Scoping Study Towards Developing a WEF Framework for Decentralised Sanitation in Rural and Peri-Urban Communities in Limpopo

Report to the
Water Research Commission

by

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WRC Report No. 3112/1/23
ISBN 978-0-6392-0575-5

January 2024

OBTAINABLE FROM
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This is the final report for WRC project no C2021/2023-00517.

Executive Summary

Background

Research and development in the Water-Energy-Food (WEF) nexus touches on numerous interrelated problems that are still experienced in low-income communities in South Africa. Almost a third of South African children live without basic nutrition and other essentials. Universal access to water, sanitation and hygiene (WASH) in peri-urban and rural villages in Limpopo has not yet been achieved. Commercial farming and the production of fertiliser are energy intensive, and often unaffordable for smallholder farmers (SHFs).

Are suitable alternative solutions available or possible?

Much research has been done on technical solutions for decentralized sanitation, and a variety of technologies are available to manage sanitation on-site and to use the waste productively for food production or energy generation. However, similar to many technology-driven development projects in many parts of the world, user acceptance of decentralized sanitation solutions remains an unsolved problem. At all levels, the problem is a complex combination of socio-cultural and institutional issues and the lack of facilities and inadequate guidelines. Technical concepts imported from one region to another without considering the socio-cultural context have too often caused failure. Education of and demonstrations to ensure the sustainable use of the given technology seldom succeed.

A key prerequisite for end-user acceptance in micro-contexts is that the new technology must become part of the daily practices of the end-users. End-users should not only be consulted, but must be enabled to become active co-developers of the solutions.

Aims of this study

The overarching goal of this study was to conduct a scoping assessment to prepare for a long-term programme with the vision to find or design and upscale a decentralised sanitation practice in a WEF framework (DSP-WEF) that is functionally integrated into the context by participating farmers and experts, and are approved by all stakeholders. To prepare for this programme, the scoping aimed to:

i. Assess the available decentralized sanitation technologies
ii. Select two representative study sites and engage with 10-20 participants in each site
iii. Develop a research team, that includes researchers in relevant disciplines, the participants in the two sites, and other stakeholders
iv. Determine potential risks for the way forward
v. Develop a research plan for the next phase (co-design phase of the research programme).

Review of current knowledge

Literature review

A literature review was done to gather and peruse all existing knowledge that can inform the development of solutions for the sanitation problem. The complex systems theory is used as a suitable general approach to integrate decentralised sanitation and smallholder (SH) farming.

It is clear that safety risks and environmental pollution of sanitation in rural and peri-urban areas should be addressed. Such problems have been discussed in this report and will become critical during the future development phase. More invisible problems such as religious and cultural thought-patterns and their effect on sanitation and other topics related to the WEF nexus are just as important to understand; they have been reviewed, and more insights may emerge as the project develops. End-user perspectives will be central to the approach followed during the next phases of the project.

The information on cultural thought-patterns from the literature is important, because:

i. It provides a theoretical framework that can be tested during the site visits
ii. It creates an awareness of potential perspectives of the people
iii. It creates respect for the culture and behaviour of the people.

Visit to eThekwini Municipality

Current research projects on decentralised sanitation at the eThekwini Municipality in KwaZulu-Natal were visited in August 2022. Site visits were conducted to the Newlands Mashu Research Site, the municipal ablution facility in the Thandanani Informal Settlement, Khanyisa Projects, UKZN Howard College and households where the urine diversion and low-flush toilets have been implemented.

During our meetings different people mentioned the following gaps in the current research:

i. The focus has been on developing front-end solutions for decentralised sanitation rather than on ways to manage the waste (back-end)
ii. The approach is mainly on developing and implementing good technologies, rather than co-designing technologies and practices with the end-users
iii. In the past, politicians and tribal councils have not been included in the project, which caused conflicts and even project failures at later stages.

Profile

Geographic Information System (GIS) mapping was done to do a profile of smallholder farmers (SHFs) in the two study areas in the Limpopo Province. Both Molati and Ga-Sekororo are representative of most of the province in terms of vegetable production by subsistence farmers. The dominant pattern of water access in Molati is that community stands are within 200 m of the dwelling, while the dominant water access in Ga-Sekororo is within the yard. The two selected sites therefore represent the two water access scenarios that are most dominant within the subsistence farming communities. The dominant type of sanitation in Molati is normal pit latrines, and Ga-Sekororo falls within a region where VIPs are most dominant. Thus, in terms of sanitation the two sites also represent two representative types of decentralised sanitation systems used in the Limpopo Province.

Stakeholder engagement

The stakeholder engagement process included the following activities:

i. Individual interviews with SHFs in Molati and Ga-Sekororo, including site observance of sanitation facilities;
ii. Two focus group sessions in both areas, in which the same individuals, as well as some others, were involved;
iii. Discussions with local stakeholders;

iv. A network has been formed with international partners in Switzerland, Mozambique and Zimbabwe.

The scoping study has done the preparation for a co-creation project that will undertake transdisciplinary research in which the SHFs play a key role in the development of suitable solutions that they see as a possibility for themselves.

Results of the individual interviews and the two focus group sessions with SHFs

One of the outcomes of this study, which is important for future research, is the team of motivated SHFs that have been assembled. Many of these SHFs have previously experimented with agricultural solutions. They have indicated that sanitation is a problem, some have tried various ways to manage waste in their pit latrines, and they are willing to cooperate to co-design a suitable decentralised sanitation solution.

Other stakeholders that were engaged included officials from the Mopani District Municipality, the University of Limpopo and a small company that cleans pit latrines in Ga-Sekororo, we call them the 'pit latrine pickers'. The pit latrine pickers were established by community members to empty the pit latrines with spades and transport the waste away to be dumped. This service is very valuable and affordable for the people whose pit latrines are full, but it is not done in an organized, dignified, effective and structured way. Through collaboration with SHFs, such a practice can be further developed to provide sanitation support that is safe and dignified, and to convert human waste into resources for agriculture.

Potential for developing a DSP-WEF Framework

The study has indicated that:

i. There is a great need for decentralised sanitation systems, and solutions to convert human waste to compost (such solutions are available but still require much research in order to integrate them into the daily practices of the local communities).
ii. There is potential within the system to develop solutions, with motivated SHFs that are willing to cooperate and a promising solution of pit latrine pickers that have already emerged, but this practice requires some refining.
iii. The research sites are representative of large areas of SHFs in the Limpopo Province, and a successful practice in the study areas is likely to be successfully upscaled to many similar areas.

Through this research we have developed an alternative approach to decentralised sanitation in rural and peri-urban communities, which is outlined by a conceptual DSP-WEF Framework and will be tested in future research. The DSP-WEF Framework follows a unique strategy, namely:

i. To address decentralised sanitation as part of a complex WEF nexus, rather than in isolation;
ii. To recognise that, unlike mechanical systems, living systems such as the WEF-nexus cannot be controlled, but that solutions can emerge through good relations and interactions between role-players; and
iii. To co-design, with end-users as important role-players, the sanitation system, starting from the back-end (i.e. ways of re-using the waste), working toward a suitable front-end (i.e. toilet seat and pedestal).

The aim of the DSP-WEF Framework is to co-design, with end-users, suitable decentralised sanitation systems that are integrated into agricultural practices, through the re-use of waste, preventing health risks, eutrophication, hunger, stunting and energy intensive farming (**Figure ES-1**).

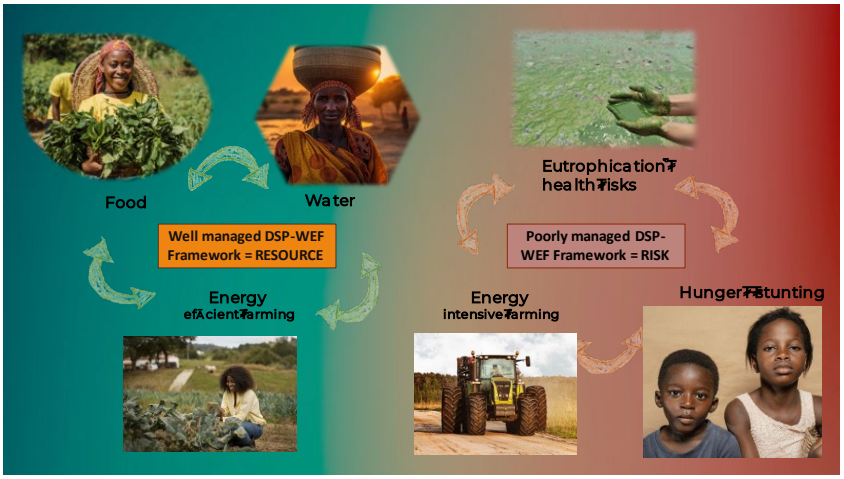

Figure ES-1: Opportunities of well a managed DSP-WEF Framework versus risks when the DSP-WEF Framework is managed poorly.[1]

Based on our evaluation of the current system, in terms of the conditions and drivers required to ensure the successful co-design of the DSP-WEF Framework, we belief that there is good potential for this aim to be realised. A transdisciplinary team, consisting of various role-players, including approximately 20 SHFs from each of the two study areas, pit latrine pickers, authorities, and relevant experts, are motivated to participate in the process. A business case will be developed based on (i) sanitation services provided by small companies (estimating that SHFs are able to pay a maximum of R300 per annum), which is a current practice in the study area and (ii) production of food crops enabled by the re-use of human waste, providing food and possibly income.

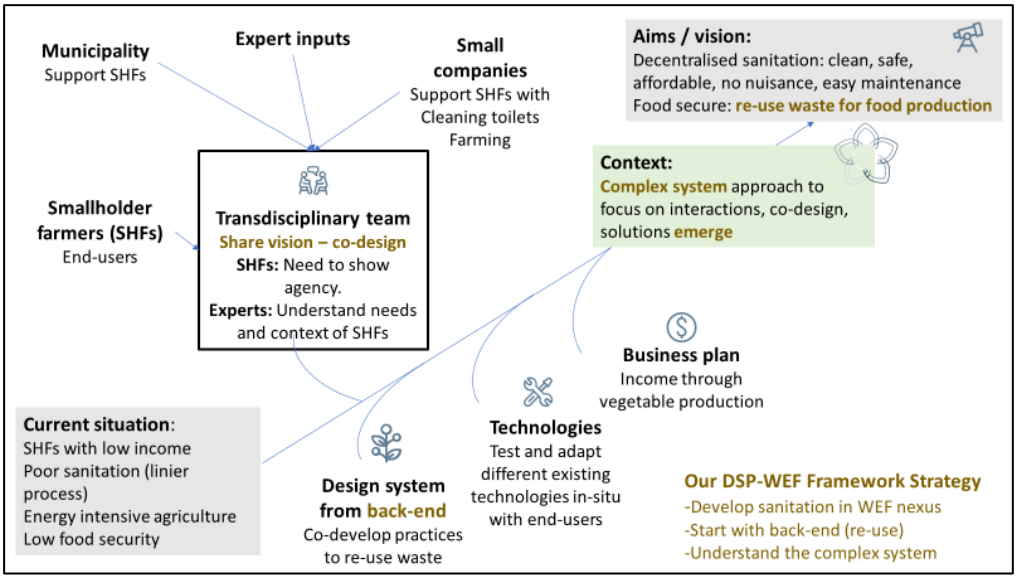

Figure ES-2: A schematic illustration of the approach towards developing a decentralised sanitation practice in the context of the Water-Energy-Food nexus, DSP-WEF Framework

Future research includes the following phases:

i. Co-design local practices (*next phase*)
ii. Develop ways to upscale to the community and municipality
iii. Develop ways to upscale to other municipalities.

