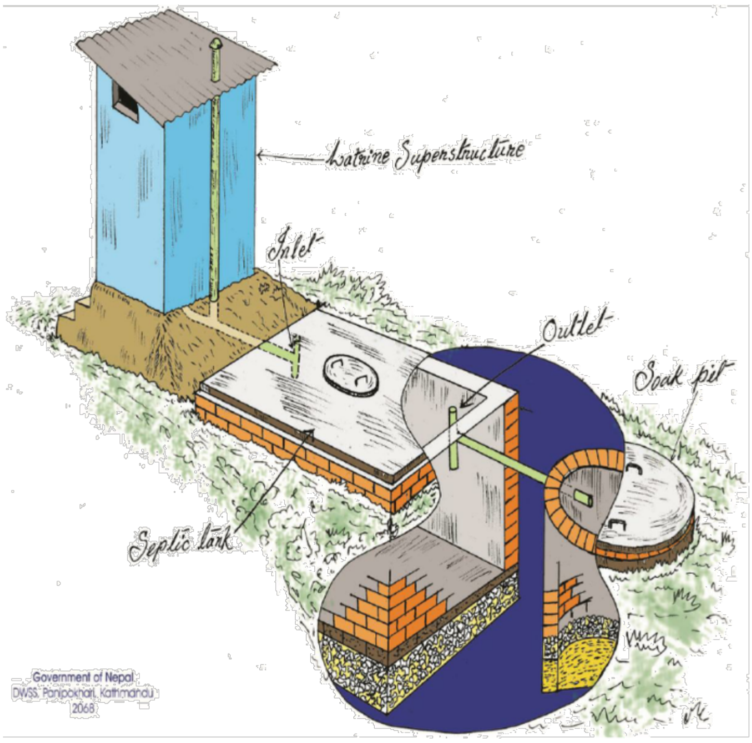


Figure 10: Scientific Septic Tank with Soak Pit (DWSS)

Pros	Cons
• Simple and robust technology • No electrical energy is required • Low operating costs and long service life • Built underground	• Low reduction in pathogens, solids and organics • Regular desludging must be ensured • Effluent and sludge require further treatment and/or appropriate discharge

Applications:

- Urban and Rural households
- Small-scale institutions like schools, offices, and clinics
- Remote areas without access to centralized sewage systems

This system is a scientific yet simple solution for effective sanitation, leveraging natural processes to treat wastewater. Its low-cost, decentralized nature makes it ideal for areas lacking access to urban infrastructure.

b. **Twin Pit Toilet System**: A twin pit toilet system is a simple, cost-effective, and eco-friendly sanitation solution designed to safely manage human waste while promoting resource recovery. It involves alternating between two pits for waste disposal, ensuring complete decomposition of fecal matter into usable compost.

How it Works:

Structure: The toilet is connected to two underground pits, typically made of brick, concrete, or lined with impermeable material. A diversion mechanism directs waste to one pit at a time.

Usage:

- Active Pit: Waste is directed into one pit while the other is sealed.
- Decomposition: Organic matter in the filled pit undergoes natural decomposition through anaerobic processes. The decomposition process, aided by microorganisms, transforms waste into harmless compost over 12-24 months.
- Alternation: Once the first pit is full, waste is directed to the second pit, while the first remains sealed for further decomposition.
- Compost Harvesting: After 12-24 months, the waste in the first pit becomes nutrient-rich compost, safe for use as a soil conditioner.

The cycle continues, ensuring continuous operation without environmental contamination.

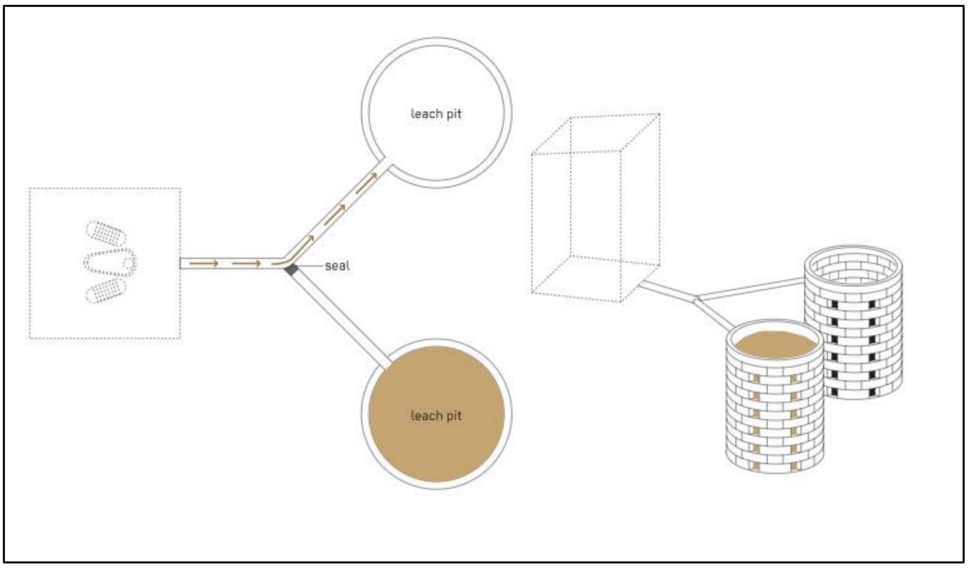


Figure 11: Twin Pit System for Pour flush toilets (Tilley, 2014)

Pros	Cons
• Because double pits are used alternately, they can have a long life • Potential for use of stored faecal material as soil conditioner • Flies and odours are significantly reduced (compared to pits without a water seal) • Can be built and repaired with locally available materials	• Manual removal of humus is required • Clogging is frequent when bulky cleansing materials are used • Higher risk of groundwater contamination due to more leachate than with waterless systems

Applications:

- Rural and Peri-Urban households
- Schools and community sanitation facilities
- Areas lacking access to centralized sewage systems
- Locations promoting eco-friendly and sustainable practices

The twin pit toilet system exemplifies a sustainable and hygienic sanitation solution, particularly suitable for rural and peri-urban areas. By combining simplicity, safety, and resource recovery, it aligns with ecological and public health goals, ensuring a dignified and environmentally responsible approach to sanitation.

c. **Waterless Toilets** (EcoSan toilets): **Ecological Sanitation (EcoSan) Toilets**, commonly known as waterless toilets, are innovative sanitation solutions that safely transform human excreta into valuable resources like compost and fertilizer. By eliminating the need for water in waste management, they offer a sustainable alternative, especially in areas with limited water access or high groundwater tables.

How They Work:

- Urine Diversion: EcoSan toilets are designed to separate urine from feces at the source. Urine is collected and can be directly utilized as a nutrient-rich fertilizer after appropriate treatment.

- Feces Collection and Treatment: Fecal matter is deposited into a sealed chamber or pit. To promote drying and reduce odors, dry cover materials such as ash, sawdust, or soil are added after each use. Over time, the feces decompose into compost, which can be safely handled and used to enrich soil.
- Alternating Chambers: Many EcoSan toilets feature dual chambers.
- Once one chamber is filled, it is sealed to allow the contents to decompose, while the second chamber is used. This alternating system ensures continuous use and effective composting.

Pros	Cons
• Water Conservation: Operates without water, making it ideal for arid regions or areas with water scarcity. • Environmental Protection: Prevents groundwater contamination, especially in regions with high water tables. • Resource Recovery: Transforms waste into valuable compost and fertilizer, promoting sustainable agriculture. • Cost-Effective: Reduces the need for extensive sewage infrastructure and water usage. • Adaptability: Suitable for diverse environments, including rural, peri-urban, and disaster-affected areas.	• User Acceptance: Requires behavioral change and user education for effective adoption. • Maintenance: Regular monitoring and management are essential to ensure hygienic conditions and proper functioning. • Initial Training: Users and maintenance personnel need training on proper use and upkeep. • Space Requirements: Dual-chamber designs may require more space compared to conventional toilets.

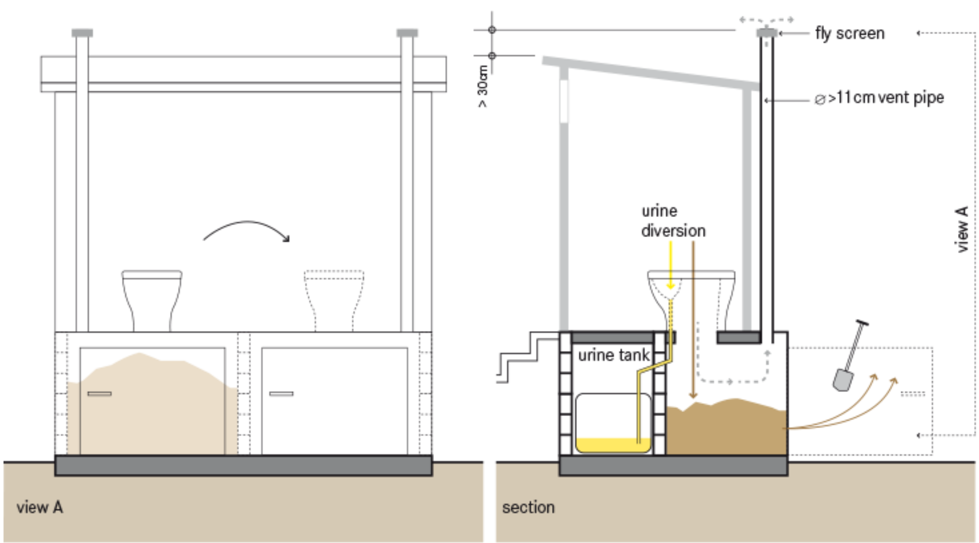


Figure 12: EcoSan Toilets with urine diversion (Wateless) (Tilley, 2014)

Applications:

- Rural and Peri-Urban Areas: Provides sanitation solutions where water supply and sewage infrastructure are lacking.
- Disaster Relief: Offers immediate and sustainable sanitation in emergency settings.
- Agricultural Communities: Supplies compost and fertilizer, supporting local farming practices.
- Water-Scarce Regions: Ideal for areas where water conservation is critical.
- EcoSan toilets represent a sustainable and practical approach to sanitation, aligning with ecological principles and resource conservation. By converting human waste into beneficial resources, they address sanitation challenges while promoting environmental stewardship.

3.2 Emptying/Conveyance

a. **Vehicle mounted compact emptying system**: The JALODBUST system is an innovative, mechanized solution designed for hygienic and efficient cleaning of septic tanks and pit latrines. It eliminates manual scavenging and ensures safe handling of human waste, aligning with sustainable sanitation goals and promoting public health.

