PAPER 12

# SUSTAINABLE ENGINEERING SANITATION INNOVATIONS FOR IMPROVING MUNICIPAL SANITATION SERVICE DELIVERY

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## ABSTRACT

South Africa's municipalities face ongoing challenges such as water scarcity, inadequate infrastructure and rapid urbanization, necessitating resilient and sustainable sanitation solutions. The Water Research Commission's South African Sanitation Technology Enterprise Programme (SASTEP) serves as a model for integrating sustainable engineering principles into the planning, development and implementation of innovative sanitation systems, with great potential to transforming municipal service delivery.

SASTEP's approach aligns with key sustainable engineering principles such as: resource efficiency, adaptability, environmental protection and social equity. The programme has piloted innovative sanitation technologies including low-flush systems, film-based container-based sanitation, Non-Sewered Sanitation (NSS) or Water Efficient Sanitation Systems (WESS), nature-based wastewater treatment systems and sludge beneficiation technologies which demonstrate these principles. These solutions optimize water use, incorporate circular economy principles, reducing reliance on centralized systems and mitigate environmental impacts. For example, low-flush systems significantly decrease water demand, while NSS/WESS supports resource recovery and reuse as well as nutrient recycling.

One of the keys of SASTEP's success lies in designing solutions to address local conditions, such as flood resilience in informal settlements and drought mitigation in water scarce regions. This adaptability ensures that municipal sanitation systems are robust against climate impacts, aligning with principles of resilience and environmental stewardship. Circular economy models promoted by SASTEP integrate waste to resource approaches, turning sludge into fertilizer and other value add products from waste. These innovations align with broader sustainability goals, reducing dependency on finite resources and creating economic value. SASTEP also fosters inclusivity, engaging communities and building local capacity to ensure equitable access to sanitation services. Through SASTEP, eThekwini Municipality and City of Cape Town are piloting some of these innovations to provide climate resilient sanitation services.

## 1. INTRODUCTION

South African municipalities are tasked to address critical challenges related to sanitation service delivery. Rapid urbanisation, water scarcity, infrastructure backlogs, growing informal settlements and climate change continues to create unsustainable pressure on existing sanitation systems (Adeyeye et al.2020). While progress has been made in provision of services, traditional service delivery models often fall short, particularly in reaching and effectively serving marginalized and indigent communities in the informal settlements. These communities frequently present unique challenges that conventional approaches struggle to address. The changing climate exacerbates existing vulnerabilities in these communities, such as increased frequency and intensity of extreme events (droughts, floods, cold spells, heatwaves, hailstorms), rainfall variability, seasonal and temperature variations and rising sea levels and changes in rainfall patterns (Zhou et al. 2022). The topography and density of settlements in these communities also makes it difficult to deploy traditional service delivery approaches, which are further challenged by the impacts of climate change.

In response to this crisis, the South African Sanitation Technology Enterprise Programme (SASTEP), an initiative led by the Water Research Commission (WRC) was established to accelerate the adoption and scale-up of non-sewered, next-generation sanitation solutions. These innovations incorporates sustainable engineering principles, offering practical, decentralised and resource-efficient alternatives to conventional sanitation (UNEP, 2022). This paper explores how SASTEP provides a replicable model for municipal application, highlighting sustainable engineering design, community integration and policy alignment.

## 2. SUSTAINABLE ENGINEERING PRINCIPLES IN SANITATION

The sustainable engineering principles, exemplified by SASTEP, namely resource efficiency, adaptability, environmental protection and social equity, are aligned with globally recognised frameworks, such as that of the United Nations Environment Programme (UNEP, 2022). These principles guide the responsible design, implementation and scaling of engineering systems to ensure long-term resilience, inclusivity and environmental stewardship.