[1] Photo references: Page 68

Acknowledgements

The research reported on here was solicited and funded by the Water Research Commission (Project C2021/2023-00517). This support is gratefully acknowledged. We particularly thank the various research teams in KwaZulu-Natal for receiving us at your research institutes and for sharing your work and knowledge with us.

The project team would like to thank the following Reference Group members for their guidance and advice during the project:

Dr L Nhamo	:	Water Research Commission (Chairperson)
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Terminology:

Toilets are connected to a sewerage system, while a latrine is connected to a cesspit (We are Water Foundation, 2023).

Abbreviations:

AD	Anaerobic digestion
BOD	Biological oxygen demand
BORDA	Bremer Overseas Research and Development Association
BTFS	Bowier Trust Foundation Switzerland
CBA	Critical Biodiversity Area
COD	Chemical oxygen demand
DEWATS	Decentralised wastewater treatment systems
DM	District Municipality
DSP-WEF	Decentralised sanitation practice in a WEF framework
DTF	Devolution Trust Fund
DWS	Department of Water and Sanitation
ESA	Ecological Support Area
GIS	Geographic Information System
IDP	Integrated Development Plan
IWRM	Integrated Water Resource Management
KZN	KwaZulu-Natal
LM	Local Municipality / ies
LOI	Letter of Interest
MDM	Mopani District Municipality
MOU	Memorandum of Understanding
RDP	Reconstruction and Development Programme
SDG	Sustainable Development Goals
SES	Socio-ecological system
SHF	Smallholder farmer
SNIS	Swiss Network for International Studies
SOR4D	Solution-Oriented Research for Development
UDDT	Urine Dehydrating Diversion Toilets
UL	University of Limpopo
VIP	Ventilated Improved Pit latrine
WASAZA	Water and Sanitation Association of Zambia
WEF	Water-Energy-Food
WRC	Water Research Commission

1 Introduction

The Sustainable Development Goal (SDG) 6 aims to ensure the availability and sustainable management of water and sanitation for all. While sanitation is a global priority, it is not a simple task. Poorly managed sanitation causes water pollution, ecological degradation, and health risks, while properly managed sanitation can potentially convert human waste into useful resources for food and energy production. The problem of sanitation, particularly in areas where centralized water-based systems are not feasible, is complex and should not be managed in isolation. The challenge should be dealt with within a complex Water-Energy-Food and Health nexus (**Figure 1-1**).

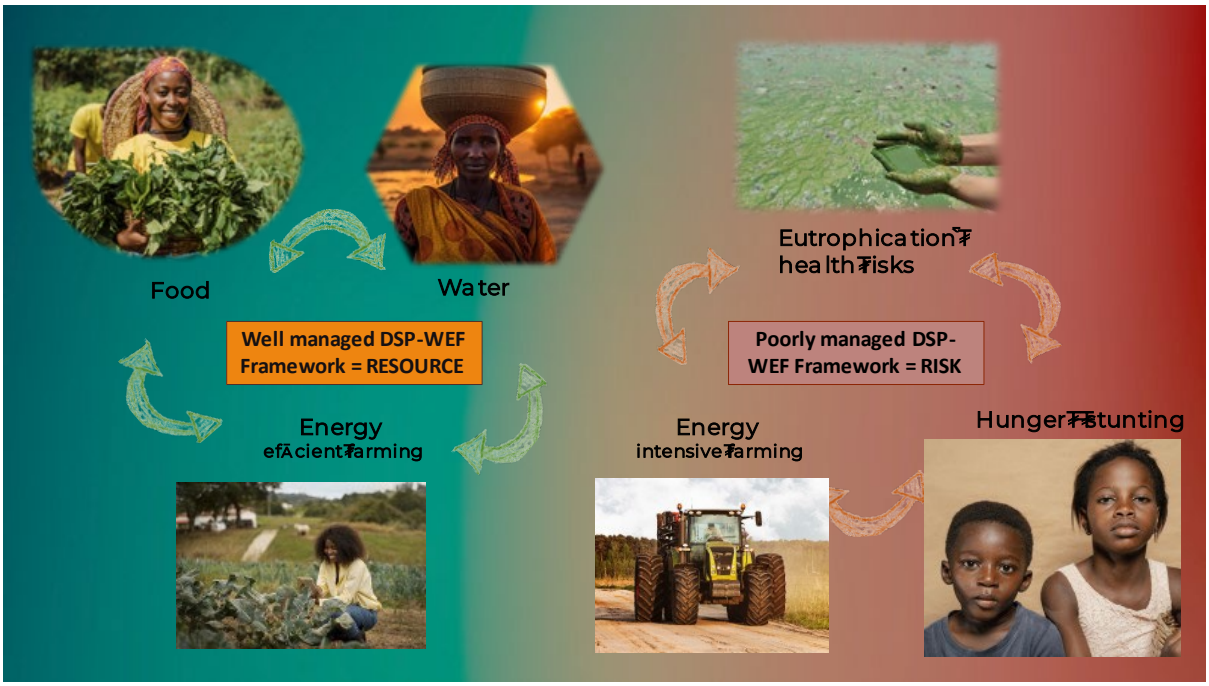

Figure 1-1: Opportunities of well a managed DSP-WEF Framework versus risks when the DSP-WEF Framework is managed poorly.[2]

Climate change and pressures on the ecology require that sanitation is included in a circular process to help solve the problems created by fertiliser that is manufactured by turning nitrogen in the air into nitrates for plants to be able to use it. This is done under very high temperatures and pressure, which requires large amounts of fossil fuels. It does not stop there. The fertiliser must be stored and transported. The additional nitrates molecules enter ecological systems in various ways, polluting waterways and entering the air, so contributing to climate change. Phosphate, which is a limited natural resource, is also used in fertiliser (Stirzaker, 2010). Re-using the nutrients in sewage for agriculture helps to reduce the pressures on the ecology and to provide food and income.

The aim of this project was to conduct a scoping study to determine the potential of developing new ways of integrating a decentralised sanitation practice in a WEF framework (DSP-WEF), by using human excreta as a resource for important household practices such as food and energy production. The DSP-WEF framework must be functionally integrated into its context by participating farmers and

[2] Photo references: Page 68

experts, and enthusiastically approved by all involved, and used and maintained by the households and SHFs.

The objectives that made it possible to determine such a potential, were to:

- Determine the available technical solutions
- Determine the profile of the target group, namely low-income rural and per-urban areas
- Select two villages that were representative of the target group,
- Gain an understanding of the socio-cultural context of these two villages
- Form a task team, consisting of a group of 10-15 smallholder farmers (SHF) in each village and researchers from relevant disciplines, with a common vision and understanding of the way in which we will pursue the aim together.

1.1 Long-term research programme

This project was the initiation of a long-term programme towards a DSP-WEF framework. What is needed is a well-planned and executed programme to consider the complexity of the socio-ecological system (SES) holistically, in contrast to a reductionist approach. A thorough investigation and integration process during the design phase is especially important, because, if the practice is thoroughly integrated into the prevailing social and ecological systems, it can be repeated more successfully in similar contexts. The design phase is, however, often neglected. The planned programme will consist of various phases illustrated in **Figure 1-2**. This report is the outcome of the scoping study or the *Roadmap Phase, conducted in the Limpopo Province*.

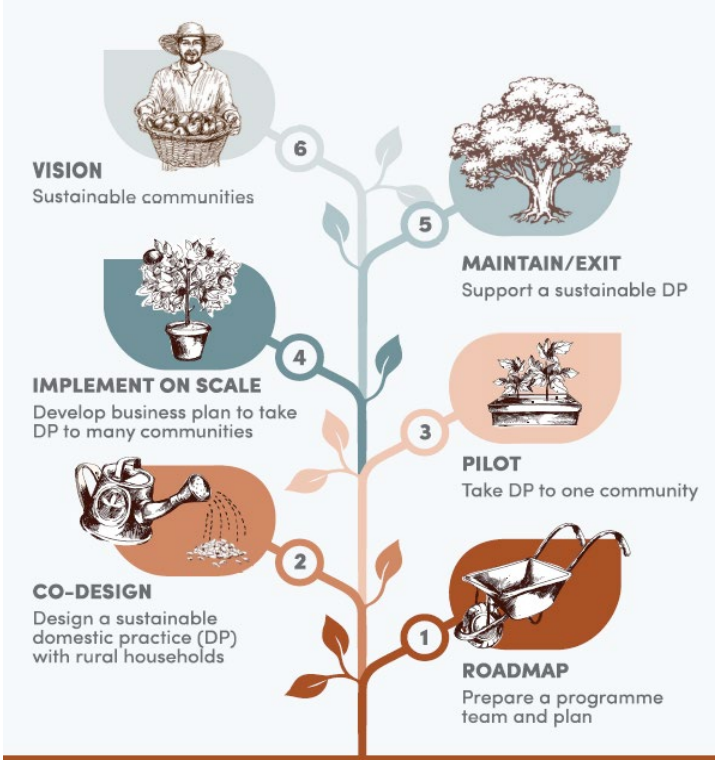

Figure 1-2: Outline of the phases of the long-term programme (this report is the outcome of Phase 1)

Following this scoping study the co-design (**nr 2 in Figure 1-2**) phase is planned during which the project team will test the most promising technical solutions with approximately 20 to 30 selected participants from the Limpopo Province, 10 to 15 from a more rural community (Molati) and 10 to 15 from a more peri-urban community (Ga-Sekororo). An iterative process of testing, evaluating and adapting the technologies will be followed until a solution emerges that complies with the needs of the end-users and is fully integrated into their daily practices. Various project proposals have been submitted and an international network has been built to find opportunities for the design phase of this research programme.