How it Works:

- Mechanized Cleaning: This machine is equipped with a suction pump and hoses for extracting sludge from septic tanks or pits. Waste is vacuumed out and collected in a sealed storage tank, ensuring no direct human contact.
- Transport and Disposal: Extracted waste is transported to a designated treatment facility or disposal site. Proper sealing prevents leakage or odor during transportation.
- Optional Treatment: Some systems include on-site treatment units to partially process the waste before transport. Treated sludge can be converted into compost or used as bioenergy feedstock, depending on the system's design.
- Operation: Operated by trained personnel, the system ensures safety and efficiency during sludge extraction and disposal.

Figure 13: Vehicle mounted compact emptying system: (JALDOBUST(R), 2024)

Pros	Cons
• Eliminates Manual Scavenging: Mechanized operations ensure dignity and safety for sanitation workers. • Hygienic and Safe: Prevents human exposure to waste, reducing health risks. • Efficient: Rapid sludge removal and transport improve operational efficiency. • Environmentally Responsible: Supports proper waste disposal, reducing environmental contamination. • Scalable: Suitable for urban and rural areas, adaptable to various sanitation systems.	• Cost of Equipment: Initial investment can be high for small municipalities or individual operators. • Accessibility: Narrow lanes or inaccessible pits may pose challenges for mechanized vehicles. • Training Requirements: Operators need training to handle equipment safely and efficiently. • Disposal Infrastructure: Requires access to treatment facilities or designated disposal sites for compliance with environmental standards.

Applications:

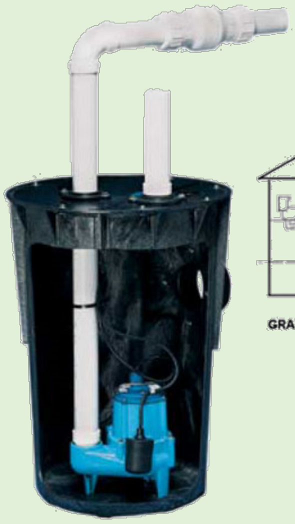
- Urban and peri-urban areas for cleaning septic tanks and pit latrines from narrow lanes
- Rural areas with twin pit or single pit latrine systems from narrow lanes
- Municipalities looking to eliminate manual scavenging
- Industrial or institutional sanitation systems requiring periodic sludge removal

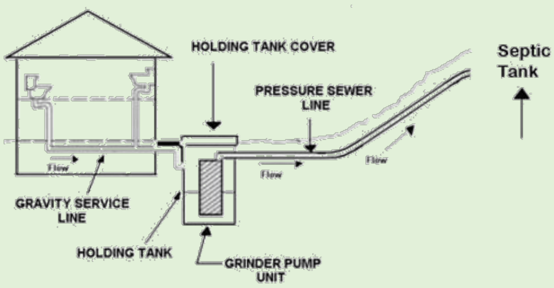
<u>A case of booster pump system for emptying</u>

In Leh, the specific booster pump model used for emptying pits and septic tanks in remote or deep locations isn't publicly documented. However, high-head sewage ejector pumps are typically employed for such tasks. These pumps are designed to handle raw sewage and can move wastewater over considerable distances and elevations.

One example is the Liberty LEH200-Series 2.0 HP High Head Sewage Ejector Pump, which can handle spherical solids up to 2 inches in diameter and offers a flow rate of 120 gallons per minute at 50 feet of head pressure. Another option is the Liberty LEH150-Series 1.5 HP High Head Sewage Ejector Pump, capable of pumping 120 gallons per minute at 40 feet of head pressure.

These pumps are constructed with durable materials like cast iron to withstand harsh conditions and are suitable for applications requiring the movement of sewage from deep or distant locations. (Source: Septic Solutions)





b. **Simplified Sewer System**: A Simplified Sewer System (SSS), also known as a small-bore sewer or shallow sewer, is an efficient and cost-effective alternative to conventional sewer systems. It is designed to collect and transport wastewater from households and communities using smaller-diameter pipes, shallow excavation, and strategic gradients, making it ideal for densely populated or low-income areas.

<u>How it Works:</u>

- Collection: Wastewater from homes and institutions is channeled into a network of small-diameter pipes. Pipes collect both greywater (from sinks and showers) and blackwater (from toilets) for centralized treatment.
- Design Features:
    - Small Diameter Pipes: Pipes are smaller in size compared to conventional sewers, reducing material costs.

  - Shallow Installation: Pipes are laid closer to the surface, minimizing excavation and construction costs.
  - Strategic Gradients: The system relies on gravity for flow, requiring fewer pumping stations.
  - Pre-Treatment: In some cases, septic tanks or interceptor tanks are used to settle solids before wastewater enters the pipes.
- Transport: Wastewater flows through the pipe network to a treatment facility or disposal point. Any solids are retained in pre-treatment systems, reducing the risk of blockages in the sewer lines.
- Treatment and Disposal: Collected wastewater is treated at a centralized facility for safe reuse or disposal.

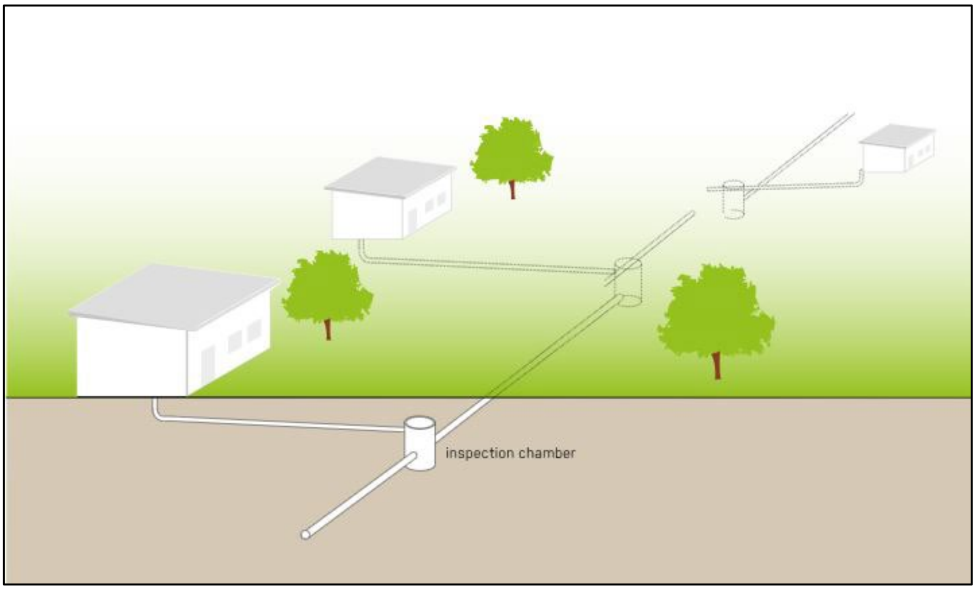


Figure 14: Simplified sewer system (Tilley, 2014)

Pros	Cons
• Can be laid at a shallower depth and flatter gradient than Conventional Sewers • Lower capital costs than Conventional Sewers; low operating costs • Can be extended as a community grows • Greywater can be managed concurrently with blackwater	• Requires repairs and removals of blockages more frequently than a Conventional Sewer • Requires expert design and construction • Leakages pose a risk of wastewater exfiltration and groundwater infiltration and are difficult to identify

Applications:

- Low-income or informal settlements in urban areas
- Small to medium-sized communities in peri-urban or rural regions
- Settlements with high density in hilly areas
- Institutions or campuses where centralized sewerage systems are not viable
- Disaster-affected areas needing quick and cost-effective sanitation solutions

The Simplified Sewer System is a practical, low-cost alternative to conventional sewerage, particularly in resource-constrained settings. By prioritizing affordability and efficiency, it ensures improved sanitation, supports public health, and reduces environmental risks while being adaptable to the unique needs of diverse communities. Some examples of where SSS has been implemented are presented below (Source: IWA):

- **Marikuppam, Karnataka -** In Marikuppam, a community of 106 households in Kolar Gold Fields, a simplified sewerage system was designed to eliminate manual scavenging and provide sustainable sanitation. The design utilized 100 mm diameter pipes set at a gradient of 1:100. A risk assessment model confirmed the system's effectiveness, with additional flow-boosting devices recommended for certain areas. This project demonstrated that simplified sewerage is a feasible and sustainable low-cost sanitation option, eliminating the need for human handling of feces at the household level.
- **Mumbai Slum Sanitation Program -** The Slum Sanitation Program in Mumbai has provided access to sanitation for a quarter million slum dwellers. This initiative has been instrumental in improving sanitation facilities in densely populated urban areas, demonstrating the potential of simplified sewerage systems in such contexts.
- **Chennai Metropolitan Water Supply and Sewerage Board -** Chennai has implemented simplified sewerage systems in various zones, covering areas like Tondaiarpet, Washermenpet, Royapuram, George Town, and Chindadripet. The city has divided its sewerage network into five zones, each with independent collection, conveyance, treatment, and disposal facilities, effectively managing wastewater in densely populated urban areas.

These case studies illustrate the potential of simplified sewerage systems to provide sustainable and cost-effective sanitation solutions in India's urban areas, particularly where conventional systems face challenges.

A case of SSS from the mountains

Implementing simplified sewerage systems in India's hilly regions presents unique challenges due to the terrain's topography and soil conditions. While specific case studies from hilly areas are limited, the following example illustrates an approach to designing sewerage systems in such environments.

A study focused on designing a sewerage system for **Baba Ghulam Shah Badshah University (BGSBU)**, located in the hilly terrain of Rajouri in J&K. The design aimed to effectively collect, treat, and dispose of wastewater, considering the area's topographical challenges. Key aspects included:

- **Data Collection**: Conducting detailed surveys to determine population distribution and topographical features.
- **Hydraulic Design**: Utilizing Manning's formula to calculate flow velocities and ensure self-cleansing velocities to prevent sediment deposition.
- **Topographical Considerations**: Preparing contour maps and longitudinal sections to design sewers that align with the natural slope, minimizing excavation and construction costs.

This approach demonstrated that with careful planning and design, effective sewerage systems could be implemented in hilly areas, addressing environmental concerns and improving public health. While this example pertains to a university setting, the methodologies applied can be adapted to other settlements in hilly regions. However, comprehensive documentation of simplified sewerage systems specifically implemented in India's hilly areas remains limited. (Source: IJIRSE)

c. **Mobile transfer station**: A **Transfer Station** is an intermediate facility in the sanitation chain, designed to temporarily hold faecal sludge or wastewater before it is transported to a treatment facility. It is particularly useful in densely populated urban areas or locations with limited access to centralized treatment facilities.