### Resource Efficiency

Sanitation systems supported by SASTEP are designed to minimise water consumption and maximise the efficient use of resources. Key innovations include low-flush toilet pedestals that use as little as 2 to 3 litres per flush, significantly reducing water demand compared to conventional toilet pedestals. In addition, SASTEP is piloting water-efficient backend systems capable of recycling water onsite while recovering valuable resources such as nutrients and energy from wastewater (See Figure 1). Many of these WESS

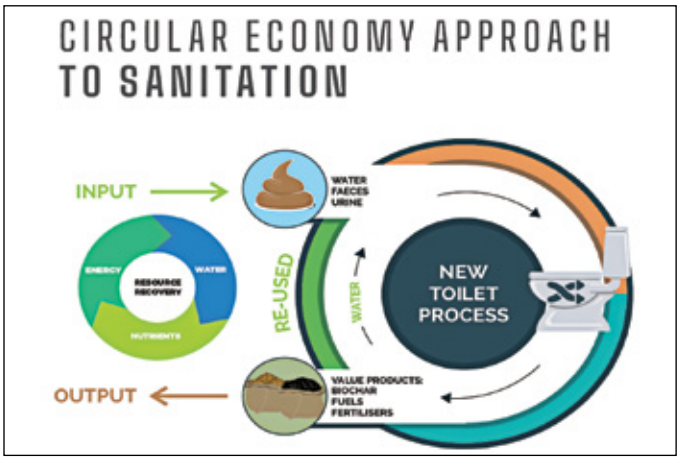


**FIGURE 1:** *Circular economy approach to sanitation through resource recovery*


**FIGURE 2:** *Water and Resource Efficient Toilet Pedestals / Frontend Systems within WRC SASTEP*

## 3. KEY INNOVATIONS IN SASTEP

**Water and Resource Efficient Toilet Pedestals / Frontend Systems**

SASTEP has piloted a range of low flush toilet pedestals designed to reduce water usage while maintaining hygiene and user experience. These technologies use 2 to 3 litres of water per flush and some of them encourage greywater reuse (see Figure 2).

These frontend innovations are critical for reducing water demand in both retrofitted and greenfield projects, particularly in water scarce municipalities.

**Water Efficient Sanitation Systems (WESS)/ Non-Sewered Sanitation (NSS)**

WESS and NSS technologies within SASTEP mostly originated from the Re-invent The Toilet (RTTs) initiative by the Gates Foundation (Gates Foundation, 2011). These systems reduce water consumption by treating and reusing wastewater onsite, transforming sanitation from a water intensive service into a resource efficient and circular economy solution.

These technologies not only address water scarcity but also recover nutrients, produce energy and create new value streams from human waste. The modular, water efficient scalable designs allow for deployment in water scarce and underserved areas as shown in Figure 3.

By shifting from a disposal based approach to a resource recovery model, these innovations present a sustainable, cost-effective solution that aligns with circular economy principles, making sanitation more resilient and adaptable to climate challenges (WRC, 2023).

**Sludge Beneficiation Technologies**

Under SASTEP, sludge beneficiation technologies play a vital role in transitioning sanitation from a linear waste disposal model to a circular economy approach (see Figure 1). These innovations focus on recovering valuable resources from human waste particularly nutrients and carbon-rich materials through processes that are safe, decentralized and scalable. One such solution is the diamond reactor (see Figure 4), a batch treatment system that extracts phosphorus and nitrogen from urine to produce struvite (a slow-release organic fertilizer suitable for local agricultural use).

Additionally, sludge can also converted into high value end products such as biochar, hydrochar and activated carbon through thermal processes (HTC-PCS) and the LaDePa converts sludge into a soil conditioner (WRC, 2023). These products not only reduce the environmental footprint

are powered by renewable energy sources, further enhancing their overall efficiency and reducing dependency on the grid infrastructure (WRC, 2023).

**Adaptability**

SASTEP technologies are designed with contextual adaptability in mind, meaning they can adjust to both current and future climate change impacts. These climate-adaptive sanitation solutions include off-grid systems that maintain functionality during power or water supply disruptions (e.g. load shedding or water cuts) and waterless or low water use technologies suitable for drought prone areas. Non-sewered, decentralised and modular systems are less vulnerable to infrastructure failures often caused by extreme events such as flooding.