The scoping or roadmap phase was done to prepare for the design phase, by conducting literature reviews, profiling SHFs in the province and identifying and connecting with the relevant stakeholders.

The literature review was done on available technologies and the cultural thought-patterns regarding sanitation, agriculture and energy. A profile of SHFs in the Limpopo Province was developed with available data and GIS mapping. Finally, the team has interacted with the SHFs, other local stakeholders (Municipality, Tribal council, University of Limpopo (UL), University of Venda) and international partners and / or stakeholders.

1.2 Sanitation and poverty in the Limpopo Province

The project takes place against the background that almost a third of the children in South Africa live under the "food poverty line", that only allows enough for basic nutrition, and no other essentials, and almost half live under the "lower bound poverty line" that allows enough for essentials such as clothing but only if some nutritional costs are sacrificed (Hall, 2021). In the Limpopo Province more than 30% of the population experienced hunger in 2013. The prevalence of stunting among boys and girls 0-3 years of age was 26.9% and 25.9%, respectively (Human Sciences Research Council, 2013). There is reason to think that poverty and hunger have worsened as a result of Covid-19. Modelled results from 44 African countries indicate that the rapid population growth that is expected will be the main cause of food insecurity and undernourishment throughout Africa, even more than the effects of climate change (Hall et al., 2017).

Universal access to water, sanitation and hygiene (WASH) in the communal tenure villages in Limpopo, both peri-urban and rural, is still far from being achieved. Rural households generally undertake their own on-site arrangements, such as pit toilets. Several risks are associated with these pit toilets, including flooding, groundwater pollution, and health risks for the community and safety of young children. The pit toilets require labour intensive maintenance and space becomes a problem each time one toilet is filled, and residents must build another (Van Vuuren, 2014, Water Research Commission, 1994). The supply of water is mostly insufficient (below 25 L per person per day), because of the lack of pipeline reticulation and the widespread nature of the households in rural villages (Mopani District Municipality, 2019).

1.3 Problems with development of decentralised sanitation systems in rural and peri-urban areas

Conventional urban sewerage may be suited to certain situations, but in other circumstances where water is scarce and rural households are widely dispersed there is a clear need for decentralised on-site sanitation preferably with permanent, emptiable toilets which do not require water. Such circumstances are becoming increasingly common.

A combination of the various factors, including the large inequality between rich and poor in South Africa, has brought about resistance to the use of decentralised sanitation in the country, centred around issues such as

- A perception that the use of on-site sanitation implies "second class"
- A perception that there is plenty of money in the country for a high level of service
- A disbelief that waterborne sewerage costs as much as it does
- A perception that waterborne sewerage is a robust system, whereas it is in fact a fragile system that is sensitive to misuse and the use of inappropriate cleansing materials. There is also a lack of appreciation of the consequences of the failure of such systems

- A perception that on-site sanitation is unhealthy, that it does not work as well as full waterborne sewerage, and will cause disease
- Concern that on-site sanitation may pollute the country's scarce water resources (Water Research Commission, 1994).

However, the two groups of SHFs that form part of our team said that waterborne sewered sanitation is unrealistic in their context, and that their ideal was decent decentralised sanitation.

The management of the human waste is a problem in decentralised sanitation systems, because households must be responsible for disposing the waste. This process involves health risks, inconveniences and creates an extra burden in terms of labour. Alternative decentralised sanitation systems to pit latrines are more expensive.

1.4 Research sites

The research sites were chosen using different criteria, including the following, in order of importance:

- The degree to which the communities represent other communities in the district and the province. This is important for future upscaling potential, and is discussed in **Section 3**.
- The distance from a town centre (one closer, one further)
- Local municipalities with different levels of intervention and assistance in rural sanitation
- Villages in which local residents practise agriculture
- Villages where support has been provided by members of the present research team, which means that a long-standing relationship of trust has been established

From the information shown in this report we have confirmed that the Molati (**Figure 1-3**) and Ga-Sekororo (**Figure 1-4**) communities are suitable sites that are well representative of most SHFs in the Limpopo Province in terms of sanitation, water access, agricultural activities, employment, etc. Molati community in the Greater Tzaneen LM and Ga-Sekororo is a community in the Maruleng Local Municipality (LM) in the Limpopo Province.

1.4.1 Biophysical description of the research sites

1.4.1.1 Vegetation

The two selected research sites are both located in the Granite Lowveld vegetation type (Mucina and Rutherford, 2006). The Granite Lowveld vegetation type ranges from tall shrubs with few trees in some areas to moderately dense low woodlands in the sandy uplands. Typical tree species include *Sclerocarya birrea* (Marula tree) *Terminalia sericea*, and *Combretum* species.

1.4.1.2 Geology

The Makhutswi Gneiss forms the geology of both research sites, which weathers into sandy soils in the upland areas (Mucina and Rutherford, 2006).

1.4.1.3 Climate

The Granite Lowveld is a summer rainfall region with dry winters and has a mean annual precipitation (MAP) of 633 mm. Ga-Sekororo may receive higher rainfall of up to 900 mm MAP, because it is located at the foot of the mountains to the west. Both areas are generally frost free. Minimum and maximum temperatures for Hoedspruit, close to Ga-Sekororo is 3.7°C and 38°C, respectively (Mucina and Rutherford, 2006).

1.4.2 Molati

Molati is a village with more rural characteristics and is located 5.6 km south of the town Letsitele (**Figure 1-3**). The Letsitele Valley lies along the Letsitele River, a tributary of the Letaba River. The valley is about 30 kilometres south of Tzaneen and is regarded as one of the main agricultural areas in the lowveld. It produces significant quantities of fruit and vegetables such as bananas, mangoes, citrus, avocados, litchis, tomatoes, and macadamia nuts. This agricultural production mostly takes place on the commercial farms in the area. There are also areas under the control of the traditional leaders, where SHFs often struggle to make a living and to find access to the markets.

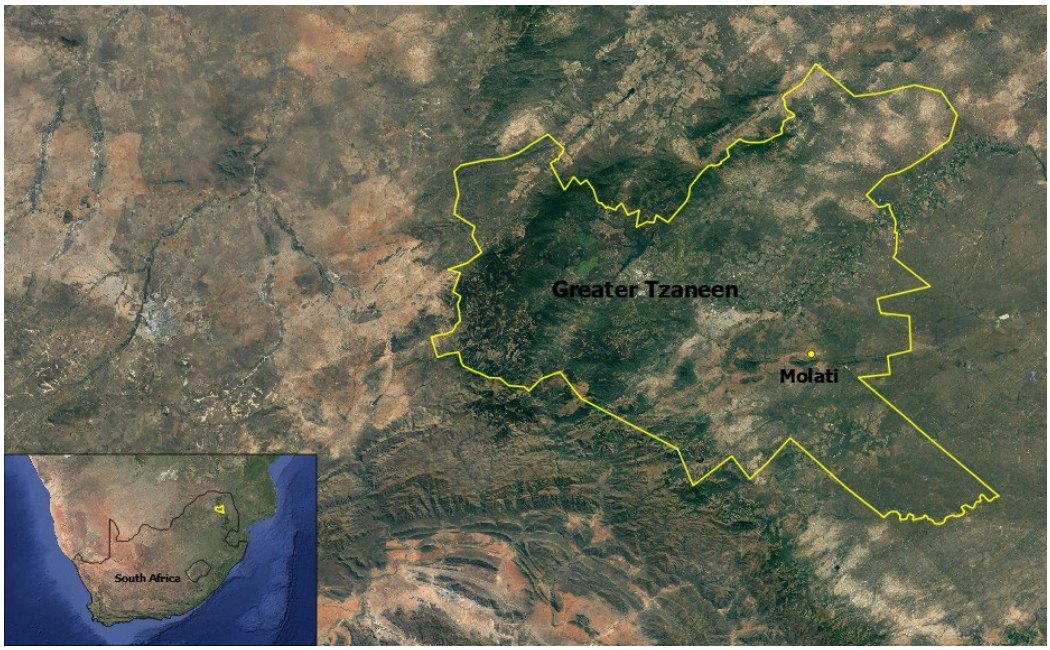

Figure 1-3: Locality of Molati Village

The village is built on the northern foot of a ridge running from east to west. Molati is within an ecological support area (ESA 2) and the ridge is an ESA 1 area. The area surrounding Molati is a critical biodiversity area (CBA 1). Water runoff from the ridge passes through Molati and, due to the lack of vegetation in the village, erosion is a problem. Approximately 180 m from the eastern border of the village, a large erosion gully has formed during previous floods. The Molatle River, a tributary of the Olifants River, originates in this ridge south of Molati. Many people in Molati farm either for own use or for selling, and there have been community farms in the past, but water for farming is not available to everyone. The village is divided in erfs of approximately 1 000 to 2 000 m^2 in size.

Letsitele and Molati are in the Greater Tzaneen LM within the Mopani District of the Limpopo Province, South Africa. There are high levels of poverty in the municipality. The vast majority, 80% of the municipality's population, live in approximately 125 rural villages (Mopani District Municipality, 2021). Unemployment is high: 36.9% of the population and 48.5% of the youth. The level of modern education is low: 9.9% completed secondary school and 1.2% higher education (Mopani District Municipality, 2019)

Pit latrines are the dominant form of sanitation in Molati and groundwater is an important source for many areas. In the Greater Tzaneen LM there is a policy to provide free basic services to those who cannot afford to pay, but the policy is ineffective due to a large backlog; the number of households with access to free basic water in this municipality is 1 295 and the number of backlogs is 85 475, while

the number of households with access to free basic sanitation is 1 360 and the number of backlogs 86 388. Furthermore, the backlog of services is growing: 'There are a growing number of households with low income in the Municipal area which result in poor payment for services' (Mopani District Municipality, 2019). The existing infrastructure, such as the wastewater works, is not big enough to cater for the existing population, even less so with the increase of households who need to be connected. Water shortages are also partly attributed to social behaviours, such as vandalism and a lack of payment for services, which is most prevalent in rural areas. Water resources are also over-used by people from all types of settlements (Mopani District Municipality, 2021).

1.4.3 Ga-Sekororo

Ga-Sekororo is located 50 km west of Hoedspruit in the Maruleng LM (**Figure 1-4**), also within the Mopani District Municipality (DM). According to the Mopani District Municipality (2021) the population in Maruleng is 94 855 and up to 98% of the population reside in rural settlements. However, many of these rural settlements are densely populated, not resembling the typical rural communities. Ga-Sekororo is a large, densely populated township with more peri-urban characteristics. Only 49.9% of households in Maruleng have access to RDP (Reconstruction and Development Programme) standard water and ventilated pit latrines is the dominant sanitation types in Ga-Sekororo.