<u>How it Works:</u>

- **Collection**: Faecal sludge or wastewater is brought to the transfer station from septic tanks, pits, or other sources by collection vehicles (e.g., vacuum trucks or human-powered devices). The station acts as a storage point where waste can accumulate.
- **Storage and Management**: The facility includes an **underground holding tank** or above-ground storage tank. Tanks are designed to prevent leakage, overflow, and contamination of the surrounding environment.
- **Transportation**: Once the storage tank is full, the waste is transferred to larger, motorized vehicles (e.g., tankers) for transportation to a treatment facility. The station reduces the need for smaller vehicles to make long trips, optimizing the transport process.
- **Additional Features**: Some transfer stations are equipped with **pre-treatment mechanisms** such as screening or settling to reduce solids or debris before

onward transportation. They may include provisions for **odor control** and hygiene maintenance to minimize public health risks.

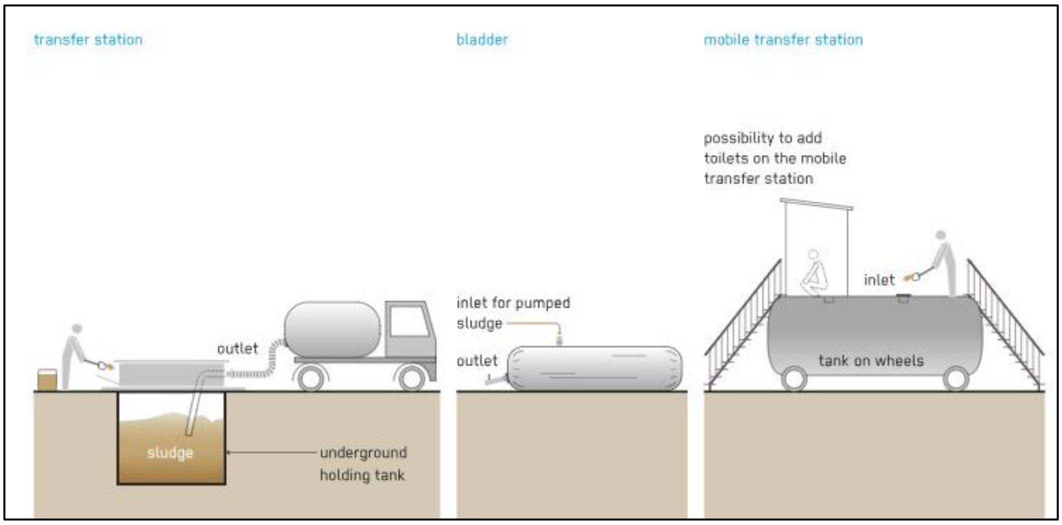


Figure 15: Mobile transfer station (Tilley, 2014)

Pros	Cons
• Makes sludge transport to treatment plant more efficient • May reduce illegal dumping of faecal sludge • Potential for local job creation and income generation	• Requires expert design and construction • Can lead to odours if not properly maintained

Applications:

- Urban areas with narrow roads or limited access for large vehicles.
- Temporary sanitation solutions in disaster zones or refugee camps.
- Peri-urban and rural locations with intermediate transport needs.
- Large-scale public events requiring temporary sanitation infrastructure.

A Transfer Station is a critical link in the faecal sludge management chain, ensuring that waste is efficiently and safely managed before treatment. Its adaptability and cost-effectiveness make it an essential component of sanitation systems in resource-constrained or high-demand settings

d. **Modern mechanized emptying and conveyance equipment** (vehicle mounted): The modern mechanized emptying and conveyance equipment by Kama Vida is an advanced sanitation solution designed for the efficient and hygienic removal and transportation of faecal sludge and wastewater. These vehicle-mounted systems are tailored to handle various urban and peri-urban sanitation challenges, emphasizing safety, efficiency, and environmental responsibility.

How it Works:

- **Mechanized Emptying**: The equipment features a **powerful suction pump** mounted on a vehicle, capable of extracting faecal sludge from septic tanks, pit latrines, or holding tanks. The pump is designed to handle varying sludge consistencies, from liquid to semi-solid.

- **Storage and Containment**: Extracted sludge is transferred into a **sealed storage tank** on the vehicle, ensuring no leakage, spillage, or odor escape during transport. The tanks are designed to be robust and leak-proof to prevent environmental contamination.
- **Transportation**: The vehicle-mounted system facilitates the **safe conveyance** of faecal sludge to treatment facilities or designated disposal sites. The system can navigate urban areas efficiently, thanks to its compact and maneuverable design.
- **Discharge**: At the treatment facility, the sludge is discharged using automated mechanisms, ensuring minimal manual handling and enhanced operator safety.

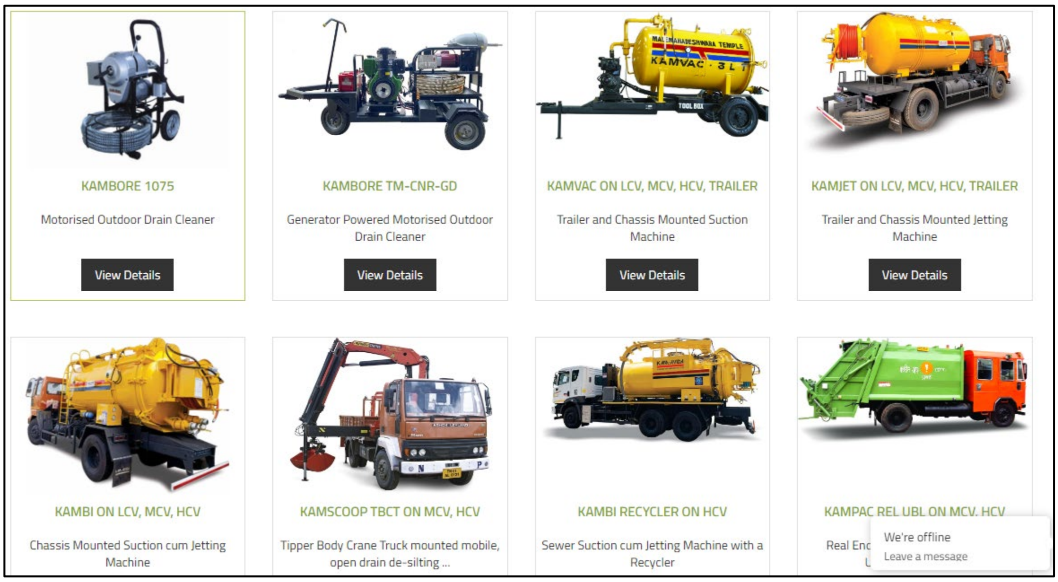


Figure 16: Modern mechanized emptying and conveyance equipment (vehicle mounted) (Kam-Avida, 2024)

Pros	Cons
• Hygienic and Safe: Minimizes human contact with waste, significantly reducing health risks for operators and the community. • Efficient: Capable of handling large volumes of sludge quickly, reducing operational time and costs. • Eco-Friendly: Sealed containment prevents leaks and odor, ensuring minimal environmental impact. • Adaptable Design: Suitable for urban and peri-urban areas, including narrow streets and densely populated regions. • Ease of Operation: Mechanized processes require less physical effort, improving productivity and safety.	• High Initial Cost: The advanced equipment requires significant upfront investment, which may be a barrier for small-scale operators or municipalities. • Maintenance Needs: Regular maintenance and servicing are required to keep the equipment functional and efficient. • Operator Training: Proper training is necessary to ensure effective operation and avoid mishandling. • Dependency on Infrastructure: The effectiveness of the system relies on the availability of suitable treatment or disposal facilities.

Applications:

- Urban and peri-urban areas with high-density populations and limited access to sanitation facilities.
- Municipalities or private operators managing faecal sludge collection and transportation.
- Large-scale sanitation projects requiring efficient and hygienic emptying solutions.
- Emergency response in disaster-affected areas to manage sanitation challenges quickly.

e. **Mobile Treatment Unit (MTU)**: MTU developed by WASH Institute and IISc (Openwater) is an innovative, portable solution for the on-site treatment of faecal sludge and septage. It is designed to address the sanitation challenges of areas lacking fixed infrastructure for waste treatment, providing a flexible and sustainable approach to managing human waste safely and effectively.

How it Works:

- **Collection**: Faecal sludge or septage is collected from septic tanks or pit latrines using vacuum trucks and transported to the MTU.
- **Treatment Process**:
    - **Screening**: Large debris and non-biodegradable materials are removed.
    - **Settling**: Solid and liquid fractions are separated in a settling chamber.
    - **Dewatering**: Sludge is dewatered using filtration or mechanical processes to reduce volume.
    - **Disinfection**: The treated effluent and dewatered sludge are disinfected using chemical or biological methods, making them safe for disposal or reuse.
- **Output**: **Treated Effluent**: Can be safely discharged into the environment or used for non-potable purposes like irrigation. **Dewatered Sludge**: Treated sludge can be used as compost or energy feedstock, depending on the level of treatment.
- **Mobility**: The unit is mounted on a vehicle, enabling it to reach remote or underserved areas. It provides a flexible solution for temporary events, disaster relief, or rural sanitation needs.

Figure 17: Mobile Treatment Units (MTU) (Wash-Institute, 2024)

Pros	Cons
• Portable and Flexible: Ideal for areas lacking fixed treatment	• Capacity Constraints: Best suited for small to medium-scale

facilities, including disaster zones and remote locations. • Eco-Friendly: Promotes safe disposal and resource recovery from faecal sludge. • Cost-Effective: Reduces the need for permanent infrastructure while addressing sanitation needs. • Rapid Deployment: Can be quickly mobilized to areas with urgent treatment requirements. • Promotes Public Health: Ensures hygienic treatment of faecal sludge, reducing disease risks.	applications; may require multiple units for larger populations. • Maintenance Requirements: Regular maintenance is essential for optimal performance and longevity. • Dependency on Skilled Operators: Requires trained personnel to operate and maintain the unit effectively. • Treatment Efficacy: The level of treatment depends on the design and technology used in the MTU.

Applications:

- Remote or rural areas lacking fixed treatment infrastructure
- Disaster relief zones requiring rapid sanitation interventions
- Temporary events like festivals or camps with high sanitation demands
- Urban and peri-urban areas where centralized facilities are inaccessible

The Mobile Treatment Unit offers a **dynamic, sustainable solution** for faecal sludge management, especially in areas with limited sanitation infrastructure. By combining portability with effective treatment processes, it ensures safe waste management, improves public health, and supports sustainable sanitation goals.

f. **Robotic cleaning system for sewers**: The Bandicoot Robot, developed by Genrobotics, is the world's first robotic scavenger designed to eliminate manual scavenging by automating the cleaning of manholes and sewers. This innovative solution enhances the safety and dignity of sanitation workers while improving operational efficiency.