Additionally, some technologies feature design flexibility, such as elevated front-end or back-end units that remain operational during climate related events. Most of the technologies piloted through SASTEP incorporate one or more of these adaptive features (WRC, 2023). Their modularity further enhances their suitability, allowing for easy scaling, retrofitting, or relocation based on community needs and space limitations.

**Environmental Protection**

SASTEP innovations contribute to environmental sustainability by promoting onsite treatment, waste separation, nutrient and energy recovery as per figure 1. Faecal sludge management (FSM) is improved through decentralised treatment systems that facilitate the safe reuse of treated outputs. These systems reduce environmental load while producing reusable water, biogas and soil conditioner (TIPS, 2018), thereby supporting both environmental and economic sustainability.

**Social Equity**

SASTEP emphasises inclusion by prioritising sanitation for the most vulnerable communities. Innovations are co-designed with communities to reflect local preferences, cultural norms and gender needs. Women and youth are specifically targeted for training in maintenance, hygiene promotion and system operation, ensuring long-term sustainability and local job creation (Sindal et al. 2021). The programme promotes equitable access to sanitation and dignity for users in schools, informal settlements and rural areas.

**FIGURE 3:** *WESS or NSS within WRC SASTEP*

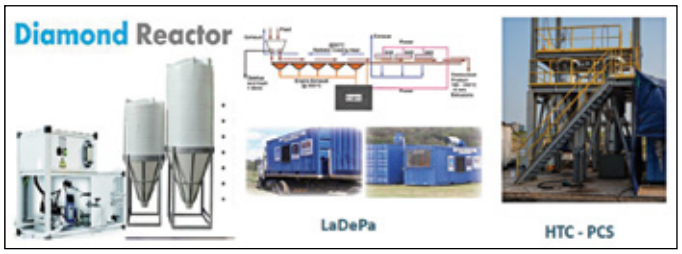


**FIGURE 4:** *Diamond Reactor, LaDePa and HTC PCS*

of sanitation but also open pathways for income generation and local enterprise development in waste valorisation.

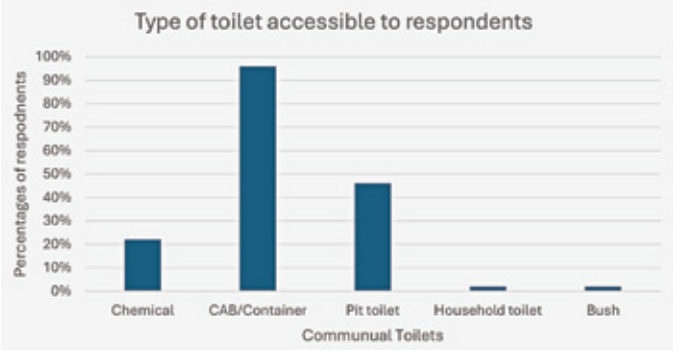


**FIGURE 5:** *Usage of various toilets by respondents*

## 4. MUNICIPAL PILOTING AND IMPLEMENTATION REALITIES

**Climate Resilient Sanitation Demonstration Objectives**

The Water Research Commission, in partnership with the municipalities of eThekwini and the City of Cape Town, embarked on a demonstration of WESS/NSS in informal settlements and underserved areas outside the coverage of sewer networks. Both municipalities were selected by WRC and funders as they are hubs of economic activity with extensive informal settlements experiencing challenges such as frequent floods, drought conditions and storm surges making these areas prone to sanitation challenges and heightened disease risk. The strategic objective is not to only provide sanitation services but also enhance community resilience to natural disasters, strengthen emergency sanitation readiness and evaluate the performance and user acceptance of these innovative sanitation systems. Municipal engineers identified the demonstration sites and the project team then conducted comprehensive needs analysis of selected sites. Municipal engineers also served on the Project Steering Committee (PSC), contributing to decisions at various stages of the project lifecycle.

