PAPER 17

BUILDING CLIMATE RESILIENCE IN THE SANITATION VALUE CHAIN THROUGH INNOVATIVE TECHNOLOGIES TOWARDS CIRCULAR ECONOMY

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ABSTRACT

It is becoming increasingly recognised that poorly managed sanitation and wastewater systems are not only a big contributor to greenhouse gas emissions, but also that climate change threatens existing sanitation systems and public health progress made over the years. Households that have gained access to basic or safely managed sanitation services risk losing them during extreme climate related disasters. There is a need to research, develop and demonstrate innovative sanitation technologies that are climate resilient and promotes circular economy principles within sanitation value chain and the purpose of this paper is gauge developmental status and progress of these technologies.

Water Research Commission (WRC) has prioritized research and innovation that links climate change and sanitation through the South African Sanitation Enterprise Programme (SASTEP). Through SASTEP, WRC is evaluating and demonstrating innovative sanitation technologies that are off grid, climate resilient and promotes circular economy within sanitation value chain through water efficiency, water reuse and nutrients recovery from human waste. It has been found that most of these technologies are both mitigative and adaptive with regards to climate change and they could be considered when selecting sanitation systems that considers future climatic projections to ensure sustainable sanitation systems in the face of climate change.

Keywords: Sanitation, circular, climate, demonstration, mitigation, adaptation

1. INTRODUCTION

It is becoming increasingly recognised that poorly managed sanitation and wastewater systems are not only a big contributor to carbon emissions, but also that climate change threatens existing sanitation systems and public health progress made over the years. Households that have gained access to basic or safely managed sanitation services risk losing them during extreme climate related disasters. There is a need to research, develop and demonstrate innovative sanitation technologies that are climate resilient and promotes circular economy principles within sanitation value chain.

Climate change is a worldwide crisis. As temperatures and sea levels rise, people around the globe are increasingly experiencing heat waves, droughts, foods, cyclones and wildfires. The effects of climate change are not equal, the most impact is felt by the poor and marginalized communities of our society. Weather patterns are increasingly becoming less favourable and the frequency as well as severity of extreme events is increasing as temperatures are projected to continue rising and rainfall patterns are expected to shift. This will result in frequent flooding, heatwaves, droughts, storms and sea level rise of which all has ripple effects on people and environment.

Climate change impacts water availability of which is going to have negative impact on people, ecosystems and the economy. This in in turn, exacerbates risks for water security, of which has negative effects on those sectors heavily depends on water such as agriculture, electricity generation, mining and industrial activities. Water is becoming more and more polluted by human activities due to inadequate sanitation, open defecation practices and wastewater treatment plants that are discharging sub-standard effluent into water bodies (DWS, 2022 Greendrop report).

The Intergovernmental Panel on Climate Change (IPCC) has stated that *"the relationship between climate change mitigation measures and water is a reciprocal one"* (IPCC,2008). This relationship between climate change and water means that investing in climate resilient water and sanitation services is a vital part of solving the worldwide climate crisis. Supporting adaptation and climate resilient water and sanitation services makes sense from a financial point of view for both governments and users. It was indicated in COP27 recently in Egypt that for every dollar ($) spent on water and sanitation services resilience equates to 21 dollars ($) in return and for every dollar spent on water flood resilient upgrades equates to 62 dollars ($) saved in flood restoration costs.

2. A NEED TO MOVE TOWARDS CLIMATE RESILIENT SANITATION SOLUTIONS

There are untapped opportunities for the water and sanitation sector to contribute reductions in greenhouse gas emissions. These opportunities include improving water and energy efficiency by integrating the use of renewable energy wherever possible for water and sanitation technologies, shifting to cleaner, more efficient sanitation and treatment processes for wastewater and excreta disposal. The National Development Plan 2030 (NDP), DWS National Master Plan and Department of Trade Industry and Competition's Industrial Policy Action Plan 2017-2020 (IPAP) supports the shift towards waterless, off-grid sanitation systems and water recycling system.