How It Works:

- **Deployment**: Bandicoot is positioned over the manhole, and its robotic arm and expandable bucket system are lowered into the sewer.
- **Cleaning Operation**: The robotic arm, with 360-degree movement and multiple degrees of freedom, mimics human actions to scoop out waste.
- Equipped with a waterproof, high-resolution camera, it provides real-time visuals to the operator, ensuring precise cleaning.
- **Waste Collection**: The collected waste is deposited into an external container for proper disposal.
- **Control and Monitoring**: Operators control Bandicoot remotely via a user-friendly interface, allowing safe operation from a distance.

Figure 18: Robotic cleaning system for sewers (Bandicoot) (Genrobotics)

Pros	Cons
• Enhanced Safety: Eliminates the need for human entry into hazardous manholes, significantly reducing health risks. • Operational Efficiency: Cleans a manhole in approximately 20 minutes, faster than traditional manual methods. • Empowerment: Provides skill development opportunities for sanitation workers, enabling them to operate advanced robotic systems. • Portability: Designed for easy maneuverability in urban areas, including narrow roads and congested spaces. • Environmental Monitoring: Equipped with sensors to detect toxic gases, ensuring safe operation.	• Initial Investment: Higher upfront costs compared to manual methods, though offset by long-term benefits. • Training Requirements: Operators require training to effectively manage the robotic system. • Maintenance Needs: Regular maintenance is essential to ensure optimal performance and longevity.

<u>Applications:</u>

- Urban Sanitation: Ideal for municipalities aiming to modernize sewer cleaning operations.
- Industrial Facilities: Suitable for cleaning confined spaces in refineries and chemical plants.
- Disaster Response: Assists in post-disaster scenarios where manual entry is unsafe.

3.3 Treatment

a. **Decentralized Wastewater Treatment System** (DEWATS): It is an integrated approach to treating wastewater at a small scale, specifically designed for communities, institutions, and small industries. It is a robust, cost-effective, and sustainable solution that combines multiple treatment technologies to manage wastewater locally, reducing environmental and public health risks.

How it Works:

- **Pre-Treatment**: The system begins with a **settler or grease trap** to remove coarse solids and grease from wastewater.
- **Primary Treatment**: Wastewater flows into an **Anaerobic Baffle Reactor (ABR)** or an **Imhoff Tank**, where settleable solids are separated, and organic matter undergoes anaerobic digestion. These processes reduce organic load and prepare the wastewater for further treatment.
- **Secondary Treatment**: Treated water is passed through **anaerobic filters** or **constructed wetlands**, where biological activity further degrades organic pollutants.
- **Final Polishing**: Additional steps like horizontal flow or vertical flow wetlands ensure the removal of pathogens, nutrients, and remaining pollutants. Treated effluent can be reused for irrigation, aquaculture, or safe discharge.
- **Sludge Management**: Sludge from primary treatment is periodically removed, stabilized, and can be used as compost or soil conditioner after proper treatment.

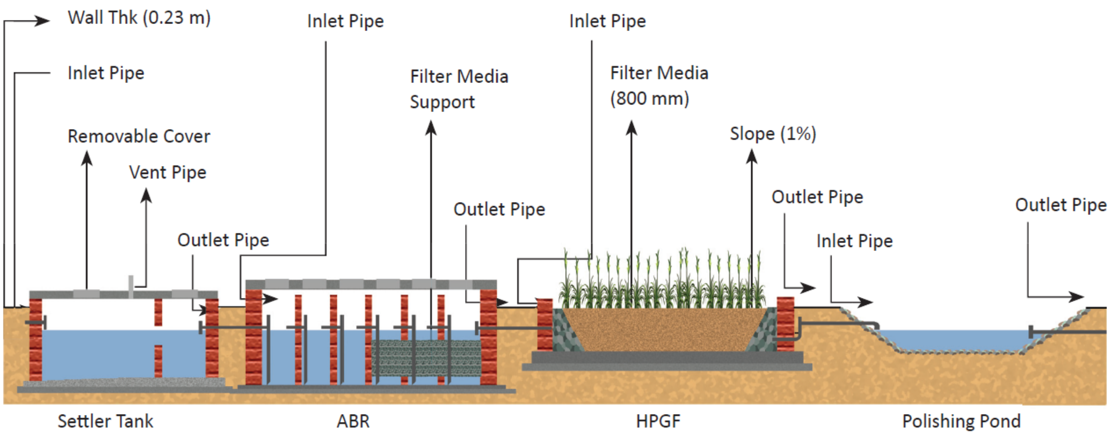


Figure 19: Decentralized Wastewater Treatment Systems (DEWATS)

Pros	Cons
• Can be operated at a range of organic and hydraulic loading rates • Efficient nitrification (ammonium oxidation) • High treatment efficiency with lower land area requirements compared to wetlands	• High capital costs • Requires expert design and construction, particularly the dosing system • Requires operation and maintenance by skilled personnel

	• Requires a constant source of electricity and constant wastewater flow

Applications:
- Rural and Peri-Urban Areas: Where centralized systems are impractical.
- Institutions and Industries: For managing wastewater on-site, including schools, hospitals, and small industries.
- Disaster Zones: Providing a sustainable sanitation solution in temporary settlements or relief camps.

DEWATS exemplifies a sustainable and decentralized approach to wastewater treatment, emphasizing resource efficiency, low-cost operation, and environmental protection.

b. **Sludge Drying Beds + DEWATS** (for fecal sludge treatment): The DEWATS technology, originally designed for decentralized wastewater management, has been innovatively repurposed for fecal sludge and septage treatment to address urban sanitation challenges. This adaptation leverages the inherent flexibility of DEWATS principles, focusing on decentralized, low-energy, and gravity-based treatment processes. The repurposed systems typically involve:
- **Primary Treatment:** Initial separation of solid and liquid waste through screening and sedimentation chambers.
- **Anaerobic Digestion:** Using digesters to reduce the organic load, stabilize sludge, and generate biogas as a by-product.
- **Sludge Dewatering:** Employing unplanted or planted drying beds for efficient dewatering of sludge.
- **Effluent Polishing:** Utilizing gravel filters or constructed wetlands for final effluent treatment to achieve discharge standards.
- **Resource Recovery:** Integrating co-composting units or energy recovery processes to repurpose treated sludge as compost or biogas.

This approach adapts the modular and scalable nature of DEWATS to the specific requirements of fecal sludge management, enabling efficient treatment while promoting sustainability through resource recovery. It has proven effective in areas lacking centralized sewerage systems, supporting local governments and urban bodies in achieving sanitation goals.

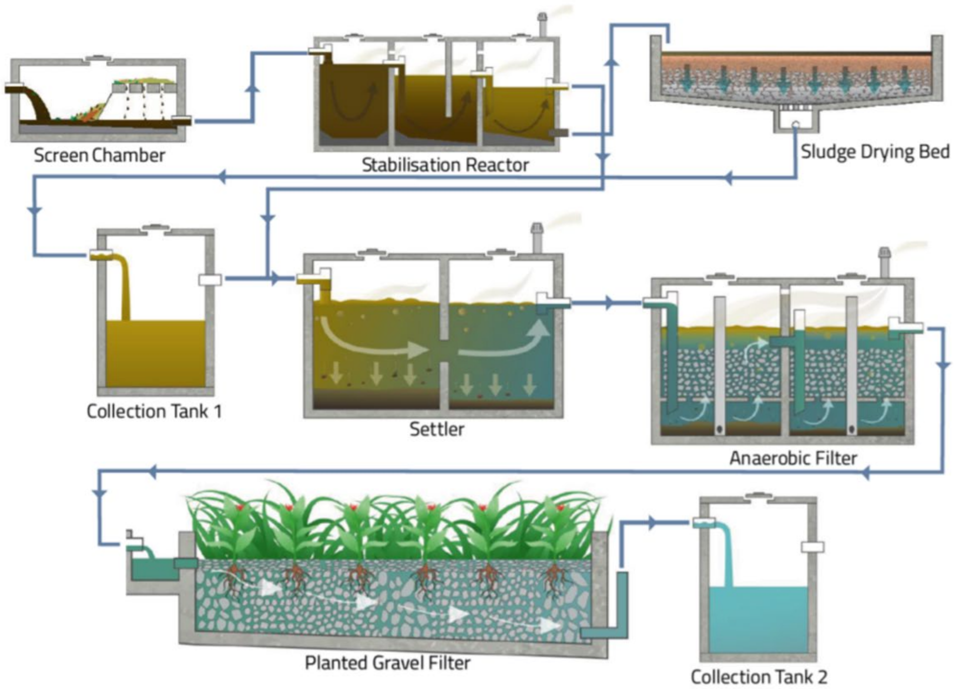


Figure 20: Reconfigured DEWATS for FS treatment

c. **Natural Wetland Systems** – These are ecosystems that play a crucial role in water purification, flood control, and habitat provision. They utilize the synergistic interactions among vegetation, soils, and microorganisms to filter and degrade pollutants from water sources. Leveraging these natural processes, wetland systems offer sustainable solutions for wastewater treatment and environmental conservation.

<u>How They Work:</u>

- Influent Introduction: Wastewater enters the wetland, spreading across the surface or through subsurface flow paths.
- Physical Filtration: As water moves through the wetland, sediments and particulate matter settle out, reducing turbidity.
- Biological Uptake: Wetland plants absorb nutrients such as nitrogen and phosphorus, incorporating them into their biomass.
- Microbial Degradation: Microorganisms in the soil and root zones break down organic pollutants and pathogens, enhancing water quality.
- Chemical Transformations: Processes like adsorption and precipitation remove metals and other contaminants from the water.
- Effluent Discharge: Treated water exits the wetland, often meeting quality standards suitable for discharge into natural water bodies or for reuse in irrigation.