Figure 1-4: Locality of Ga-Sekororo

Along the western boundary of Ga-Sekororo is a mountain range running in a north to south direction. Water runoff from the mountains form streams that cross the settlement flowing in an eastern direction. Ga-Sekororo is between the Malomanye and Molomahlapi Rivers and 15km north of the Olifants River. The mountain range to the west is considered a CBA 1 and the streams crossing the village are classified as ESAs (Vromans et al., 2019). The natural vegetation within Ga-Sekororo is cleared and therefore not considered sensitive. However, socio-economic practices within the village can impact the sensitive surroundings.

2 Literature Review

2.1 Introduction

This literature review was conducted to gather all readily available knowledge on the topics of sanitation, food and agriculture and energy in the African socio-cultural context. Attention is first given to the complex systems theory approach, which can help to establish a process from which an DSP-WEF system can emerge. This review also investigates the existing sanitation technologies, existing knowledge on integrating sanitation with food and energy production, solutions that have been implemented previously and possible reasons for failure if those solutions were unsuccessful. A scientific peer-reviewed book chapter has been produced from the outcomes of this literature review (**Appendix 7**).

2.2 Complex system theory

Decentralised sanitation and smallholder farming have, each on their own, many of the characteristics of complex socio-ecological systems (SES), with many different actors and numerous interconnected subsystems. If they are integrated with each other the complexity increases. Solving problems within complex systems requires special approaches, and in our approach we follow guidelines developed according to the complex systems theory. A complex SES is typically a dynamic cross-scale system, where global decisions impact local conditions and emergence on local scales in turn impact global conditions (Reyers et al., 2018). This creates difficulties to implement sustainable solutions. Developing effective interventions are dependent on selecting the most appropriate scale at which to focus, without neglecting the interactions between the chosen scale and the scales above and below it.

Cilliers (2008) hesitated to give a definition of the complex systems theory, because it is not simple enough to apply fixed characteristics to it. Nor is there a prescribed methodology for applying the complex systems theory; what is needed is for a scientist to develop a feeling and a certain attitude to engage with these systems (Cilliers, 2008, Preiser, 2019). According to Preiser (2019), complex systems have certain characteristics which should influence the way we engage with them, for example:

- Complex systems are not only driven by the components within the system, but also by the interactions between the components
- Interactions within complex systems are dynamic and nonlinear, making them unpredictable, so that they cannot be controlled
- The context is important, because complex systems evolve and organize themselves according to changes in the environment. The boundaries between the complex system and its environment are not clear
- Solutions to problems that may occur in complex systems must emerge from within the system, or at least be integrated into the system. It can usually not be produced outside the context and then merely imported into the system

2.2.1 Complex versus complicated systems and holistic versus reductionist approaches

It is easier to understand complex systems theory in terms of how it differs from complicated systems and the traditional scientific methodology. Complicated systems, e.g. a computer, can be disassembled into its components and reassembled to operate in a specific way. To understand

complicated systems, the reductionist approach can be used, where the components of a larger system can be studied to determine linear cause-and-effect relationships without the 'interference' of the rest of the system. Reductionism produces isolated technologies that operate in predictable ways (Van Rooyen et al., 2017). The scientific method typically follows the reductionistic approach, because it is designed to study the components of a system in order to learn something about the system as a whole.

Complex systems, on the other hand, comprise a number of factors – things and thoughts – that interact and combine, to produce unpredictable and even highly surprising outcomes. Emergence, defined as new system configurations and behaviours, is a typical property of complex systems, that occurs when the whole system has properties that are different and nonreducible to the properties of the system's components (Preiser, 2019, Van Rooyen et al., 2020). Therefore, the reductionist approach is not appropriate for complex systems (Cilliers, 2008). If the isolated technologies that are produced through the reductionist approach are implemented in a context where they have to function within a larger, complex system, this larger system often interferes with the intended cause-and-effect relationships. In complex systems, in contrast to the reductionist approach, an integrated holistic approach is required to take all the factors and their interactions into account.

2.2.2 Context and intervention

Complex systems are open systems, meaning that the boundary between the system and its environment is not clear. Changing the context of a system will also change the system itself (Preiser, 2019). In complexity theories, Jean Boulton stated, the emphasis should be on the context and not on the intervention (Boulton, 2019). The complex system theory perspective also requires that we bring social systems and ecological systems together in a way that they are "not just overlapping and interdependent, but inseparable. This perspective emphasizes that people, economies, societies, and cultures shape, and are in turn shaped by, ecosystems" (Reyers et al., 2018).

2.3 African cultures and the Water-Energy-Food nexus

Culture is one of the multiple perspectives that are brought together in this study. Culture can be seen as a strategy to deal with the world in which people live, and a way of associating with and interacting with each other and with nature. Cultural aspects include practices, consisting of patterns of *behaviou*r and the *meanin*g that people give to these patterns of behaviour, and the *feelings* or emotions associated with them. We can talk about "patterns of culture" (Benedict, 1989).

A practice is a subdivision of culture, an established way of doing certain things. Practices also have patterns and must fit into the larger cultural patterns which in turn must fit into the larger social and ecological patterns. Our cars, for example, fit well into our cultural patterns, but not into the larger ecology. Practices, like cultures, are constantly changing, sometimes faster, sometimes slower. They emerge from the ongoing interaction and combination of multiple things and thoughts, such as traditions, new technologies, ecological conditions, political and economic events, etc.

The concept of linear versus circular economies is relevant in this study, and should be considered from an African perspective. Current economic practices are often based on linear pathways of take-make-dispose, whereas the African perspectives of cycles may be more open to adapt to circular economical practices. Water, energy and food are relevant topics in the African context, and it is necessary to understand the cultural and religious context of these topics. In the following sections

we will give attention to cultural patterns in Africa regarding energy, agriculture, food, cooking and cuisine, and sanitation.

2.4 Energy

In 2013 K. J. Wessels and a group of researchers reported that over 80% of households across sub-Saharan Africa rely on biomass as their primary energy source. They calculated that at current levels of fuelwood consumption, biomass in the region where the potential study areas are located would be exhausted within thirteen years. It further showed that it would require a 15% annual reduction in consumption for eight years to a level of 20% of households using fuelwood before the use of biomass would reach sustainable levels. They concluded that the severity of dwindling fuelwood reserves in African savannahs underscored the importance of providing affordable energy for rural communities (Wessels et al., 2013).

The rich significance that sitting and living around the fire has for traditional family life shows how domestic energy use is integrated into household practices. However, there is a tendency to replace the practice of sitting around the fire by sitting in front of the TV. If that happens, the wood stove can potentially be replaced by other sources, such as biogas from sewage, depending on how the household as a system changes.

Decentralised sanitation is relevant for energy use in several ways: (i) saving energy that would have been used to build and maintain centralised sanitation and treat waste water, and (ii) the possibility to generate biogas from sewage through anaerobic digestion (AD), and (iii) by integrating sanitation with agriculture the emission of greenhouse gasses during the production, transport and storage of fertiliser can be prevented.

According to Msibi and Kornelius (2017), you either need waste from approximately 205 chickens, 8 cows, 20 pigs or 63 people to feed a 2500 L/day biodigester, which is generally enough energy to satisfy cooking requirements of one household. Therefore, biogas production is not feasible on a household scale. They further calculated that one non-sewered household generates enough greywater to feed a 2500 L/day biodigester, and the use of greywater is recommended. According to Lin et al. (2018), AD is economically more profitable than composting on a larger scale, while composting is more profitable on a smaller scale. The use of biogas digestion is currently limited by a lack of supporting policies, unsuitable climates, limited support from the private sector, installation, operation and maintenance costs of the digesters, lack of technical knowledge, and limited water availability (Msibi and Kornelius, 2017). According to Meegoda et al. (2018), if a biodigester is overloaded, it could cause acidification and stop the microbial breakdown process. It needs fairly intensive managing.

2.5 Food and agriculture

2.5.1 Agriculture in the traditional African culture

In traditional African cultures food production is regarded as being closely related to the fertility of people and of the land. In this tradition fertility is essentially a religious concept. Fertility is a manifestation of a mysterious life force. It depends on the relation with the ancestors and ultimately, and more remotely, on God. It requires harmony between forces and not control over nature in search of progress and a better future – which is the modern approach.

Mother Earth is a dominant motif throughout modern African literature (Cartey, 1969). It is also a dominant motif in local cultures, specifically in agriculture. In 1938 Jomo Kenyatta, who later became the first president of Kenya, wrote:

> "In Gikuyu life, the earth is so visibly the mother of all things animate, and the generations are so closely linked together by their common participation in the land, that agricultural ritual, and reverence for ancestral spirits, must naturally play the foremost part in religious ceremonial.... Communion with the ancestral spirits is perpetuated through contact with the soil in which the ancestors of the tribe lie buried.... the earth is the most sacred thing above all that dwell in or on it ... Ceremonies are performed to cause the rain to fall, to purify and bless the seeds, and again to purify the crops" (Kenyatta, 1985).

Rain is regarded in Zulu tradition as fertilization of the earth by the sky, as a husband fertilizes his wife. The earth cannot bear fruit if the rain does not work on it with water (Berglund, 1976). Berglund (1976) describes a ritual in Zulu culture to make the field fertile. The ritual contains many male and female symbols to ensure fertility. When Berglund asked a diviner about it, the diviner said that the field is "the mother from whom we eat". The ritual could not be performed by a male, because "Men do not sow. They slaughter the animals when there is to be meat. But they do not sow."

The Nigerian Bishop and International Chairman of the Organization of African Instituted Churches (OAIC), Daniel Okoh, said to Öhlmann et al. (2019):

> "People from Sub-Saharan Africa … are highly religious... So, for Africa, because of the religious nature, you'll always find a way of using it to get the … commitment of the people to the project, whatever it is. If it is water, it must be explained spiritually. If it is [an] agricultural project, it must be explained spiritually…. Honestly, if you don't do that, you will lose it."

The question is how strong such traditions are in the study area, and what role they play.

2.5.2 Food in the traditional African context

For this study, eating patterns are just as important as sanitation patterns. The eating pattern will determine what food can be produced and what not in the integrated practice of decentralised sanitation and smallholder farming.

In his study of the history of food and cuisine in Africa, James McCann (2010) emphasises two things: (i) African cooking and cuisines have formed over history and have expressed an agility in keeping up with changing times, and (ii) that food is deeply imbedded in culture. McCann (2010) frequently refers to the dynamism of African foods over the years. There is a rich variety of cuisines across different regions of the continent. "Contact with world regions like the Indian Ocean rim (from at least the first century CE) and the Atlantic world (after 1500) brought many more challenges and opportunities that African cooks built into their stews, porridges, and breads." This include the use of food that was borrowed from other continents, such as maize, bananas and spices. In different regions, different influences from elsewhere have combined with local cultures so that, in each place, some type of cooking has emerged that involves the layering of ideas, daily rituals of eating, ingredients, and methods of assembling foods for both public and private meals. "Cuisine is a product of history, and a meal is a conjuncture of time, place, particular ingredients" (McCann, 2010).