At the National Sanitation Indaba on 18 May 2015, Mrs Nomvula Mokonyane, the then Minister of Water and Sanitation said that:

"We must introduce new technologies that appreciate that water is a scarce resource and as such provide solutions to dispose of effluent via alternative methods. It's not all about flushing and that is the Sanitation Revolution we are here to instigate, we must begin by challenging the property development sector through regulation and licensing requirements to invest itself in developing properties less reliant on water for sanitation in order to ensure we introduce the alternative solutions to low, middle- and high-income areas" (https://www.gov.za/speeches/national-sanitation-indaba-18-may-2015-0000).

The National Water and Sanitation Master by DWS in 2016 identified that there is a need to develop, demonstrate and validate appropriate alternative waterless and off grid sanitation solutions by 2024. Department

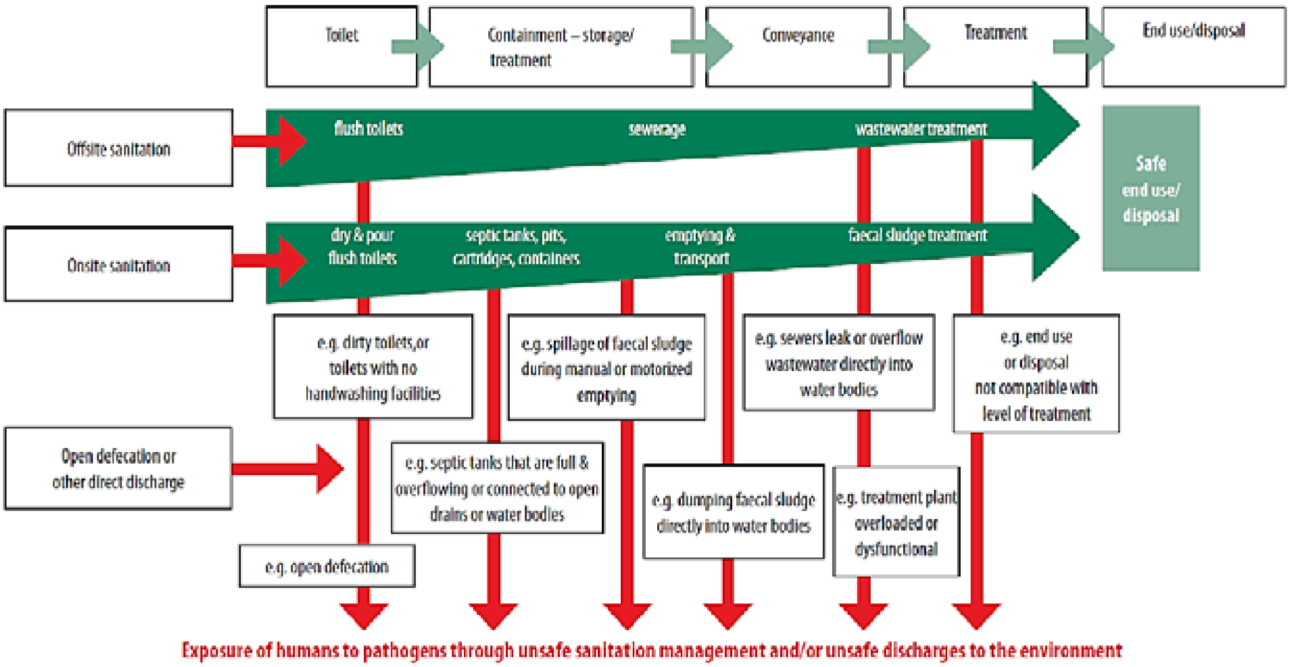

FIGURE 1: *Excreta flow diagram showing examples of climate related hazardous events at each step of the sanitation service chain (adapted from Peal et al., 2014)*

of Trade, Industry and Competition, through the IPAP 2017-2020 then also identified that the development of off-grid sanitation technologies will lower water requirements for sanitation and that will enable reallocation of water to alternative needs, economic sectors and more effective service delivery in rural, peri-urban and water-scarce areas. This paper aim to unpack the developmental status and progress of innovative technologies that are climate adaptive and resilient.

3. CLIMATE CHANGE IMPACT ON SANITATION

The sanitation value chain comprises of collection/storage, transport/ conveyance, treatment, and discharge/disposal or recycle/re-use (figure 1). Each area of the chain is vulnerable to the effects of climate change and examples of some of the vulnerability are briefly discussed below:

3.1 Collection/storage

In areas that not connected to sewer systems, on-site sanitation systems (septic tanks, conservancy tanks, pit toilets) are typically used and these systems are susceptible to adverse weather conditions and climate change as they can become flooded, overflow and pollute the environment (USAID, 2015). Flooding may also result in the areas with on-site sanitation becoming isolated, leading to them not being emptied as they may not be accessible during floods roads.