**Technology Deployment and Site Preparation**

The demonstration involved the installation and commissioning of blackwater and greywater systems, with a minimum 12 months operational period post-commissioning. Before installation, SASTEP and its implementing partners conducted desktop evaluations of various WESS/NSS technologies within SASTEP portfolio against the identified sanitation needs of each site. This process ensured that appropriate technology is matched based on environmental conditions, space availability, community preferences and technical feasibility. A comprehensive site information package was developed for each location to guide technology deployment and installation processes.

**Operational Support and Municipal Capacity Building**

Throughout the demonstration period, operations and maintenance (O&M) responsibilities are managed by the technology partners. A local operator from the relevant municipality was contracted to conduct daily, weekly and monthly operational checks, ensuring system functionality and timely reporting of incidents. Structured classroom and on-site training sessions were conducted for municipal staff, covering preventative maintenance, routine servicing and emergency response protocols.

**Monitoring, Evaluation and Independent Assessment**

Comprehensive monitoring activities included technical performance, water and energy usage, influent and effluent quality and climate resilience parameters. An independent evaluation to assess the system performance, climate resilience, community response and environmental impact is underway. Municipal engineers played an active role in evaluating the project outcomes and are expected to use the findings to support the potential scale-up and integration of these systems into broader municipal sanitation planning.

**User Experience, Hygiene Promotion and Behavioural Change**

Hygiene promotion and behavioural change activities were included as part of the demonstration project. Community workshops promoted best practices and both baseline and endline surveys assessed user acceptance, satisfaction and shifts in hygiene behaviour. Early findings indicate increased user satisfaction, improved hygiene habits and greater community ownership of the new sanitation infrastructure. Figure 5 shows the usage of the newly installed toilet block from one the communities:

**Costs and Sustainability Planning**

The demonstrations included detailed cost assessments covering technology procurement, installation, O&M, training, consumables and security services. During the demonstration period, SASTEP provided funding support, including janitorial services, hygiene consumables and security personnel. Post-demonstration, the municipalities will assume full operational responsibility, guided by comprehensive O&M manuals and handover documents to be provided. Cost ranges for Capex and Opex for WESS/NSS are indicated in Table 1 (specific WESS/NSS could not be provided as this is confidential information).

**TABLE 1:** *Capex and Opex cost for WESS/NSS*

| Capex (Backend only) | Opex (Monthly) | Capacity (Litres/day) | Users (per day) |
|---|---|---|---|
| **R80 000.00 - RI 800 000.00 ($ 4 500.00 - $100 000.00)** | **RIO 000.00 - R22 000.00 ($560.00 - $1240.00)** | **600 - 8 000** | **20 - 1 380** |
| Includes design, supply, installation & commissioning of the WESS/NSS (Backend only)<br><br>Excludes solar supply and Installation | Covers day to day operations, janitor, periodic maintenance, breakdowns, equipment replacement under warranty | Note that WESS/NSS treats blackwater only (Only one system covers both blackwater and greywater) | This includes number of users who are using the WESS/NSS on a daily basis |
| *Note - This are estimatory/budget figures and they are not firm quotes/prices and specifics cannot be provided as this would be divulging into confidential information.* | | | |

**TABLE 2:** *Tools, Products or Guideline developed under SASTEP*

| Products/Tools/Guidelines | Brief description |
|---|---|
| **Field-Testing Guideline** | A document that provides standardised field-testing guideline, assessment and evaluation criteria for innovative technologies |
| **SANS 30500/24521 Awareness and Training Material** | A document that introduces SANS 30500 and SANS 24521, the process of certification and compliance, alignment of these standards with existing regulatory frameworks and the latest development South Africa and Worldwide |
| **Selecting Sanitation Systems** | A document providing a framework for understanding sanitation systems and suggests key criteria to consider in selection of systems |
| **SaniSelect Decision Making Tool** | An MS Excel tool created to assist decision makers in weighing different technology options along the sanitation value chain, based on the criteria considered in selection of sanitation systems |
| **Writing a Sanitation Policy** | A document providing some guidance on how municipalities can craft a sanitation policy |
| **Procurement Processes for Alternative Sanitation Systems** | A document that suggests various approaches to procuring alternative sanitation systems |
| **Cost Comparison Tool for WESS/NSS vs Conventional Sanitation Systems** | A tool for techno-economic cost modelling tool that can used to compare WESS/NSS and conventional sanitation solutions thus increasing sanitation service delivery options and effectiveness |