Globally, cooking and cuisine can be seen as a creative composition at the heart of all cultural expressions of ourselves... food, like dress, music, and art, carries deeper structures of cultural identity

that forms a marker of group coherence and solidarity—food helps define who we are (McCann, 2010).

In an African society, social values are not separated from religious, political, and moral values, as they form the undertone that influences the life choices of the African people. For example, the most important thing at any ceremony is the amount of food you prepare, one ought not to disappoint their guests or starve them (Phasha et al., 2020). However, the emphasis on the agility of African cuisine is an indication that the beliefs and taboos around food have not been so strict as it is, for example, in Jewish religion.

Some traditions may have a negative impact, if viewed from the outside. Traditional food taboos often have a bearing on the relation between men and women. Lung'aho (2021) states that, in Sub-Saharan Africa, pregnant women are forbidden from eating protein rich foods such as eggs and snails for several reasons, including the fear that the child may develop bad habits. In some cultures, men eat before women and children. And boys may eat before girls. Africa's cooks were women, but they often serve food to the men and children first, and get to eat at the end when everyone else has had their fill. If food is scarce a mother may sacrifice to the children the food that is left after serving the men. Community education and socio-behavioural change are needed to give equal priority to the nutrition of all family members.

Similarly, Chakona and Shackleton (2019) documented food taboos and beliefs amongst pregnant isiXhosa women and found that cultural beliefs and food taboos followed by some pregnant women influence their food consumption, which impacts the health of mothers and children during pregnancy and immediately afterwards. Overall, 37% of the women reported one or more food practices shaped by local cultural taboos or beliefs. The most commonly avoided foods were meat products, fish, potatoes, fruits, beans, eggs, butternut and pumpkin, which are rich in essential micronutrients, protein and carbohydrates. Most foods were avoided for reasons associated with pregnancy outcome, labour and to avoid an undesirable body form for the baby.

2.6 Sanitation

2.6.1 Sanitation in the traditional African context

2.6.1.1 Human excreta and the concept of impurity

There are clear differences in attitudes towards the use of sanitation facilities and the handling of excreta between diverse cultures. Our cultures and contexts structure the basic instinctive repulsion towards excreta into attitudes and patterns of treating it. Attitudes toward human excreta differ within cultural groups (Warner et al., 2008), but there are certain trends that are widely spread across sub-Saharan Africa, such as the impact of modernity, a lack of proper sanitation for many and the religious meaning that is given to material things.

Meaning associated with such concepts as dirt, pollution, hygiene and disease evolves in relation to situated cultural experiences, with special forms of values and risks. However, the ambivalence characterizing such meanings underlies the sanitation and hygiene challenges. In most reports across Sub-Saharan Africa, local knowledge and the equation of cleanliness with godliness and beauty sharply contrast with actual physical sanitation and hygiene practices and behaviours in many contexts and forms. In African contexts real life or well-being cannot be treated outside either the prevailng

phsyical conditions or the spiritual, social and religious world-views, and matters related to WASH are better understood from the perspective of 'subjective' rather than 'objective' worldviews (Douglas, 2003).

Mönnig (1978) emphasises the central role of "impurity" among the Pedi, which is one of "a great variety of supernatural forces (that) may cause unfortunate events". However, these supernatural forces often act with and within natural causes, and do not preclude a person to treat the unfortunate event, such as sickness, in a natural way. One of the words used to describe impurity is *ditšhila*. The word is often used for excreta but it also means sin. Ditšhila literally means dirt, "but it may be better translated as impurity, and more particularly ritual impurity". Conditions of impurity include: "A woman giving birth, as well as the unborn child, the placenta and the hut where the birth has taken place..... children who are born unnaturally, i.e. twins, malformed children, children who are born with teeth...The condition of ditšhila is closely connected with the critical changes of life, particularly with its beginning and its end". The impurity requires ritual cleansing (Mönnig, 1978).

In his book, *Bantu Heritage*, Junod (1938) does not refer to sanitation. On p93 it is said: "Bantu women have a strong sense of modesty, which is unfortunately deteriorating. They always take great care to choose a special place for bathing and the men who dare to approach this place are booed." No reference was found to an association between impurity and bad sanitation practices, also not in Stayt (1931). However, when healing is needed, faeces is often associated with the evil that has caused the illness. A prominent theme in *Zulu Thought-Patterns and Symbolism* (Berglund, 1976) is that of cleansing from evil by physically ejecting something from the body, like spittle, vomit and emetics (page 292), and blowing out of medicines (page 352). *Ukuhlanza* (to clean)...

> "refers to vomiting and expulsion of faeces after an emetic or purge... All bodily excess, particularly faeces, which is vile, must be disposed of outside the homestead and, preferably, be buried. 'This thing is vile. A home is good. They do not agree. That is why it must be concealed somewhere at a distance from the homestead.' Zulu accept this disposal of something vile as normal… Evil which, on the other hand, is not expelled normally, must be cast out through acts such as enemas and vomiting. Today castor-oil and a large number of other purges are obtainable in chemist shops and made use of extensively. There are Zulu who 'cleanse the stomach from poison' regularly every week, even more frequently, sometimes making use of both laxatives and enemas. In cases of sickness, disregarding the type, enemas, laxatives and vomiting are often automatically administered to the patient, especially if the sickness causes a rise in temperature. 'If the sick person is hot (i.e. runs a temperature) it is certain that there is a great medicine (i.e. sorcery) inside (him/her). Where does the medicine enter? Is it not through the mouth? So it is in the stomach. That is why there must be vomiting and enemas. These things remove the poison which causes the sickness.'"(pages 328-9) (Berglund, 1976).
>
> 'Cleaning the baby out' by intestinal washes is believed to cool the child down and protect it by purging harmful evil influences" (Van Andel et al., 2015).

Again, the question is how prevalent such thought-patterns are in the study area.

2.6.1.2 Open Defecation

Open defecation is still practiced, mostly based on convenience, lack of sanitation facilities, a lack of privacy at badly constructed pit latrines (especially for women), unclean and unhygienic conditions in

toilets, the lack of toilet training for children, a lack of water and lack of toilet paper. Some participants mentioned traditional beliefs and practices as well (Dittmer, 2009).

Cultural taboos and beliefs relating to the location and type of toilet facility have played a role in encouraging open defecation practices. Some examples include:

- In some areas, communal and public toilets were not used, because of the belief that one person's excreta should not be put on top of another's.
- Below-ground storage of faecal waste is sometimes considered to contaminate the dead and is unacceptable in cultures where ancestor veneration is practiced.
- Fear of using a pit for defecation would give traditional healers easy access to an individual's excreta for malevolent purposes. This belief is strongly related to menstrual excreta, as blood is considered a very powerful fluid used by traditional healers. Menstrual liquids, pads and the like are meant to be washed thoroughly before discarded, buried or preferably burnt to dissuade access (Akpabio and Takara, 2014).

2.6.1.3 Gender and generational considerations

> "Cases of treating children's faeces and other waste products with tolerance have been widely reported; linked not only with the idea of inoffensiveness of child excreta, but such tolerance also carries spiritual implications for parents and potential parents. Every material element of child hygiene (sputum, faeces, urine and other child waste products) entails potential blessing, depending on how it is handled" (Akpabio and Takara, 2014).

There are many cultural restrictions and taboos regarding women's menstrual hygiene management as well as the beliefs associated with it. Despite the belief that blood can be used by traditional healers, as mentioned above, there is also a cultural belief linking menstruation to evil spirits and curses. At productive ages, women and girls menstruate every month and require information and facilities for the proper disposal of hygiene products. Menstrual hygiene management requires access to water for washing hands, the body and used menstrual cloths; access to private and hygienic sanitation facilities for changing and disposing of sanitary protection materials and for bathing; and access to necessary and relevant hygiene information, as well as an adequate solid-waste management system for the disposal of cloths and pads. In Sub-Saharan Africa, people hardly talk about these issues. This is mostly because of cultural perceptions and religious myths, which mostly classify menstruation in the realm of taboos, myths, pollution and evil spirits, while the women in their menstrual cycles are dominantly perceived as 'unclean'. Given the shame and taboos often associated with menstruation, used cloths are often hidden in unhygienic areas, exposing and multiplying women's risk of infectious disease (Hickling and Hutton, 2014). In addition, when women go out at night to do their ablutions far from their homes, they are vulnerable to harassment and assault. Women often refrain from drinking so that they do not have to go to a toilet. This practice can lead to severe health consequences, i.e. bladder infections, constipation, or kidney problems (Warner et al., 2008).

Women pay more attention to privacy and safety when making decisions on where and when to defecate. In general, the natural environment with its bushes and shrubs suits their requirements the most. Defecating in the early hours of the day or at night is an option in favour of privacy, but safety becomes a problem. In any case, the risks linked to privacy and safety depend on the circumstances of the environment.

2.6.1.4 Environmental, socio-economic and behavioural considerations

In the complex theory approach, factors such as the environment, socio-economic conditions and human behaviour must all be integrated into one undividable whole. The question is how that must be done.

Van Oel (2002a) also mentions a whole range of factors to consider when selecting the best options for improvement of sanitation (environmental, economic and social), which can be summarized as:

- Geological subsurface considerations.
- Access to water.
- Affordability by the recipient community for capital as well as for maintenance costs.
- Future upgrading must be considered.
- The recipient community must be involved fully in the choice of a system.
- To stimulate real involvement, the community must be trained to do the development work themselves wherever possible.
- The local authority must have the institutional structure necessary for the operation and maintenance of the system.
- A system must operate in spite of misuse by unsophisticated users and should require as little maintenance as possible (Van Oel, 2002a).

We generally agree with Van Oel (2002a), but would formulate two statements (5 and 7) differently. In our approach we emphasise the design of a sanitation practice with the recipient community, rather than just involving them in the choice of a system (as mentioned under nr 5). In cases where the local authority does not have the institutional capacity for the operation and maintenance of toilet systems, the statement under nr 7 is not feasible. Taing et al. (2014) have shown that poor maintenance was due to a lack of responsible people in situations where a number of households share one toilet. Therefore, the household should be able to construct their own toilet system and maintain it. If the household owns the toilet, they will take responsibility for it.