3.2 Transport/conveyance

In urban areas, sewage is typically conveyed through a system of pipes, pumps, and other associated infrastructure to a centralised wastewater treatment plant. These sewer systems may be damaged by extreme climatic events and cause uncontrolled discharge of raw wastewater into water resources (DEFRA, 2012), which can lead to pollution of the water resources water (Howard *et al*., 2016). This was experienced in eThekwini Municipality during the floods in April 2022 where sanitation infrastructure was damaged.

Overflow of wastewater discharge onto streets or open ground poses health risk to people and animals (DWS, 2016; EPA, 2004). Long periods without any rainfall cause the degradation of sewers and the resulting accumulation of solid waste sediments can cause blockage which can result in backflow of raw sewage.

3.3 Treatment

Wastewater treatment plants are mostly located on low-lying areas as sewer systems rely on gravity, however this makes them vulnerable during flooding or sea-level rise. Declining annual rainfall or drought leads to unavailability of water required to flush adequately and accompanying higher temperatures can have an impact on how sewage systems operate. Every extreme climate event (flooding or drought) affects the influent water quality of the wastewater treatment plants and that negatively impacts the operating efficiency and treatment ability of the plants. (Howard *et al*., 2016).

3.4 Discharge/disposal

Flooding and drought affect the water quality of the receiving water bodies as the quality of the effluent is dependent on the volume of effluent discharge in the water resources (Miller & Hutchins, 2017). Drought has been observed to reduce the capacity of surface water to dilute, attenuate and remove pollution (DWA, 2013).

4. RESEARCH OBJECTIVES

WRC has prioritized research and innovation that links climate change and sanitation. WRC initiated South African Sanitation Technology Enterprise Programme (SASTEP) which is jointly funded by the Department of Science and Innovation (DSI) and the Bill and Melinda Gates Foundation (BMGF) to demonstrate and commercialize appropriate sanitation technologies that are able to address the South African sanitation needs and challenges. Through the SASTEP programme, WRC aims to scan, evaluate and demonstrate innovative sanitation technologies that are off grid, climate resilient and promotes circular economy within sanitation value chain through water efficiency, water reuse and nutrients recovery from human waste. This paper draws data from the SASTEP programme to measure the developmental status and progress of innovative sanitation technologies.

The technologies were classified according to the following categories:

- Front end solution that requires little or no water for flushing
- Urine diversion technologies
- Off-grid faecal sludge treatment technologies
- Off-grid blackwater treatment technologies
- Innovative off-grids sanitation solutions that produce beneficial products from sanitation waste

The above-mentioned technologies are climate mitigative and adaptive in nature and these is discussed briefly below:

4.1 Mitigation

Mitigation infers to those technologies that results in lower release of greenhouse gases to the atmosphere. Previous studies indicate that improving water and energy efficient as well as recovering resources from wastewater (nutrients, energy and water) lead to less emissions of greenhouse gases (GHG) as shown figure 2. Figure 2 assist in classifying if the technology is mitigative due its contribution toward emission of GHGs.

Technologies on the SASTEP portfolio are mitigative as they are in the following categories:

- Water reuse and recycling technologies
- Sludge beneficiation technologies (fertilizer, energy, biogas, etc.)
- Technologies that recover nutrients from urine
- Technologies that recover water and beneficiate sludge

Some of the technologies can run off-grid (uses renewable energy) not only reducing the GHGs but also contributing to the growing the 'green economy'.