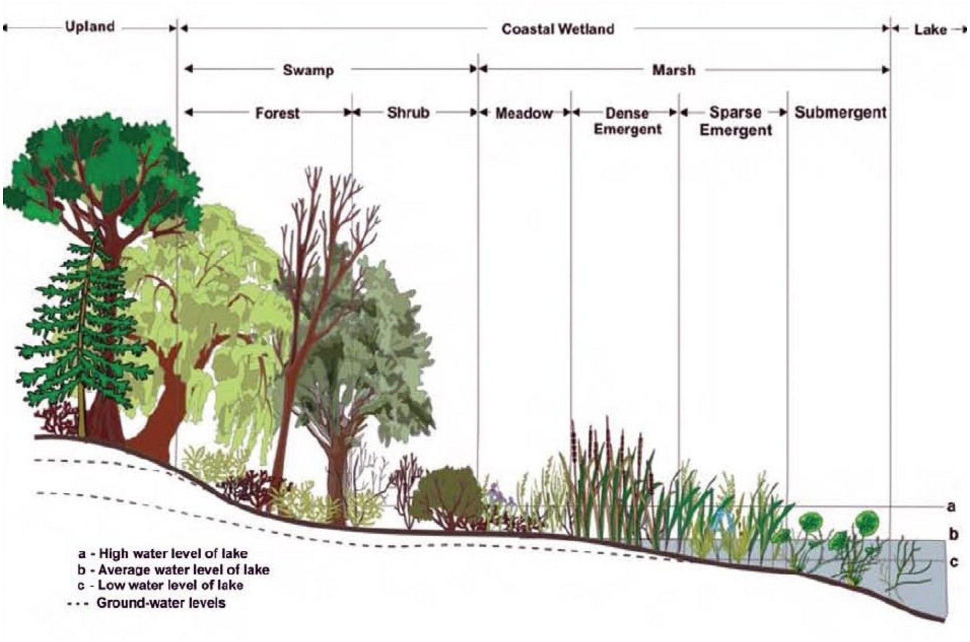


Figure 21: Natural Wetland Systems

Pros	Cons
• Cost-Effective Treatment: Utilizes natural processes, reducing the need for expensive infrastructure and energy inputs. • Biodiversity Support: Provides habitat for a wide range of plant and animal species, enhancing local ecosystems. • Flood Mitigation: Acts as a buffer by absorbing excess rainfall and surface runoff, reducing flood risks. • Carbon Sequestration: Captures and stores carbon dioxide, contributing to climate change mitigation efforts. • Aesthetic and Recreational Value: Offers green spaces for recreation and education, improving community well-being.	• Land Requirement: Requires substantial land area, which may not be feasible in densely populated regions. • Variable Performance: Treatment efficiency can fluctuate with seasonal changes and varying pollutant loads. • Maintenance Needs: Regular monitoring and management are necessary to maintain optimal functionality. • Potential for Mosquito Breeding: Standing water can become a habitat for mosquitoes if not properly managed.

Applications:

- Municipal Wastewater Treatment: Serves as a secondary or tertiary treatment stage for urban sewage.
- Agricultural Runoff Management: Treats nutrient-rich runoff from farmlands, preventing eutrophication in downstream water bodies.
- Stormwater Management: Controls and treats urban stormwater, reducing pollutant loads entering natural waterways.
- Industrial Effluent Treatment: Handles wastewater from industries such as food processing, where contaminants are biodegradable.

d. **Constructed Wetland System**: A Constructed Wetland System is a natural, sustainable solution for treating wastewater by replicating the processes of natural wetlands. It leverages the physical, chemical, and biological interactions within a vegetated filter bed to treat wastewater efficiently, offering an eco-friendly and low-maintenance alternative for decentralized treatment.

How it Works:

- Influent Introduction: Wastewater, including blackwater or greywater, is pre-treated to remove solids and then fed into the wetland bed through evenly distributed inlets.
- Treatment Process:
  - Filtration and Sedimentation: The water flows through layers of gravel and sand, filtering out solids and trapping contaminants.
  - Microbial Action: Microorganisms attached to plant roots and the substrate break down organic matter and remove pathogens.
  - Nutrient Absorption: Wetland plants (like reeds or cattails) absorb nutrients such as nitrogen and phosphorus, aiding water purification.
  - Aerobic and Anaerobic Processes: The system alternates between oxygen-rich and oxygen-poor zones, enabling comprehensive degradation of organic compounds.
- Effluent Discharge: Treated water is collected at the outlet, suitable for reuse in irrigation or safe discharge into the environment, depending on its quality.

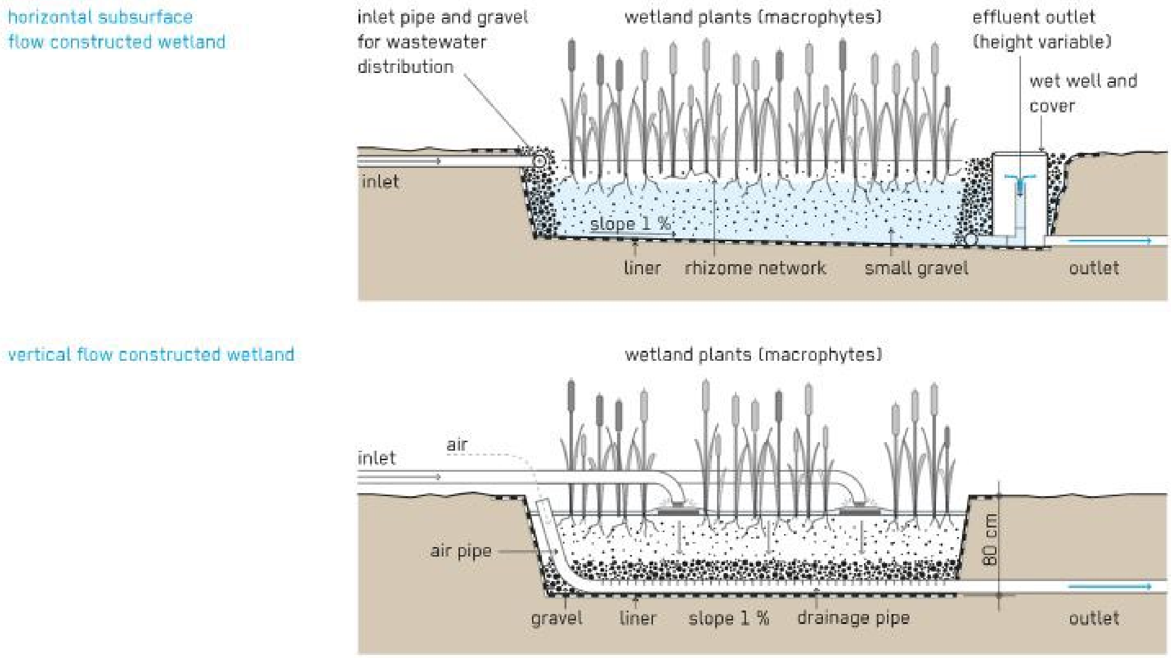


Figure 22: Constructed Wetland System (Tilley, 2014)

Pros	Cons
• Low O & M requirements • Robust treatment performance and resistant to sudden loads of organic material or flow increases • Adaptable to local conditions • Long service life and possible use of the harvest material	• Land requirement • Risk of clogging, depending on pre- and primary treatment • Electric pumps required for intermittent loading of • VF and French VF wetlands (if landscape does not allow gravity-driven systems)

Applications:

- Rural and peri-urban communities with limited access to centralized wastewater treatment.
- Decentralized systems for institutions, schools, and housing complexes.
- Polishing effluent from secondary or tertiary treatment systems.

Constructed Wetland Systems are ideal for communities seeking an environmentally conscious wastewater solution. By combining natural processes with simple design, they align with sustainable sanitation and water management goals

<u>Constructed wetlands for inline treatment of wastewater flowing in natural drains</u>

Constructed wetlands (CWs) are effective solutions for inline treatment of wastewater flowing through large natural or constructed drains. They function by channeling wastewater into wetland zones, where pollutants are removed through sedimentation, filtration, and biological processes. Inline CWs can be designed as Free Water Surface (FWS) wetlands, with wastewater flowing over a planted bed, or Subsurface Flow wetlands, where it filters through a medium like gravel. These wetlands are strategically placed along the drain path to treat wastewater progressively, reducing organic loads, nutrients, and contaminants while improving downstream water quality and promoting ecological restoration.

<u>Conditions for Implementation</u>: The successful implementation of CWs in large drains requires site-specific assessments of flow rates, pollutant loads, and land availability. Pre-treatment mechanisms like grit chambers and trash racks should be installed to remove debris and sediments. Modular designs, including sequential wetland zones, can be aligned with existing drain layouts for phased treatment. Key considerations include ensuring adequate space, preventing waterlogging, and accounting for seasonal variations in flow and temperature. Regular maintenance, such as removal of sludge and invasive plants, is essential to sustain efficiency and avoid clogging, making CWs both a low-cost and eco-friendly intervention.

<u>Case Studies of Constructed Wetlands</u>: Constructed wetlands have been successfully implemented in various urban contexts. In Delhi, the Yamuna Biodiversity Park Wetland treats wastewater from nearby drains, enhancing water quality while creating habitats for native flora and fauna. Similarly, the Alappuzha Canal Restoration Project in Kerala uses CWs to clean urban drain flows, integrating treatment with public green spaces and aesthetic enhancements. These examples demonstrate the scalability and adaptability of CWs in urban and semi-urban areas, addressing water pollution while promoting biodiversity and urban resilience. They serve as models for integrating nature-based solutions into city-level water management strategies.

e. **Trickling Filter system**: The Trickling Filter System is a fixed-bed biological reactor designed to treat wastewater under aerobic conditions. It uses a bed of porous material to support a biofilm of microorganisms, which degrade organic matter as wastewater trickles over the surface. This efficient and cost-effective technology is suitable for semi-centralized wastewater treatment applications.

<u>How it Works:</u>

- Influent Distribution: Pre-treated wastewater is distributed over the surface of the filter bed, typically using a rotating sprinkler or similar mechanism.
- Biofilm Interaction: As the water trickles through the porous filter medium (e.g., rocks, gravel, or specially designed plastic media), organic pollutants are degraded by microorganisms in the biofilm. The biofilm oxidizes organic matter into carbon dioxide and water, producing new microbial biomass.
- Aeration: The design allows air circulation within the filter, ensuring aerobic conditions for efficient degradation of organics.

- Effluent Collection: Treated water exits the bottom of the filter and is collected for further treatment or discharge. Sloughed-off biomass is also carried away with the effluent, necessitating settling or secondary clarification.