2.6.2 Sanitation technologies

There are various alternative decentralised sanitation solutions available that could potentially be used in rural and peri-urban communities. A distinction is made between wet and dry sanitation systems. The choice of technology depends on many variables, including the local conditions and resources that are available to the people, the trade-offs between advantages and disadvantages of the systems and, most importantly, what the end-users consider to be desirable and manageable. An elaborate review on various toilet and waste treatment systems is included in **Appendix 1**. We discuss some of the technologies that are most likely to be suitable in a rural or peri-urban context here.

Table 2-1 presents a summary of the key strengths and weaknesses for dry and wet sanitation systems.

Table 2-1: Summary of the advantages and disadvantages of wastewater treatment systems

PROCESS	TYPE	ADVANTAGES	DISADVANTAGES
DRY SANITATION	Pit latrine	Easy to construct Better alternative to open defecation Commonly used	Odours Flies Soil & groundwater contamination Health risks Safety Requires de-sludging No material available for agriculture
	Ventilated Pit Latrine	Reduced odours Easy to construct Better than unventilated pit latrine Commonly use	Soil & groundwater contamination Health risks Safety Requires de-sludging No material available for agriculture
	Compost toilets and Urine diversion	Can be used in-doors or out doors Little odour Reduced health risks Material is available for agriculture	Require ongoing composting Cover material is required Public perception
WET SANITATION	Pour- and Low-flush	Low water use Low cost Safe use for woman and children Can be inside the house Reduced odours and flies Can be used in areas without water reticulation	Blockage (rare) Pouring water may be inconvenient Extreme water shortages may be a problem (Pillay and Bhagwan, 2021)
	Septic tanks	Proven technology Can collect all water and scraps from the household Low risk of contamination of soil and groundwater	Requires available water Requires secondary treatment Requires periodic de-sludging
	Aquaprivy	Low cost Low water use Water seal reduces flies and odours	Requires periodic de-sludging and treatment of sludge Problems arise from inappropriate operations Cannot be installed inside the house Risk of leakages – cannot be used in dolomitic areas.
	Biogas digesters	Biogas can be drawn off for use in cooking and heating Treated waste can be used as fertilizer.	Construction needs are high Variable pressure of gas System requires de-sludging System requires water
	Package treatment plants	All in one system Modular so components and sizing can be tailored to each site Material is available for agriculture	High cost Requires technical competence to operate May require electricity

2.7 Combining sanitation with food production

Apart from cultural and economic issues, there are two main factors in the use of decentralised sanitation solutions products in agriculture: nutrients for plants and health risks for users and consumers. As detailed earlier there are 2 broad categories of decentralised sanitation solutions: namely dry and wet.

2.7.1 Dry treatment systems

Dry treatment systems essentially comprise of composting the faecal sludge for subsequent use as a soil amendment (Moya et al., 2019a). Although there are a variety of composting methods, thermophilic composting is preferred because of the high temperatures (over 45°C) as a result of rapid aerobic decomposition. The advantages of a thermophilic system as opposed to mesophilic or "ambient" systems include higher rates of degradation and rapid inactivation of pathogens (Preneta et al., 2013). There are three distinct phases in the composting process:

- Mesophilic or moderate-temperature phase: This lasts for few hours to a few days, and is characterized by mesophilic microorganisms (MMO) breaking down soluble, easily degradable compounds, releasing heat and increasing the general temperature.
- Thermophilic or high-temperature phase: During this phase which may last several months, the heat produced by the MMOs shifts the type of organisms towards thermophilic microorganisms which results in a temperature increase to above 45°C. Once the temperature rises above 50°C rapid human pathogen destruction occurs
- Curing or Maturation Phase: Once high energy material is used up, the temperature within the compost falls and MMOs outcompete the thermophilic organisms to break down the remaining low energy materials (Preneta et al., 2013).

2.7.1.1 Nutrient availability

In Madagascar, Moya et al. (2019a) demonstrated that vermicompost had 85% less nitrogen (N) compared to compost from human excreta, however N-compounds in vermicompost was in a more available form. Phosphate compounds in a plant available form were also ten time higher in the vermicompost. They also found that the use of human excreta did not have a negative impact on soil or crop growth.

2.7.1.2 Human pathogens

Human pathogens in compost generally decline in numbers over time. As mentioned earlier, as the temperature increases within the compost, so pathogen die off can be expected to occur. Preneta et al. (2013) found that after two weeks, *Escherichia coli* showed a reduction from 10^5 counts *E. coli* to almost zero in the middle of a compost pile. A study by Eastman et al. (2001) found that over the whole composting process, faecal coliforms saw a 6.4 log reduction, an 8.6 log reduction in *Salmonella spp*, a 4.6 log reduction in enteric viruses and a 1.9 log reduction in helminths. It must be noted however, that in a similar study by Keim (2015) the indicator levels, while reduced, still exceeded accepted values for bio solids delineated by the US EPA but were below the WHO guidelines for excreta use in agriculture.

2.7.2 Wet Treatment Systems

Wet treatment systems typically have a high liquid to solids ratio and it is perhaps more important to look at the effluent produced by such systems for agricultural use. Solids can generally be removed from the system periodically and composted as a dry treatment system.

2.7.2.1 Nutrient availability

It is important to differentiate between single systems and integrated systems in decentralised wastewater treatment systems (DEWATS). A single system is typically a septic tank where effluent is diverted through a soil infiltration system such as a French drain. An integrated system is where effluent from a septic tank or primary settler is fed into an anaerobic contact chamber then through an aerobic chamber and finally through a post treatment system such as a constructed wetland or maturation pond.

Effluent from septic tank systems typically has a high chemical oxygen demand (COD) and biological oxygen demand (BOD) and nutrients (Ayers and Westcot, 1985, Eliasson, 2004). Eliasson (2004) reports average COD concentrations in US septic tanks of more than 150 mg/l and BOD of 200 mg/l. The challenge with using water with such high concentration of COD and BOD for irrigation, is that the water will scale up irrigations systems, will cause clogging of soil layers and will eventually lead to ponding and reduced infiltration (Eliasson, 2004, Müller and Cornel, 2017). Müller and Cornel (2017) recommends a maximum limit of 150 mg/l for COD. For nutrients and identified irrigation and nutrient requirements for a range of crops in Namibia (**Table 2-2**)

Table 2-2: Irrigation and nutrient requirements for various crops for wastewater irrigation water

CROP	WATER	TOTAL NUTRIENT REQUIREMENTS					
		N	P	K	N	P	K
	m^3/ha	**kg/ha**	**kg/ha**	**kg/ha**	**mg/l**	**mg/l**	**mg/l**
BEAN	4 000	30	50	85	7.5	12.5	21.3
SUNFLOWER	8 000	75	32.5	92.5	9.4	4.1	11.6
SAFFLOWER	9 000	85	22.5	32.5	9.4	2.5	3.6
BANANA	17 000	300	52.5	260	17.6	3.1	15.3
PEPPER	7 500	135	37.5	75	18	5	10
WATER MELON	5 000	90	42.5	57.5	18	8.5	11.5
WHEAT	5 500	125	40	37.5	22.7	7.3	6.8
MAIZE	6 500	150	65	80	23.1	10	12.3
SUGARBEET	6 500	150	60	130	23.1	9.2	20
TOMATO	5 000	125	87.5	201	25	17.5	40.1
CABBAGE	4 400	125	57.5	115	28.4	13.1	26.1
OLIVE	7 000	225	62.5	185	32.1	8.9	26.4

The FAO guideline for irrigation recommends an upper limit of 30 mg/l of nitrogen. Some crops are more sensitive to high nitrogen concentrations, for example sugarbeet (*Beta vulgaris*) increases in size and yields lower sugar with poorer quality. It also causes a reduction in fruit production and late maturing of fruits in grapes (*Vitis vinifera*), apricot (*Prunus armeniaca*), *Citrus spp* and avocado (*Persea americana*). High nitrogen in the water results in excessive growth in grain crops, but thinner stalks which can't support the grain. Maize (*Zea mays*) is less sensitive to higher nitrogen concentrations (Ayers and Westcot, 1985).

In integrated DEWATS, the poor quality of effluent water undergoes secondary treatment, for example in an anaerobic chamber and final polishing treatment in, for example, a constructed wetland to reduce the organic load. Musazura and Odindo (2021) studied crop production at a DEWATS system installed in KwaZulu-Natal. Three sources of water were used for a 33-month trial on taro and banana: Effluent from the anaerobic filter; water from the horizontal flow wetland and tap water plus chemical fertiliser. The results indicated no difference in crop production of the whole trial period, concluding that there was no negative effect using DEWATS water for irrigation. The water from the anaerobic filter had sufficient nutrients throughout the irrigation period, but monitoring was required to ensure excess nutrients did not result in environmental harm. Water from the constructed wetland could generally supply all the required nutrients but at times there may be a requirement to supplement with additional nitrogen and phosphorous.

2.7.2.2 Human pathogens

The World Health Organization (1987) distinguishes between high-risk transmission of intestinal parasites (helminths eggs), and lower-risk transmission of diseases caused by pathogenic bacteria. Amoah et al. (2018) studied the soil transmitted helminth and *Taenia spp*. egg reduction efficiency of selected anaerobic baffled reactors and planted gravel filters compared to centralized wastewater treatment plants in South Africa and Lesotho. Amoah et al. (2018) found that eggs of *Ascaris spp*., hookworms (*Ancylostoma duodenale* and *Necator americanus*), *Trichuris spp*., *Taenia spp*., and *Toxocara spp*. were commonly found in untreated wastewater. The DEWATS plants however removed between 95 and 100% of the STH and *Taenia spp*. eggs, with centralized plants removing between 67 and 100%. It was also found that Helminth egg concentrations in the final effluents from the centralized wastewater treatment plants were regularly higher than those in the WHO recommended guideline (≤ 1 helminth egg/L) for agricultural use resulting in higher risk of ascariasis (World Health Organization, 1987).

Musazura and Odindo (2021) investigated the use of water from a KwaZulu-Natal DEWATS system anaerobic filter. During the investigation microbial contamination was studied. It was found that using the anaerobic filter effluent in overhead irrigation was suitable for maize because of the need to cook the maize before consumption. However, the cultivation of lettuce and cabbage should rather use drip irrigation because they can be eaten uncooked. If overhead irrigation is used, then further treatment, such as by ozonation or UV radiation, would be required.

2.7.3 Additional risks of combining sanitation and food production and possible management requirements

There are a number of additional risks which need to be considered in using human waste for irrigation in agriculture:

- Global GAP is the most widely adopted standard for quality assurance of horticultural crops (Moya et al., 2019b). The problem is, the use of human sewage sludge is currently not allowed on certified farms. Interviews with stakeholders in Kenya along the food export chain showed that Global GAP certified farmers were not willing to use human excreta fertiliser on their farms even if local regulations recognise treated sludge as a valid input to agriculture (Moya et al., 2019b).
- In a study by Gomo (2016) in the Limpopo Province in South Africa, the use of wastewater for crop production was not supported by the communities and famers' sales were negatively affected by this.