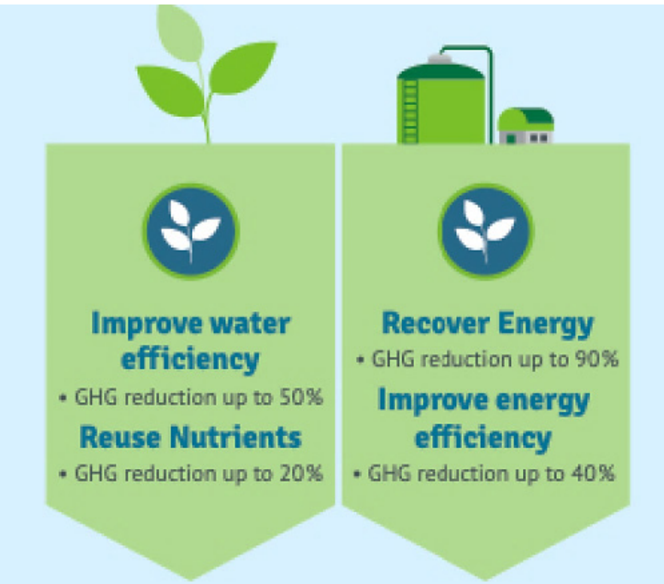

FIGURE 2: *GHG reduction for water and sanitation facilities (From Ballard, et al. (2018). Roadmap to a Low-Carbon Urban Water Utility. IWA.)*

4.2 Adaption

Adaptation infers to those technologies that adjust to the current and future effects of climate change. Climate adaptive sanitation technologies includes:

- Off-grid solutions as they improve resilience during grid outages (e.g loadshedding/water cuts)
- Technologies that require no water or are waterless in case of drought.
- Non-sewered/decentralized/modular systems are considered less vulnerable to compared to centralized system that depends on infrastructure that may have damaged during the extreme climate event such as flooding.
- Technologies that have adaptive capacity through potential design changes (e.g raising of front end or backend such that it is still accessible during flooding)

Most of the technologies within SASTEP can be considered climate adaptive as they have one or more of the above-mentioned climate adaptation pathways.

5. DEMONSTRATION ON INNOVATIVE SANITATION TECHNOLOGIES

WRC conducted a technology scan of existing late-stage development innovations with Technology Readiness Level (TRL) 7-9 that met the above-mentioned categories and those meeting the requirements were shortlisted for demonstration and localization. Before going on to demonstrate any technology, WRC conducts due diligence assessment for intellectual property, technology transfer agreements and as well as capability assessment of the organizations that are interested in demonstrating innovative sanitation technologies.

Once due diligence is completed and funds to demonstrate are available, then shortlisted innovative sanitation technologies are demonstrated of the field. The field demonstration is essential in gathering scientific and technical based evidentiary information on the sanitation technology. The demonstration might be between 3-12 months depending on the technology and the aims of the demonstration. The demonstration allows data collection and evaluation of technologies which then informs the developmental progress of each technology and hence assist in achieves the objectives of this research.

6. RESULTS

There are number of climate resilient and innovative sanitation technologies that have been evaluated and demonstrated by WRC in various settings such as schools, informal settlements and rural areas and most of them are market ready. The results discussed below are from field demonstrations of innovative sanitation technologies under the WRC SASTEP programme. The next section briefly describes each technology, its development status, climate adaptative and mitigation pathways.

These technologies are categorized as follows:

- Reuse or recycles water
- Beneficiate sludge (fertilizer, energy, biogas, etc.)
- Recovers nutrients from urine
- Recovers water and beneficiate sludge

6.1 Technologies that recover or recycles water

6.1.1 Clear Recycle Toilet Description

The Clear toilet uses a full water recycling process for treatment of the sewage. An advanced unique "Biofilm Membrane Bio Reactor" treatment process is employed as the core technology for treatment, producing a stable and clean effluent that is further disinfected to ensure safety of the effluent for reuse.

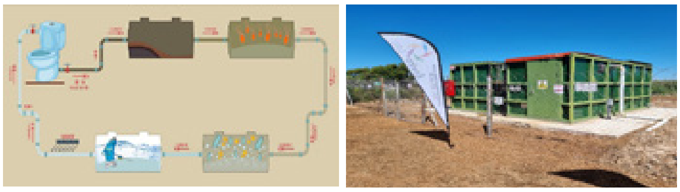

FIGURE 3: *Enviro Loo Clear Recycle Toilet Process (Left) and demonstration (Right)*

TABLE 1: *Clear Recycle Toilet development and climate change aspects*

Development status	Climate mitigation aspect(s)	Climate adaptation aspect(s)
• Demonstrated in schools and informal settlement • Locally manufactured. • TRL 9 (Market ready)	• Fully recycles effluent for flushing • Lower energy consumption • Can be off grid if solar is used • Does not require continuous water supply for operation	• Can be off grid if solar is used • Does not require continuous water supply for operation • It is non-sewered and modular • Has adaptive capacity through potential design changes

6.1.2 Aquonic Tank Recycle Toilet description

The Aquonic is a modular and decentralised wastewater treatment plant that turns blackwater and greywater into pathogen-free reusable water that can be used for toilet flushing and irrigation. It treats wastewater through a series of biological processes and electro-chemical disinfection.