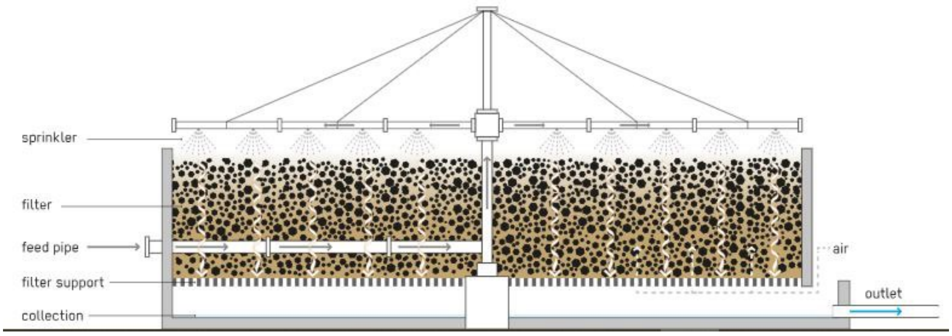


Figure 23: Trickling Filter system (Tilley, 2014)

Pros	Cons
• Can be operated at a range of organic and hydraulic loading rates • Efficient nitrification (ammonium oxidation) • High treatment efficiency with lower land area requirements compared to wetlands	• High capital costs • Requires expert design and construction, particularly the dosing system • Requires operation and maintenance by skilled personnel • Requires a constant source of electricity and constant wastewater flow

Applications:

- Peri-Urban and Rural Areas: Ideal for locations lacking centralized wastewater treatment facilities.
- Institutional and Community Settings: Suitable for schools, hospitals, and residential clusters.
- Industrial Pre-Treatment: Can handle wastewater with moderate organic loads before advanced treatment.

f. **Moving Bed Biofilm Reactor (MBBR) Technology**: It is an advanced biological wastewater treatment process that utilizes free-floating plastic carriers within an aeration tank to support biofilm growth. Developed in the late 1980s by Professor Hallvard Ødegaard at the Norwegian University of Science and Technology, MBBR systems offer efficient and flexible solutions for treating municipal and industrial wastewater.

How It Works:

- Influent Introduction: Wastewater enters the aeration tank containing thousands of polyethylene biofilm carriers.
- Biofilm Development: Microorganisms attach to the surfaces of these carriers, forming a biofilm that degrades organic pollutants.
- Aeration and Mixing: An aeration system keeps the carriers in constant motion, ensuring thorough mixing and oxygen supply for aerobic digestion.

- Effluent Discharge: Treated water exits the tank through sieves that retain the carriers, while the purified effluent moves on for further treatment or discharge.

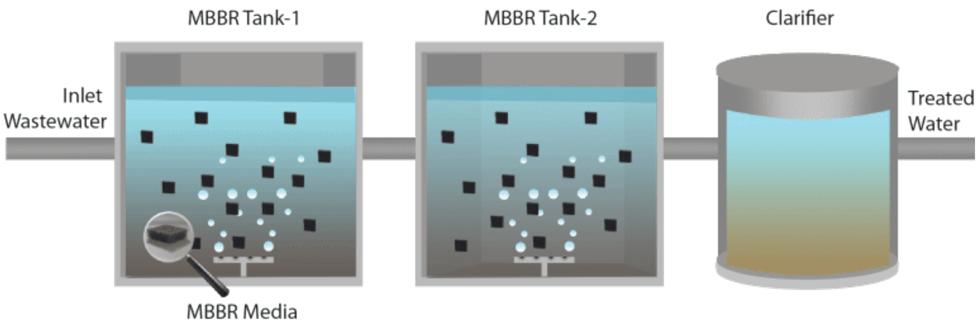


Figure 24: Moving Bed Biofilm Reactor (MBBR)

Pros	Cons
• Compact Footprint: Requires less space compared to traditional activated sludge systems due to higher biomass concentration. • Operational Flexibility: Adapts easily to varying loads without extensive operator intervention. • Low Sludge Production: Generates less excess sludge, reducing handling and disposal costs. • Resilience to Toxic Shocks: Biofilm's protective environment enhances system stability against toxic influents. • Scalability: Allows for capacity expansion by simply adding more carriers, facilitating easy upgrades.	• Carrier Accumulation: Potential for carriers to accumulate at effluent sieves, requiring regular maintenance. • Mixing Challenges: Ensuring homogeneous mixing can be complex, impacting treatment efficiency. • Carrier Loss: Damaged or destroyed carriers may escape the system, necessitating replacement. • Energy Consumption: Aeration systems demand continuous energy input, affecting operational costs.

<u>Applications:</u>

- Municipal Wastewater Treatment: Effectively treats sewage in urban and suburban areas.
- Retrofit Projects: Enhances capacity and performance of existing treatment plants without significant structural changes.
- Decentralized Systems: Suitable for small communities or remote locations lacking centralized infrastructure.

g. **Packaged Treatment (NbS)**: Absolute Water's Packaged Treatment Plant is a nature-based solution (NbS) designed to provide efficient and sustainable wastewater treatment. By integrating natural processes with engineered systems, it offers a compact and effective approach to managing wastewater, particularly suited for decentralized applications.

How it Works:

- **Influent Introduction**: Wastewater enters the system and undergoes preliminary screening to remove large solids and debris.
- **Primary Treatment**: The screened wastewater flows into a sedimentation chamber where settleable solids are allowed to settle, reducing the organic load.
- **Secondary Treatment**: The partially clarified water moves into a constructed wetland or similar biofiltration unit. Here, plants and microorganisms work synergistically to degrade organic matter and remove nutrients.
- **Tertiary Treatment**: Further polishing of the effluent is achieved through additional filtration or disinfection processes, ensuring the water meets quality standards for reuse or discharge.
- **Sludge Management**: Accumulated sludge from the sedimentation chamber is periodically removed and can be treated further for safe disposal or use as fertilizer.

Figure 25: Packaged Treatment (NbS) developed by Absolute Water (absolutewater, 2024)

Pros	Cons
• Sustainable Treatment: Utilizes natural processes, reducing reliance on chemical treatments and minimizing environmental impact. • Compact Design: The packaged system requires less space compared to traditional treatment plants, making it ideal for areas with limited land availability.	• Maintenance Needs: Regular upkeep is essential to ensure optimal performance, including plant care and sludge removal. • Climate Sensitivity: Performance may vary with climatic conditions, potentially affecting treatment efficiency. • Land Requirement: Despite its compact design, the system still

• Energy Efficiency: Operates with lower energy requirements due to the incorporation of passive treatment processes. • Scalability: Can be tailored to various capacities, serving small communities, institutions, or industrial facilities. • Enhanced Biodiversity: The integration of constructed wetlands promotes habitat creation and supports local biodiversity.	requires adequate space for the constructed wetland component. • Initial Setup Costs: The integration of natural and engineered components may involve higher upfront costs compared to conventional systems.

Applications:

- Decentralized Wastewater Treatment: Ideal for rural or peri-urban areas lacking access to centralized sewage systems.
- Institutional Facilities: Suitable for schools, hospitals, and residential complexes seeking on-site wastewater management solutions.
- Industrial Effluent Treatment: Can be adapted to treat specific industrial wastewater streams, ensuring compliance with discharge regulations.
- Temporary Settlements: Provides a viable solution for wastewater treatment in disaster relief camps or construction sites.

h. **Thermal Faecal Sludge Treatment via Pyrolysis** is an advanced thermochemical process that decomposes organic materials in faecal sludge at elevated temperatures under oxygen-deficient conditions. This method effectively reduces waste volume and transforms it into valuable by-products such as biochar, syngas, and bio-oil, contributing to sustainable waste management and resource recovery.

How It Works:

- **Feedstock Preparation**: Faecal sludge is collected and dewatered to achieve the desired moisture content, enhancing the efficiency of the pyrolysis process.
- **Pyrolysis Process**: The prepared sludge is subjected to high temperatures, typically between 300°C and 700°C, in an oxygen-limited environment. Under these conditions, the organic components thermally decompose into solid (biochar), liquid (bio-oil), and gaseous (syngas) fractions.
- **Product Recovery**: **Biochar**: A carbon-rich solid that can be used as a soil amendment, enhancing soil fertility and sequestering carbon. **Bio-Oil**: A liquid fuel that can be refined and utilized for energy production. **Syngas**: A combustible gas mixture that can be used to generate heat or electricity, often utilized within the pyrolysis system to sustain the process.

Figure 26: Thermal FSTP (Pyrolysis)

Pros	Cons
• Volume Reduction: Significantly decreases the volume of faecal sludge, easing disposal challenges. • Pathogen Elimination: High temperatures effectively destroy pathogens, resulting in sanitized end-products. • Resource Recovery: Produces biochar, bio-oil, and syngas, which can be repurposed for agricultural and energy applications. • Environmental Protection: Minimizes greenhouse gas emissions compared to traditional sludge treatment methods. • Energy Efficiency: The syngas generated can be harnessed to fuel the pyrolysis process, reducing external energy requirements.	• High Capital Costs: Initial investment for pyrolysis equipment and infrastructure can be substantial. • Technical Complexity: Requires skilled operation and maintenance to ensure optimal performance. • Feedstock Variability: Inconsistent sludge characteristics can affect process efficiency and product quality. • Regulatory Compliance: Adherence to environmental regulations is essential, particularly concerning emissions and by-product utilization.

Applications:

- Municipal Waste Management: Treatment of sewage sludge in urban wastewater treatment facilities.
- Industrial Waste Processing: Management of sludge from industrial processes, including food and beverage production.
- Decentralized Sanitation Systems: Application in areas lacking centralized wastewater treatment infrastructure.

i. **Co-treatment of Fecal Sludge at existing STPs** - The fecal sludge and septage collected from the onsite systems can be co-treated at exiting STPs, provided they have spare capacities. Some of the key methods used for co-treatment are presented below.

- **Direct addition method** - This method involves directly introducing the waste stream, such as sludge, leachate, or other co-treatment materials, into the treatment system. The material is typically added to the influent stream or specific treatment units like aeration tanks or anaerobic digesters. The direct addition method is simple to implement and requires minimal modification to existing systems. However, careful monitoring of loading rates is essential to prevent overloading the system, which could disrupt treatment efficiency.

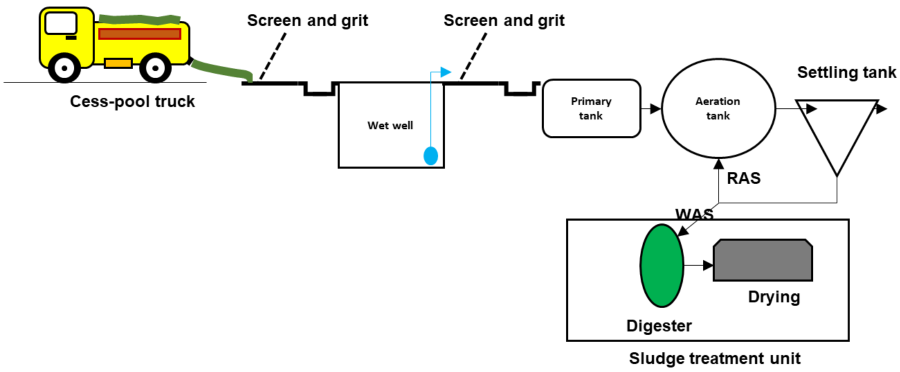


Figure 27: Direct addition method

- **Solid-liquid separation method** - In this approach, the solid and liquid fractions of the waste are separated before entering the treatment system. Solid fractions are treated through methods such as composting or incineration, while the liquid fractions are introduced into the wastewater treatment process. This method reduces the organic and nutrient loading in the liquid stream, thereby enhancing the overall system performance. However, it requires additional infrastructure or equipment for the separation process, which can increase costs.