Irrigation with sewage effluent is a common practice throughout the world and a number of studies have been conducted to determine the safety of irrigating with sewage effluent. The negative impact of irrigating with treated sewage effluent on soil properties, crop yields, nutrient uptake and leaching was found to be insignificant (Musazura et al., 2015). Insignificant levels of leaching could, however, possibly be due to very precise irrigation scheduling done for scientific experimentation, and this risk may require management under normal farming conditions. Risks of using sewage effluent for irrigation was low in terms of certain human pathogens, especially if the water is disinfected (Chale-Matsau, 2005) or if the crop is cooked before consumption (Al-Lahham et al., 2003). Heavy metal accumulation has been studied and may pose some risks that require monitoring and management (Ogbazghi et al., 2015).

According to Tilley (2021) the handling of the waste by farm workers is more of a concern than the consumption of the crops that were produced. In a WRC research study, Buckley et al. (2008) found the spread and infection by geohelminths, such as *Ascaris* spp, during the handling of excreta to be the highest health risk. Other pathogens, such as *Salmonella* spp, *Campylobacter* spp, *Escherichia coli*, *Clostridium* spp and Somatic coliphages can be present in human excreta.

Protecting people from such risks will be an important part of the DSP-WEF framework. The management of such risks must be acceptable to the end-user and it must become part of the daily SHF practices.

2.7.4 Previous sanitation development projects

2.7.4.1 eThekwini District Municipality (DM), KwaZulu-Natal (KZN)

A project was done to improve on-site sanitation practices for rural and peri-urban villages in eThekwini DM in KZN. Urine dehydrating diversion toilets (UDDTs) have been installed in peri-urban and rural communities in 2002. The advantages of UDDTs are that nutrients in the urine can be recovered, and faeces are dryer, enabling more hygienic treatment on-site (Mkhize et al., 2017).

Odindo et al. (2016) conducted focus group meetings with 48 participants from rural and peri-urban areas in eThekwini to determine their attitudes towards the use of human excreta in agriculture. Overall, they found that people responded positively to the idea. Despite this positive attitude, Odindo et al. (2016) noted the poor adoption of practices to use human excreta as fertilizer. Thus, more research is required to better understand the culture, behavioural patterns and beliefs of the people in terms of the concept of reusing human excreta for agriculture.

2.7.4.2 Fresh Life Toilets, Kenya

A lack of sanitation services in informal settlements in Kenya motivated the founders of Sanergy to implement new toilet systems, consisting of high-quality, low-cost sanitation units. With a urine-diverting squat plate, they separate solid and liquid waste, making collection and conversion safe and easy. Amenities include a handwashing station with soap, water and a bin for feminine hygiene products. Daily waste collection service is provided as part of the service, and excreta is treated and converted to organic fertilizers. They currently serve 126 690 people per day, have removed 43 473 tonnes of waste in 2021 and achieved a 30% increase in crop production (Sanergy, 2022). Although this system is more cost effective than sewerage networks, it requires funding and cooperation between government, private sector and civil society (Stradley, 2017).

2.7.4.3 Example of a biogas system, Zambia

Familiar problems with poor service delivery, including sanitation, were also experienced in informal settlements in Zambia when the Devolution Trust Fund (DTF), "a basket financing instrument with the aim to assist the commercial water supply and sewerage utilities to extend their services to the urban poor was established by the National Water and Sanitation Council to improve the water supply and sanitation problems. Since the DTF started operations in 2003, they have improved water supply services in 850 000 households in informal settlements. Together with the local NGO, WASAZA (Water and Sanitation Association of Zambia), and German NGO BORDA (Bremer Overseas Research and Development Association) a sanitation approach has been developed for these areas. This approach involves a robust, low-cost decentralised sanitation system resembling a simpler version of conventional sewerage systems. Low-water toilets such as pour-flush toilets were installed, and the sewage is treated in biogas digestors or conventional water treatment systems with ponds, anaerobic baffled reactor and gravel filters. Surrounding households can use the biogas for cooking. Biogas digestors must be emptied once a year and vacuum tankers are used to extract stabilised sludge from settler ponds, which are treated in specialised facilities. The sludge is dried and sold as fertilizer (Mulanga, 2013).

2.8 Discussion on the way forward

There are many decentralised sanitation technologies that can potentially be used in service of rural and peri-urban communities in South Africa. Many of these technologies have been tested in previous projects, but in many cases the reasons for successes or failures of different solutions are not yet clear. Previous studies have engaged with the end-users to determine their willingness to use different sanitation solutions, but as far as we know, there has not been a thorough analysis of cultural and religious aspects and thought-patterns of the end-users that are potentially relevant for the proposed technologies, or co-creating sanitation practices that integrates the available technologies within the context of the end-users, including their socio-cultural context.

2.8.1 Problems experienced with decentralised sanitation solutions implemented in previous projects

2.8.1.1 Technical problems

The University of KwaZulu-Natal constructed a pilot scale DEWATS in Newlands East in eThekwini Municipality in 2009, which treated wastewater from 84 households. The plant included a settling chamber, anaerobic baffled reactor, anaerobic filter, vertical flow planted gravel filter, and horizontal flow planted gravel filter (Truyens et al., 2018). Buckley et al. (2014) mentioned the following challenges faced during the initial phases:

- The Anaerobic Batch Reactor, which was the main treatment step, underperformed. This was attributed to system overload due to stormwater intrusions and chemical and trash dumping, as well as a low methanogenic activity of the biomass;
- Scum formation in the settlers due to soaps and detergents made the treatment less effective
- Rubbish and sanitary products blocked the pipes and caused system breakdown.

These technical problems that were experienced may be an indication that the scale was not appropriate. If too many people make use of one facility there is a risk that they may be using it in the wrong way.

2.8.1.2 Poor uptake of solutions

Social acceptability is repeatedly mentioned as one of the most important problems in the implementation of decentralised sanitation solutions (Martin and Pansegrouw, 2009, Odindo et al., 2016, Taing et al., 2014). Key findings of a study looking at qualitative and quantitative indicators of the perceptions of UDDTs showed:

- Despite the fact that 97% of recipients use UDDTs, 95% of interviewees did not consider these toilets as a permanent sanitation solution for their households and were waiting for water-born sewage.
- The majority of the participants reported that they do not identify with the UDDT benefits, such as using urine as a fertilizer
- The participants felt that the UDDT was not sensitive about their comfort since one has to be mindful all the time if your urine or faecal matter is going to the right place
- The fear of allowing children between two years and five years to use the UDDT toilet was one of the highly discussed issues. The majority of the participants reported that they discouraged their children from using the UDDT and they practice open defecation instead.
- Among those who were users, 80% were not maintaining the UDDT properly. The findings reveal that the UDDTs are mainly cleaned by females in the household, and this includes the emptying of the toilet. A small proportion of respondents reported that the task to empty the toilet is done by older females, because being in contact with faecal matter will bring bad luck to younger females.
- The older generation preferred the VIP toilet because they are accustomed to it, it requires less responsibility from the user and mostly the user does not have to empty it and
- The doors, back covers and seats were reported to be items that easily break, which made people feel that they were given cheap *toilets that were not customized to their reality*. (Mkhize et al., 2017)

The report concludes: “There is an urgent need for increased community participation to address users’ perceptions, attitudes and behaviour concerning the UDDT.

2.8.2 Applying the principles of the complex systems theory in the SHF context

Application of the complex systems theory may seem arbitrary and uncertain, but there are some proven approaches that can be used. The following general principles will be applied in this research:

2.8.2.1 Emergence through cooperation and shared vision

Firstly, as mentioned by Cilliers (2008), it is important to engage with the SHFs with a learning attitude and not with preconceived ideas of what the solutions should be. The eventual DSP-WEF must emerge out of the interaction between the different role-players. This is in line with the fact that relationships are important in complex systems, the understanding of problems and potential solutions could not originate from a single person’s perspective, but should involve perspectives of as many different parties as possible. The viewpoints of the SHFs themselves are especially critical in this assessment of problems and development of solutions. This approach can be called transdisciplinary research, in which SHFs, relevant NGOs and government officials, markets and scientists, etc. put their heads together to solve an everyday problem. Together, all role-players must develop a common vision.

Limited interaction between the different role-players during the development phase would prevent learning and the emergence of more beneficial outcomes (Van Rooyen et al., 2017)

2.8.2.2 Working on the right scale

In a complex system it is important to develop solutions at the correct scale. One disadvantage of a larger scale project, e.g. sewerage systems or the collection and central treatment that is done in Kenya (Sanergy, 2022), is that the individual households are dependent on the larger system and good management thereof. Small-scale solutions give the household more control to solve their own problems. Solutions at various scales (single households to some combination of local households) will be tested during the future development phase to better understand the needs and requirements of the target communities.

2.8.2.3 Importance of context

We agree with Boulton (2019) that the focus should be on context rather than on the interventions. The context is shaped by its history and the existing economic, social, cultural, ecological, political and other issues. However, we would formulate it slightly differently: our emphasis is on how these contextual factors are experienced by the relevant role players, and what meaning they give to it. Attending to the way that people experience something and what meaning they give to it is called a phenomenological approach (Aydin, 2007). Thus, the emphasis must be on the process in which technical interventions are integrated into and become embedded in the SHF practices, which in turn are embedded in the wider context.

2.8.2.4 Knowing the system: Internal or external evaluation

Complexity can either be (i) observed and analysed or (ii) one can "participate in and creatively co-construct the phenomenological experiences of everyday instances and encounters of a messy, complex reality" (Preiser, 2019). We follow this second approach (internal evaluation), not disregarding the first (external evaluation).

2.8.3 Addressing behavioural and cultural thought-patterns in this study

It is obvious that problems such as safety risks and environmental pollution of sanitation in rural and peri-urban areas should be addressed. Such problems have been discussed in this report and will become critical during the future development phase. More invisible problems such as religious and cultural thought-patterns and how they affect sanitation and other topics related to the WEF nexus are expected to emerge as the process continues and are just as important to understand; these problems will be central to the approach followed during this study and the next phases.