FIGURE 4: *Aquonic Recycle Toilet process (Left) and Demonstration (right)*

TABLE 2: *Aquonic Recycle Toilet development and climate change aspects*

Development status	Climate mitigation aspect(s)	Climate adaptation aspect(s)
• Demonstrated in commercial and residential units • Locally manufactured • TRL 9 (Market ready)	• Fully recycles effluent for flushing • Lower energy consumption • Can be off grid in solar is used	• Can be off grid if solar is used • Does not require continuous water supply for operation • It is non-sewered and modular • Has adaptive capacity through potential design changes

6.1.3 Dewdrop Nature Based System description

The DEWdrop is a decentralized ecological wastewater treatment system with a modular design that provides convenient reuse greywater for toilet flushing, car washing and garden watering. The treatment process includes the anaerobic baffled reactor, a constructed wetland, tree filters and biochar filters.

FIGURE 5: *DewDrop Recycle Toilet Process (Left) and Demonstration (Right)*

TABLE 3: *Dewdrop Recycle Toilet development and climate change aspect*

Development status	Climate mitigation aspect(s)	Climate adaptation aspect(s)
• Demonstrated in schools • Locally manufactured • TRL 9 (Market ready)	• Fully recycles effluent for flushing • Lower energy consumption • Can be off grid in solar is used	• Can be off grid if solar is used • Does not require continuous water supply for operation • It is non-sewered • Has adaptive capacity through potential design changes

6.2 Technologies that beneficiate sludge

6.2.1 LaDePa Description

LaDePa is a machine that provides a containerized method of processing sludge into a nutrient rich soil conditioner. The technology removes the detritus, pasteurizing and drying the sludge to beyond the sticky phase.

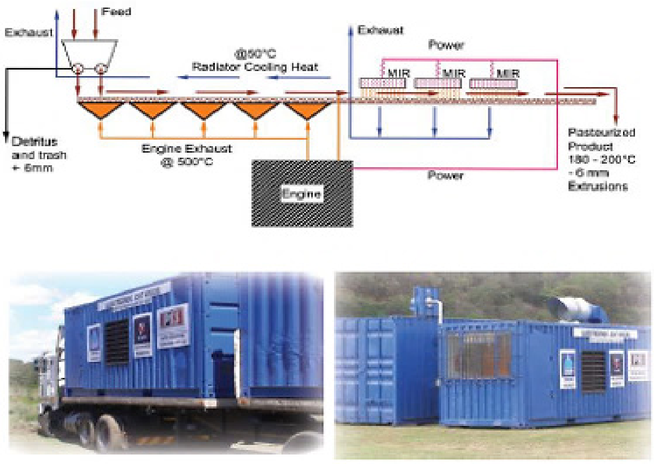

FIGURE 6: *LaDePa Process (Up) and Demonstration (Down)*

TABLE 4: *LaDePa development and climate change aspects*

Development status	Climate mitigation aspect(s)	Climate adaptation aspect(s)
• Demonstrated at low scale • Large scale pilot in the pipeline • Locally manufactured • Technology at TRL 8	• Beneficiates sludge to a soil conditioner	• It is modular • Has adaptive capacity through potential design changes

6.2.2 Enhanced Hydrothermal Carbonisation (EHTC) Description

Enhanced Hydrothermal carbonisation (EHTC) converts sludge predominantly into a carbon-rich hydrochar solid products using high temperature and high pressure. The feed sludge can be digestate, sewage sludge, municipal organic waste and other carbon rich wastes.