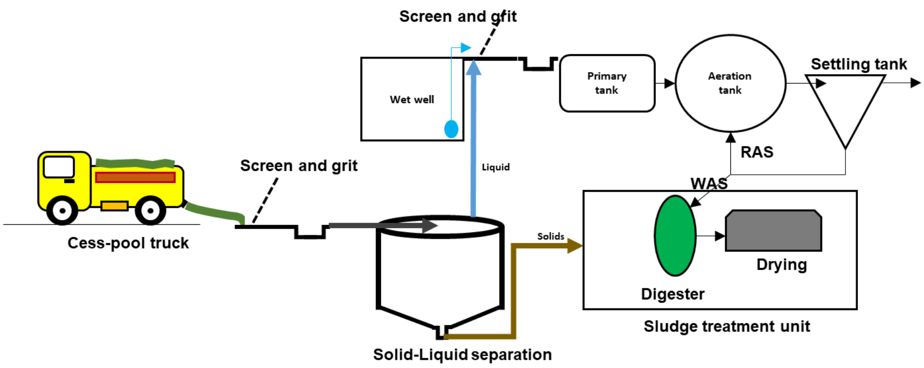


Figure 28: Solid-liquid separation method

- **Loading into solid stream** - This method involves integrating the co-treatment material into the solid waste treatment stream, such as sludge handling or biosolids processing systems. It is particularly suited for waste materials with high solid content or those that can be digested along with biosolids. This approach facilitates resource recovery, such as biogas production or fertilizer generation, and reduces the amount of waste sent to landfills. However, it may require modifications to existing solid waste treatment processes to accommodate different waste characteristics.

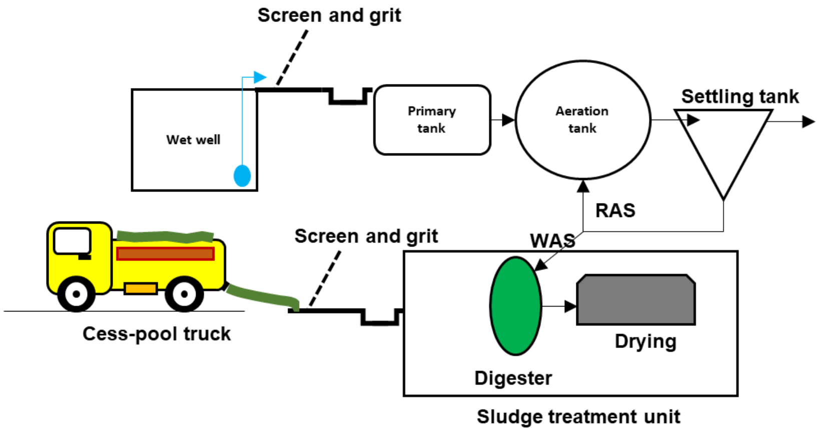


Figure 29: Loading into solid stream

The selection of a co-treatment method depends on factors such as the nature of the waste, treatment plant configuration, and regulatory requirements. Waste characteristics, such as solid or liquid content and contaminant levels, determine its compatibility with specific methods. The design and capacity of the treatment plant influence feasibility, while compliance with environmental regulations ensures legal and operational standards are met. Balancing these factors helps optimize performance, reduce environmental impacts, and ensure sustainability while maintaining cost efficiency.

j. **Technologies for managing fecal sludge during emergencies** (disasters): There predominantly two methods for safely and quickly managing fecal sludge during emergency situations to avoid any public health outbreak. Each of the systems are described below.

- Lime stabilization - The lime stabilization method is a widely used, cost-effective, and rapid approach for managing fecal sludge during emergency situations. This method is particularly suitable for temporary and resource-limited settings, such as post-disaster or conflict scenarios, where immediate measures are required to manage sanitation and prevent public health risks.

  Process Overview: Lime stabilization involves the addition of quicklime (CaO) or hydrated lime ($Ca(OH)_2$) to fecal sludge to:
  - Increase pH to above 12, creating an alkaline environment.
  - Inactivate pathogens by disrupting their cellular structures and inhibiting metabolic processes.
  - Control odors by neutralizing the volatile compounds.
  - Enhance dewatering by altering the chemical structure of the sludge, making it easier to separate water from solids.

  Benefits

- Pathogen Reduction: Alkaline conditions effectively kill bacteria, viruses, and helminths, reducing disease transmission risks.
- Odor Control: Neutralization of ammonia and sulfides reduces offensive smells.
- Rapid Implementation: Lime is readily available, and the process is easy to deploy with minimal technical expertise.
- Cost-Effectiveness: Especially suitable for emergencies due to the low cost of lime and basic equipment needs.

Limitations

- Logistics: Requires a reliable supply chain for lime, which can be challenging in remote or disaster-stricken areas.
- Handling Risks: Lime is caustic and requires safe handling practices to protect workers.
- Temporary Solution: While effective in emergencies, lime stabilization is not a substitute for long-term fecal sludge management systems.
- Environmental Concerns: Overuse of lime can lead to soil alkalinity issues if the treated sludge is applied to land.

Applications

- Post-disaster sanitation management in refugee camps or disaster relief shelters.
- Temporary stabilization of fecal sludge in areas awaiting more permanent sanitation solutions.
- Emergency responses to cholera outbreaks, where rapid pathogen control is critical.

- Disinfection using chlorine - Chlorine disinfection is an effective and widely practiced method for treating fecal sludge during emergency situations. This approach leverages the strong oxidizing properties of chlorine to kill pathogens, minimize public health risks, and ensure the safe handling of waste in temporary and resource-constrained scenarios, such as disaster relief settings or refugee camps.

  Process Overview: Disinfection using chlorine involves adding chlorine compounds (e.g., calcium hypochlorite [$Ca(OCl)_2$], sodium hypochlorite [NaOCl], or chlorine gas [Cl_2]) to fecal sludge. The chlorine reacts with organic and inorganic substances in the sludge, releasing free chlorine (hypochlorous acid and hypochlorite ions) that inactivates pathogens.

  The calculation of chlorine dosage for fecal sludge disinfection depends on the sludge's organic load and pathogen density. Organic load, measured as Biochemical Oxygen Demand (BOD) or Chemical Oxygen Demand (COD), determines the chlorine demand since chlorine reacts with organic matter before targeting pathogens. High organic loads require increased chlorine to achieve effective disinfection. Pathogen density, which indicates the concentration of bacteria, viruses, and parasites, also influences the dosage; a higher density necessitates more chlorine to ensure complete inactivation. Laboratory or field testing of sludge characteristics is essential to optimize chlorine use, balancing efficacy, cost, and environmental impact.

Benefits

- High Pathogen Kill Rate: Chlorine effectively inactivates bacteria, viruses, and many protozoa.
- Rapid Disinfection: Offers quick pathogen reduction, critical during disease outbreaks.
- Odor Reduction: Helps control odors associated with untreated fecal sludge.
- Ease of Use: Simple to implement with basic training and equipment.
- Accessibility: Chlorine compounds are widely available and cost-effective.

Limitations

- Chlorine Demand: High organic content in sludge can increase chlorine demand, reducing efficiency.
- Chemical Handling Risks: Chlorine is toxic and corrosive, requiring safe storage and handling practices.
- By-Products: Disinfection can produce harmful by-products like chlorinated organics and trihalomethanes.
- Limited Effectiveness on Helminths: Chlorine is less effective against certain helminth eggs and cysts compared to bacteria and viruses.
- Environmental Concerns: Excessive chlorine residues can harm aquatic life if not properly neutralized.

Applications

Emergency sanitation in disaster zones, refugee camps, or areas impacted by natural calamities.
Rapid response to disease outbreaks such as cholera or typhoid.
Temporary fecal sludge management in areas lacking infrastructure for long-term waste treatment.

3.4 Reuse or Safe Disposal

a. **Co-composting** (for Reuse of treated FS): Co-composting is a controlled aerobic treatment process that combines faecal sludge with biodegradable solid waste to optimize organic degradation and produce high-quality compost. This method leverages the complementary properties of these materials: faecal sludge provides moisture and nitrogen, while solid waste contributes carbon and bulk, ensuring effective aeration.

How it Works:

- **Feedstock Preparation**: Faecal sludge is mixed with sorted biodegradable solid waste at specific ratios:
  - Dewatered sludge: 1:2 to 1:3 (sludge to solid waste).
  - Liquid sludge: 1:5 to 1:10 (sludge to solid waste).
- **Composting Process**: The mixture is arranged into long heaps (windrows) or placed in a controlled in-vessel system. Aerobic microorganisms break down organic matter, generating heat (55-60°C), which reduces pathogens and stabilizes the material.

- **Turning and Monitoring**: Windrow piles are periodically turned to ensure oxygenation and uniform heat distribution. In-vessel systems maintain controlled moisture and air supply, enhancing decomposition efficiency.
- **Maturation**: Compost is allowed to cure, achieving full stabilization and becoming a nutrient-rich soil conditioner.

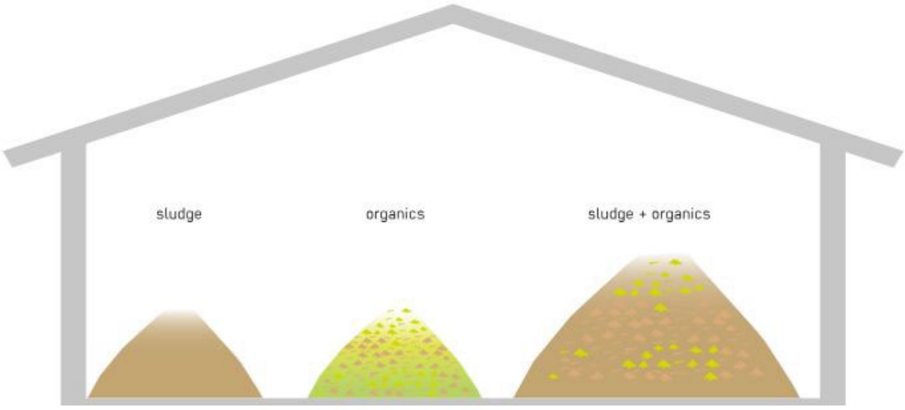


Figure 30: Co-composting with wet solid waste (Tilley, 2014)

Pros	Cons
• Sustainable management of organic waste • Proven, effective treatment method • Can be built and maintained with locally available materials • Valuable end-product available for many uses and can be sold to defray operational costs	• Requires a large, well located land area • Long treatment times • Transport of input products can be costly • Control over input quality is required

Applications:

- Urban and Peri-Urban Settings: Where both faecal sludge and biodegradable solid waste are generated in significant quantities.
- Municipal Solid Waste Management: As a complementary process in integrated waste management systems.
- Agriculture: Producing compost for use as a soil conditioner in farming.