**Demonstration challenges**

Demonstration challenges included access to sites, which was facilitated by the municipalities, inappropriate user practices such as flushing unsuitable materials and disposing of night buckets into the toilets, these were mitigated through community engagement workshops, delays in municipal approvals which were addressed with the support from municipal engineers, weather-related delays and rework due to substandard quality of work by local contractors. These challenges were vital to inform site selection, user behaviour and contractor management, all of which shapes the roadmap for scaling up.

**Future Outlook and Lessons Learned**

The pilots in eThekwini and Cape Town illustrate the feasibility of deploying innovative sanitation systems in unserved areas. Lessons learned includes the importance of site-specific needs analysis, structured training, early municipal involvement and clearly defined post-project responsibilities. Municipal engineers are expected to lead the integration and scale-up of suitable technologies based on demonstrated success and local context.

## 5. SCALING SUSTAINABLE SANITATION IN MUNICIPALITIES

**Replicability of SASTEP Model**

SASTEP's success lies in its field testing of sanitation technologies in various settings within South African contexts. Municipalities can replicate these models using clear implementation toolkits and operational guidelines as shown in Table 2 developed under SASTEP (WRC, 2022). Technologies are designed for modular deployment, enabling gradual scale-up based on budget availability and community readiness.

**Integration into Municipal Infrastructure**

Municipalities are encouraged to integrate decentralised sanitation into spatial development frameworks, housing upgrades and public infrastructure. Retrofitting public ablution blocks, schools and informal settlements with next-generation sanitation enhances service equity and resilience. Infrastructure grants, disaster response budgets and green funding sources can be leveraged for integration.

**Community Engagement and Capacity Building**

Municipal adoption of these innovations should be accompanied by inclusive community engagement. Local champions, inclusive maintenance teams and hygiene promotion programmes increase system acceptance and reduce vandalism. Municipalities should invest in training to build local technical skills for installation, maintenance and monitoring (Sindall et al.2021).

## 6. POLICY, REGULATORY AND STANDARDS CONSIDERATIONS

**Policy Influence**

Advocacy and technical support provided by SASTEP has significantly contributed to the revision of policy and regulatory frameworks to support sustainable sanitation practices. Through collaboration with the Department of Water and Sanitation (DWS), SASTEP has facilitated mainstreaming of NSS into national policy instruments (See figure 6 below). Key milestones also include the recognition of NSS in the revised national norms and standards for sanitation and its incorporation into the DWS National Sanitation Implementation Plan (NSIP). These policy shift marks a transformative step towards institutionalising alternative sanitation technologies as viable complements to traditional sewered infrastructure.

**Standards Adoption**

SASTEP has also played a vital role in driving the adoption of international standards for WESS/ NSS technologies. South Africa was the second country globally to adopt ISO 30500 an international standard for prefabricated NSS systems through its national equivalent, SANS 30500 in 2019. This inclusion in the national building regulations ensures that NSS technologies are implemented with technical rigour, safety and user acceptability in mind.


**FIGURE 6:** *Greendrop Regulation being amended to include NSS/WESS*


**FIGURE 7:** *Capacity building on WESS/NSS standards*


**FIGURE 8:** *Free Online Self-Paced National Awareness Campaign on NSS/ WESS Standards*

The WRC, in partnership with regulatory stakeholders, continues to support national capacity-building efforts by offering training programmes to familiarise municipal officials, regulators and service providers with these standards (See Figure 7 & 8).