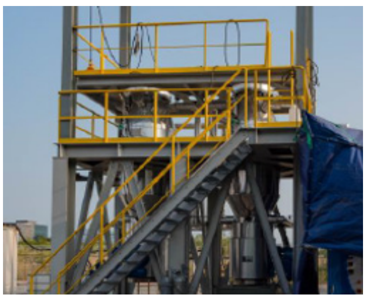

FIGURE 7: *Enhanced Hydrothermal Carbonisation Process*

TABLE 5: *EHTC development and climate change aspects*

Development status	Climate mitigation aspect(s)	Climate adaptation aspect(s)
• Demonstrated at low scale • Large scale pilot in the pipeline • Locally manufactured • Technology at TRL 8	• Beneficiate sludge to various carbon-rich solid products depending on feed waste	• It is modular • Has adaptive capacity through potential design changes

6.3 Technologies that collect urine to recover nutrients and water

6.3.1 Diamond Reactor description

An automated nutrient recovery system which recovers high value fertilizer and water from urine without the need for connections to sewers, treatment plants, water supplies or continuous electricity.

FIGURE 8: *Struvite Reactor Units*

TABLE 6: *Diamond Reactor development and climate change aspects*

Development status	Climate mitigation aspect(s)	Climate adaptation aspect(s)
• Demonstrated in commercial and public buildings • Fertilizer produced going through DAFF Approval • Locally manufactured • Technology at TRL 9	• Recovers water and struvite from urine • Can be off grid in solar is used	• Can be off grid if solar is used • It is non-sewered and modular • Has adaptive capacity through potential design changes

6.4 Technologies recover water and beneficiate sludge

6.4.1 NEWgenerator Recycle Toilet description

The NEWgenerator a compact, portable, and modular resource recovery machine that eliminates waste while recovering fertilizer nutrients, renewable energy and clean water. It consists of an anaerobic baffled reactor as well as a nanomembrane filter which allows the generation of liquid fertilizer and biogas that can be collected and harvested for cooking/heating.

FIGURE 10: *NEWgenerator Process (Left) and Demonstration (Right)*

7. DISCUSSION

As shown in the previous section, most of the innovative sanitation technologies within the WRC SASTEP programme has both mitigative and adaptive aspects with regards to climate change. These technologies at advanced technology readiness level and have a potential to not only to offer access to dignified sanitation that minimizes pollution, enables valorisation and promotes health, safety and water security but also alleviates to climate change through reduction of greenhouse gas (GHG) emissions and they are adaptive to drought by not requiring continuous water supply for operation. They also have adaptive capacity to floods

TABLE 7: *NEW generator development and climate change aspects*

Development status	Climate mitigation aspect(s)	Climate adaptation aspect(s)
• Demonstrated in schools and informal settlement • Locally manufactured • TRL 9 (Market ready)	• Fully recycles effluent for flushing • Lower energy consumption • Can be off grid in solar is used	• Can be off grid if solar is used • It is non-sewered and modular • Has adaptive capacity through potential design changes

through potential design changes such as raising of front end and or backend such that it is still accessible during flooding.

WRC will be further demonstrating some of these innovative sanitation technologies in the City of Cape Town as a measure to drought that has been experienced and also in eThekwini Municipality due to floods experienced that has damaged existing sanitation infrastructure.

8. CONCLUSIONS

On-site sanitation facilities and wastewater treatment plants emit varying amounts GHGs therefore, therefore technology choice during planning can exacerbate or alleviate climate change. WRC through the SASTEP programme is demonstrating several technologies are available for moving towards climate resilient and resource efficient sanitation value chain with each at advanced technology readiness levels. Some of these technologies address both climate adaptation and mitigation pathways simultaneously by being water or energy efficient, reducing GHG emissions as well as being off grid.

9. RECOMMENDATIONS

It is recommended that:

- the selection of appropriate sanitation technologies should also be based on screening their vulnerability and adaptability to different climate scenarios apart from technical, financial, economic, social and environmental considerations.
- selected climate-resilient sanitation technologies should have relatively low vulnerability and high adaptability to climate change.
- existing infrastructure and technologies should be assessed for climate change resilience and robustness and be modified to reduce the adverse impacts of climate related events where possible.
- Water and Sanitation Engineers should consider climate resilient and resource efficient sanitation technologies in planning and implementation of sanitation projects to ensure sustainable sanitation service provision in the face of climate change.

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