Co-composting is an eco-friendly, low-cost solution for managing faecal sludge and organic waste while producing a valuable by-product. It supports sustainable sanitation and waste management goals, particularly in regions with limited access to centralized treatment systems

b. **Trenching** (for Safe Disposal of FS): Trenching is a method for the safe disposal of faecal sludge, particularly effective in emergency situations or areas lacking adequate sanitation infrastructure. This technique involves excavating trenches to contain and isolate faecal waste, thereby minimizing environmental contamination and health risks.

How It Works:

- **Site Selection**: Choose a location with suitable soil conditions and a safe distance from water sources to prevent contamination.
- **Trench Excavation**: Dig trenches to appropriate dimensions based on the volume of faecal sludge to be disposed of. Ensure trenches are deep enough to contain the waste and allow for soil coverage.
- **Sludge Deposition**: Transport faecal sludge to the site and deposit it into the trenches. Spread the sludge evenly to facilitate decomposition.
- **Covering**: After deposition, cover the sludge with soil to a specified depth, typically 15 cm, to reduce odors and prevent vector attraction.
- **Site Management**: Monitor the site regularly to ensure there is no leakage or surface runoff. Implement measures to prevent unauthorized access and maintain site integrity.

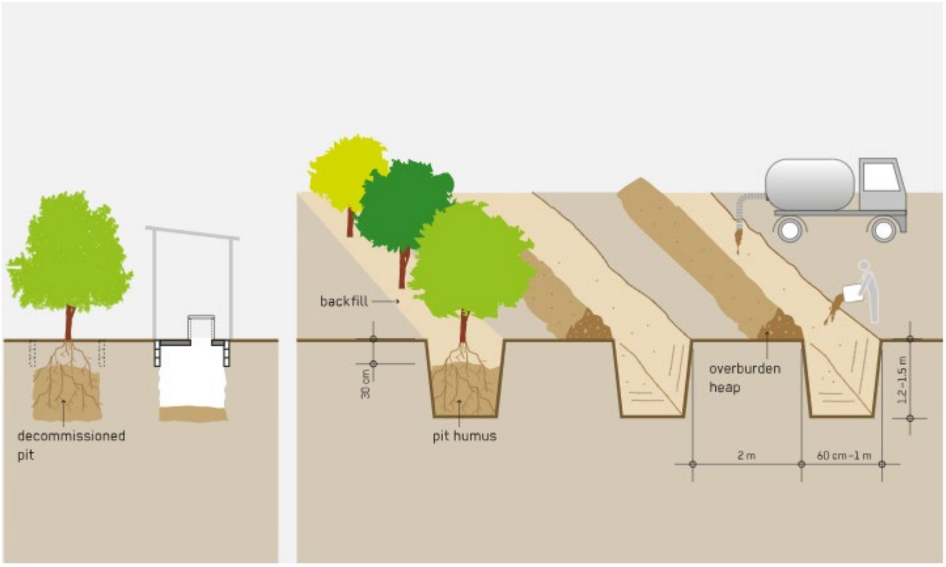


Figure 31: Trenching (shallow and deep row) for safe disposal of fecal sludge (Tilley, 2014)

Pros	Cons
• Rapid Implementation: Trenching can be quickly established, making it ideal for emergency scenarios. • Cost-Effective: Requires minimal resources and infrastructure, reducing financial burdens. • Environmental Protection: Properly managed trenches minimize the risk of groundwater contamination. • Health Safeguarding: Covering sludge reduces exposure to pathogens and deters disease vectors.	• Land Intensive: Requires significant land area, which may not be available in densely populated regions. • Soil Suitability: Not suitable in areas with high water tables or impermeable soils. • Temporary Solution: Serves as a short-term measure; long-term sanitation solutions are necessary. • Potential Odors: Improper covering can lead to unpleasant odors and attract pests.

Applications:

- Emergency Response: Provides immediate sanitation in disaster-affected areas.
- Rural Settings: Applicable in rural communities lacking formal waste treatment facilities.
- Construction Sites: Offers sanitation solutions for temporary labor camps.
- Agricultural Use: Treated sludge can be repurposed as fertilizer, enhancing soil fertility.

3.5 A snapshot of technology options and their applicability

Table 2: A snapshot of technology options and their applicability

Sl. No.	Name of the technology	Type of Used Water		Value Chain Components			
		for Blackwater	for Greywater	Collection	Conveyance / Emptying	Treatment	Reuse/ Safe Disposal
1	**Scientific Septic Tank with Soak Pit**	o		o			
2	**Twin Pit System**	o		o			
3	**Waterless Toilets** (EcoSan toilets)	o		o			
4	**Vehicle mounted compact emptying system**	o			o		
5	**Simplified sewer system**	o	o		o		
6	**Mobile transfer station**	o		o	o		
7	**Modern mechanized emptying and conveyance equipment** (vehicle mounted)	o			o		
8	**Robotic cleaning system for sewers**	o	o		o		
9	**Mobile Treatment Unit**	o			o	o	
10	**DEWATS**	o	o			o	
11	**Sludge Drying Beds + DEWATS** (for FS treatment)	o				o	
12	**Natural Wetland System**	o	o			o	
13	**Constructed Wetland System**	o	o			o	
14	**Trickling Filter system**	o	o			o	
15	**MBBR**	o	o			o	
16	**Packaged Treatment** (NbS)	o	o			o	
17	**Thermal FSTP** (Pyrolysis)	o				o	
18	**Co-treatment of Fecal Sludge at existing STPs**	o				o	
19	**Technologies for managing fecal sludge during emergencies**	o				o	o
20	**Co-composting with wet solid waste**	o					o
21	**Trenching**	o					o

The solutions outlined in this compendium have been tested against the challenges and contexts identified in Uttarakhand's pilot study of seven local bodies. The table below lists probable and recommended solutions across the sanitation value chain for each of these local bodies.

Name of the local body	Local context	Collection system - Solutions	Conveyance systems- Solutions	Treatment systems- Solutions	Disposal/Reuse system- Solutions
Champawat (ULB) (District: Champawat)	Groundwater table is high (1.5 to 3 meters) and at risk of contamination from percolating onsite sanitation systems. During monsoons, households open these systems and empty them into drains, polluting receiving water bodies. Narrow pathways in densely populated areas hinder cesspool trucks' access to septic tanks for emptying.	Septic tanks without soak pits Periodically desludging of septic tanks	Vehicle mounted compact emptying vehicle for faecal sludge Piped conveyance for wastewater from households, routing through existing drains	Sewage treatment plant – DEWATs, constructed wetlands, Packaged STPs Co-treatment of faecal sludge in STPs	Disposal of treated water into natural drains
Khark Kharki and Mudiyani (GPs) (District: Champawat)	sparse and scattered households, with some houses not having road access.	Twin pits	Vehicle mounted compact emptying vehicle for faecal sludge With booster pumps	Nature based faecal sludge treatment plant – such as planted drying beds Grey water: Constructed wetlands near drain end points Community soak pits	Treated water from FSTP can be used for localized usage such as ground water recharge, landscaping
Mussoorie (ULB) (District: Dehradun)	Existing sewage systems, underutilized due to households not connecting. Traffic congestions	Core areas: to connect to sewer network	Connecting to existing sewer system	Conventional sewage treatment systems – MBBR,	Treated water to be discharged into natural water bodies

	and narrow roads, creating issues for faecal sludge transportation	Peripheral or non-sewered areas: Septic tanks without soak pits	Transfer stations for faecal sludge	packaged treatment units Mobile treatment units for faecal sludge from septic tanks or transfer stations	
Barkot (ULB) (District: Uttarkashi)	Large holding tanks used for onsite containment of faecal sludge, with irregular desludging and risking ground water contamination Grey water discharged into open areas	Septic tanks with soak pits (in areas where ground water table is very low)	Drain network to be strengthened and I&D systems implemented to divert wastewater from directly entering into water bodies	Conventional and packaged STP for used water from drains. Co-treatment of faecal sludge at STPs	Treated water to be discharged into natural water bodies
Kharsali (District: Uttarkashi) And Kolukheth (GPs) (District – Dehradun)	Dense settlements in flat lands. Onsite systems used for grey water and black water, however not maintained as per standard procedures.	Twin pits for black water Soak pits for grey water	Vehicle mounted compact emptying vehicle for faecal sludge	Nature based faecal sludge treatment plant – such as planted drying beds Grey water: Constructed wetlands near drain end points Community soak pits	Treated water from FSTP can be used for localized usage such as ground water recharge, landscaping

Section 5: **List of References**

1. absolutewater. (2024, Decemeber 1). *Absolute Water*. Retrieved from www.absolutewater.in: https://absolutewater.in/our-products/#bio-filter-based-stp
2. BORDA. (2015). *Preparing the Urban Governance and Infrastructure Improvement - UGIIP III: Sanitation Action Plans and Technology Demonstrations for 30 Pourashavas.* Manila: Asian Development Bank.
3. CDD India. (2019). Gulper. Bangalore, Karnataka, India.
4. DWSS, 2. (n.d.). Retrieved from Research Gate: https://www.researchgate.net/figure/Latrine-with-septic-tank-and-soakpit-Source-DWSS-2014_fig6_269397287
5. Genrobotics. (n.d.). *genrobotics*. Retrieved from genrobotics.com: https://www.genrobotics.com/ProductPages/bandicoot
6. JALDOBUST(R). (2024, December 1). *Jaldobust*. Retrieved from www.jaldobust.com: https://jalodbust.com/
7. Kam-Avida. (2024, December 1). *Kam-Avida*. Retrieved from www.Kamavida.com: https://www.kamavida.com/
8. McKay, J. (2018). *https://sfd.susana.org/graphic-generator.* Retrieved from https://sfd.susana.org: https://sfd.susana.org/graphic-generator
9. sswm. (2024). *sswm*. Retrieved from www.sswm.info: https://sswm.info/taxonomy/term/3806/trickling-filter
10. Strande, L. (2023). Integrating recent scientific advances to enhance non-sewered sanitation in Urban Areas. *Nature Water*, 405-418.
11. Tilley, E. U. (2014). *Compendium of Sanitation Systems and Technologies (2nd Revised Edition).*
12. Wash-Institute. (2024). *Wash Institute*. Retrieved from www.washinstitute.org: https://www.washinstitute.org/view-gallery.php?view=Mzg=

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