## 7. IMPACT AND CONCLUSION

The alignment of national policies and standards with innovative sanitation solutions has led to increased demand and regulatory readiness for WESS and NSS technologies across municipalities. These changes have established an enabling environment for piloting, scaling and mainstreaming sustainable sanitation innovations nationwide. To date, SASTEP has:

- piloted sanitation innovations in 21 demonstration sites, benefiting over 10,000 users in schools and informal settlements.
- catalyzed national scale-up, with the Department of Basic Education further procuring WES/NSS for 48 schools covering 31,000 learners in 3 provinces (KZN, EC and LP)
- enabled private sector organisations through donors, donations and tenders to procure 21 WESS/NSS (for schools, industrial sites and residential areas) which supported a further 4054 users

To date, SASTEP has enabled dignified, off-grid and water-efficient sanitation access for more than 46,000 individuals, directly addressing service gaps in underserved communities. SASTEP has proven that sustainable engineering principles can be applied effectively to improve municipal sanitation service delivery. WESS/NSS addresses the core challenges, water scarcity, infrastructure deficits, social inequity and environmental impact.

Municipalities across South Africa are encouraged to replicate this approach, tailoring it to local conditions and aligning it with development goals and climate change plans. With appropriate policy support, community engagement and technical capacity, sustainable sanitation innovations can redefine municipal service delivery for a more equitable and resilient future.

## 8. RECOMMENDATIONS

To effectively scale sustainable sanitation solutions, municipalities should integrate decentralised systems into their planning instruments, such as Integrated Development Plans (IDPs) and Water Services Development Plans (WSDPs), particularly for informal settlements and underserved areas. Policy reforms are necessary to enable the adoption of next-generation sanitation technologies by aligning municipal by-laws and building codes with standards like ISO 30500. SASTEP has established demonstration sites showcasing these technologies to build public trust and facilitate learning. Simultaneously, municipalities should invest in capacity building by partnering with local training institutions and NGOs to develop technical skills for installation, operation and maintenance.

In addition, municipalities are encouraged to strengthen public-private partnerships to mobilize resources and co-develop context specific solutions. Inclusive community engagement should be institutionalized, ensuring active participation from women, youth and local leaders to enhance ownership and system sustainability. Monitoring and evaluation systems should be established to track key performance indicators, such as water savings, emissions reduction and job creation.

Lastly, aligning sanitation efforts with national and global sustainability frameworks, such as the Sustainable Development Goals (SDGs) and South Africa's climate commitments, will reinforce the strategic importance of innovative sanitation as a driver of sustainable urban development.

## 9. REFERENCES

Adeyeye, K, Gibberd, J., Chakwizira, J 2020, Water Marginality in Rural and Peri-Urban Communities, Journal of Cleaner Production, vol. 273, 122594

Gates Foundation, 2011, Water, Sanitation and Hygiene: Re-invent the toilet challenge factsheet

Majeke, P, 2023. *Building climate resilience in the sanitation value chain through innovative technologies towards circular economy*, Water Research Commission, Pretoria

Trade Industrial Policy Strategies (TIPS), 2018, *Forward-looking approach to next generation sanitation and industrial development in South Africa*

Pillay, S,2021. *Products that can be made from our Pee and Poop,* Water Research Commission, Pretoria

Sindall, R.C., Cottingham, R., Arumugam, P., Mercer, S.J., Sutherland, C., Alcock, N., Buckley, C.A.

Gounden, G. 2021 *Lessons learned from operating a pre commercialisation field-testing platform for innovative non-sewered sanitation in Durban, South Africa,* Water SA, 47(4).

Sindall, R., Cottingham, R., Sutherland, C., Mercer, S., Pocock, J., Arumugam-Nanoolal, P., Reddy, M, 2021. *Field-testing and Demonstration of Sanitation Technologies: Guidelines for the South African Sanitation Technology Enterprise Programme*. Pretoria.

United Nations Environment Programme (UNEP), 2022. *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*.

Zhou, L.; Kori, D.S; Sibanda, M.; Nhundu, K. *An Analysis of the Differences in Vulnerability to Climate Change: A Review of Rural and Urban Areas in South Africa*. Climate **2022**, 10, 118.