At this stage of the project, it is uncertain to what extent traditional thought-patterns and symbolism play a role in the target community of this project, and to what extent modern ways of thinking have been acquired. Modern technology has been introduced, and the relationship with the land has been modernised, but it is uncertain what has remained of the traditional, cultural and religious thought-patterns, what influence they will have in the planned project and how they should be taken up in and shape the practices that will emerge out of the various interactions that will occur during this project. The answer to this question will have to be determined in each local context by the relevant stakeholders and role-players together. The information on cultural thought-patterns from the literature is, however, important for the following reasons:

- It provides a theoretical framework that can be tested during the site visits,
- It creates an awareness of potential perspectives of the SHFs,
- It creates respect for the culture and behaviour of the people.

From the literature we can derive that, traditionally, human excreta is seen as vile, something that has to be concealed somewhere at a distance from the homestead. Sickness is both a natural and/or a spiritual matter. It can be caused by evil through witchcraft or jealousy, but it often has a physical presence in the body that can be cleansed out by being expelled from the body. Laxatives and enemas can help to cleanse the body. During the fieldwork it must be determined to what extent human excreta is experienced as impurity in normal circumstances, and if any rituals are involved in the normal daily affairs. If human excreta is seen as impure and associated with evil, the question would be how participants can be motivated to consider it as a resource.

An interesting aspect of impurity (ditšhila in Sepedi) is that it is closely connected with the critical changes of life, particularly with its beginning and its end. Life is often seen in a cyclical way: when you are born you come from the world of the ancestors, and when you die, you go back to them. In modern African literature birth and death are often taken up in the cycle of life, so that life comes from death, like a plant grows from a seed that is buried in the ground. The seed has to die for the plant to grow. Does this imply that impurity is also taken up in the circle of life? Could this thought-pattern contribute to the development of a circular agricultural pattern, in which human excreta are taken up in the agricultural practice?

2.9 Conclusion

Many scientists have grappled with the complexity of combining decentralised sanitation with smallholder farming practices in Africa. Even though the combined management of human excreta with food or energy production can potentially solve several problems in rural and peri-urban communities, many have realised that the principal problems are not merely technical and that the end-users should not be blamed for the poor uptake of the technologies that are given to them. We have noted a few references to culture in our discussion of the literature on sanitation technologies and combining sanitation with food production, but no one that follows a culture-based approach to the process of designing a DSP-WEF.

The complex systems theory provides guidelines, not methodologies, to work on the problems with the end-users, rather than to try and solve it for them. This is the approach that we intent to follow.

This literature review outlines some environmental and socio-economic problems, such as easy access and privacy as well as thought-patterns and cultural aspects surrounding matters such as energy use, food production and sanitation. It is clear that such issues could potentially play a critical role in the uptake of sanitation-with-SHF technologies. The intention of this project is to develop a good relationship with the target communities and a thorough understanding of their culture, thought-patterns, problems and feelings, while working on solutions with them.

3 Profile of Smallholder Farmers in the Limpopo Province

3.1 Introduction

Considering that this research is part of a long-term programme, and that much work will be invested in the co-design of decentralised sanitation solutions with SHFs, it is important to select communities that are representative of the district or province. The practices that are developed in one representative community is more likely to succeed in other similar communities. Therefore, the selection of study areas in which the co-design phase will be undertaken is critical for the future potential to upscale the practices that are developed.

This report outlines general characteristics of SHFs in the Limpopo Province which motivated the selection of the research sites. Important characteristics to be considered for site selection and the potential for upscaling to new areas include:

- Agricultural practices, including crops grown, size of the land, subsistence or backyard farmers, etc.
- Water supply and availability
- Sanitation
- Population density
- Poverty and employment

Broadly, communities can be classified as peri-urban or rural, and one research site from each of these categories will most likely represent a larger number of households in the province.

3.2 Methodology

3.2.1 Defining rural versus peri-urban

In order to select one rural and one peri-urban community, it is important to define the concepts of rural and peri-urban. The process of urban migration from rural areas has resulted in peri-urban communities that are located at the borders of cities and towns. In theory, these peri-urban communities differ from the traditional rural communities, for example by being a combination of people from various backgrounds and traditions, having access to municipal services, and having different socio-economic characteristics, because peri-urban people generally find employment in the city or town and are less involved in agriculture. **Table 3-1** lists the theoretical differences between rural and peri-urban which we have considered in the classification of our selected sites.

Table 3-1: Characteristics of rural versus peri-urban communities (based on own observations unless otherwise specified)

Characteristic	Rural	Peri-urban
Population density*	Less dense and more spread out	More densely populated
Social involvement and mutual support	Stronger community involvement	More individualistic
Access to roads	Poor access to roads & transport. Spaza shops can be available. People buy vegetables from neighbours / small vendors	Access to roads and transport Closer to a city or town
Access to piped water*	Mostly use natural water sources such as groundwater	Piped water and water from trucks
Use of firewood and electricity	Use more firewood	Use more electricity
Agricultural activities (at home / work on farms)*	More agriculture at home	Less agriculture at home
Employment	Mostly temporary employment at farms	More permanent employment in town
Culture	Community of one culture, more traditional	Mixed cultures, people migrating from various places to find employment in towns

* FROM (DIJKSTRA ET AL., 2020)

The characteristics in **Table 3-1** have important implications in terms of the adoption and sustainable use of practices that are co-designed. For example, people who use electricity may not be interested in converting human waste to biogas. However, in reality such distinctions between rural and peri-urban are not as clear, for several reasons:

- Rural areas are lately also switching to a cash economy and rural people could also find employment, although many live on grants or on money that is sent from relatives (Tsegay et al., 2014).
- Providing municipal services to rural areas is a problem and very often not feasible. People in peri-urban areas should receive municipal services, although this is often lacking. This situation differs from one municipality to the next.
- The structures of traditional rural communities are changing with men, and women, moving away to find employment, while leaving their children with their grandmother, people adopting more modern practices and some people in rural areas building large houses that cover the entire yard (where it is not such a big yard) and exclude any possible agriculture, etc.

It is therefore not simple to classify communities as rural and peri-urban, the various characteristics of each community can only be described relatively. In order to simplify the classification of our two selected sites, Molati and Ga-Sekororo, we used the criteria suggested by Dijkstra et al. (2020), namely population density and access to potable water. We have also included access to sanitation and waste management in terms of dumping of nappies, which is relevant because of the water pollution risks involved.

3.2.2 Map survey

A map survey was undertaken to characterise SHFs in the Limpopo Province in general and the two selected study areas in particular. Maps were sourced from Statistics South Africa (Statistics South Africa, 2011) and R-projects (Kahle D and Wickham H, 2013, Pebesma E, 2018, Wickham H, 2016,

Wickham H et al., 2019). Shapefiles on water access, sanitation, agriculture, population density and employment rates were used in the map survey, to better understand the current levels of services in Limpopo, agricultural potential and socio-economic circumstances.

3.3 Results: Characterisation of Limpopo

3.3.1 Agriculture in the Limpopo Province

Figure 3-1 shows the main agricultural regions in the Limpopo Province. The majority of the western part of the province is suitable for cattle, grains are produced in the southern parts, and the eastern parts, excluding the Kruger National Park, have fruits and forestry. Notable areas in Limpopo, especially towards the east, are characterised by subsistence farming, which are the target areas of this project.

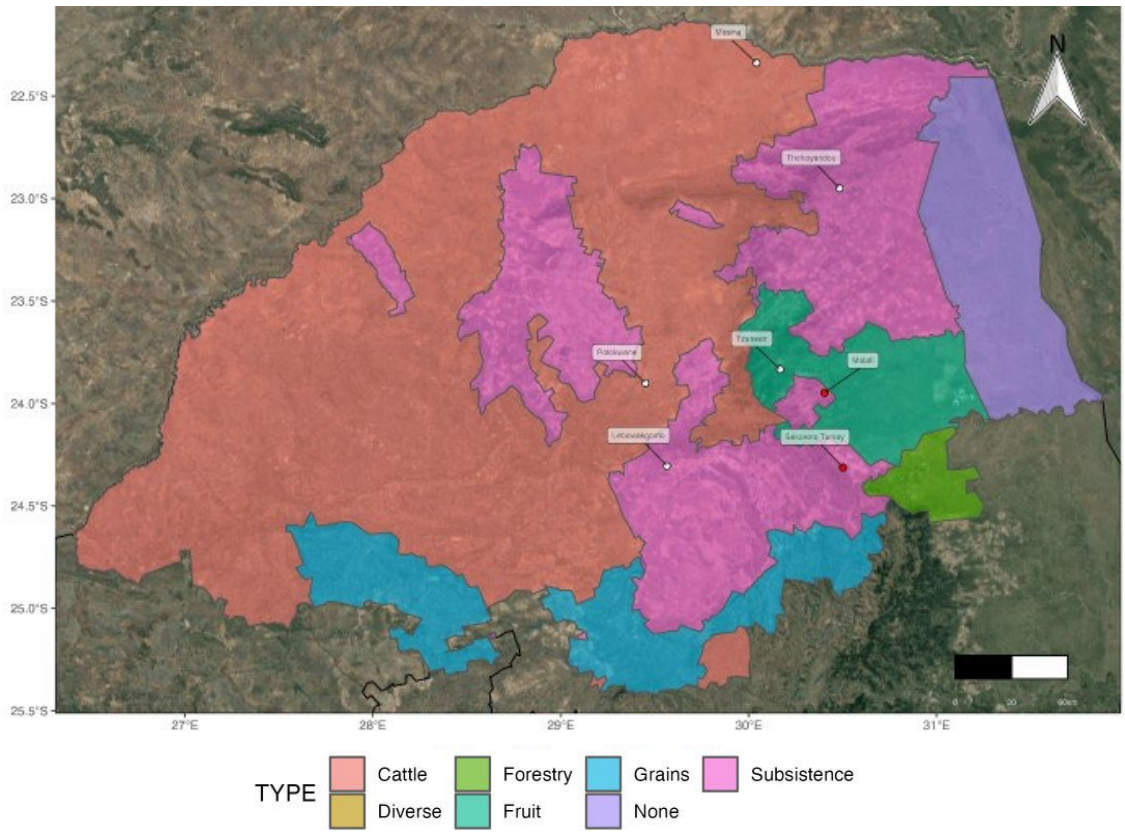

Figure 3-1: Agricultural regions in Limpopo

Figure 3-2 shows that relatively little vegetables are produced, but regions with slightly higher percentage vegetable production roughly coincides with the subsistence farmers. Vegetable farmers in Molati represent between 20% and 30% of all households per ward. According to **Figure 3-3** and **Figure 3-4** the percentage backyard and communal farms in Molati is about 10-30% and 0%, respectively. This means that almost all vegetable farmers in Molati are backyard farmers. **Figure 3-2** to **Figure 3-4** indicates very little vegetable production in Ga-Sekorokoro. Both Molati and Ga-Sekororo are representative of most of the province, especially the subsistence farmers, in terms of their involvement in vegetable production.

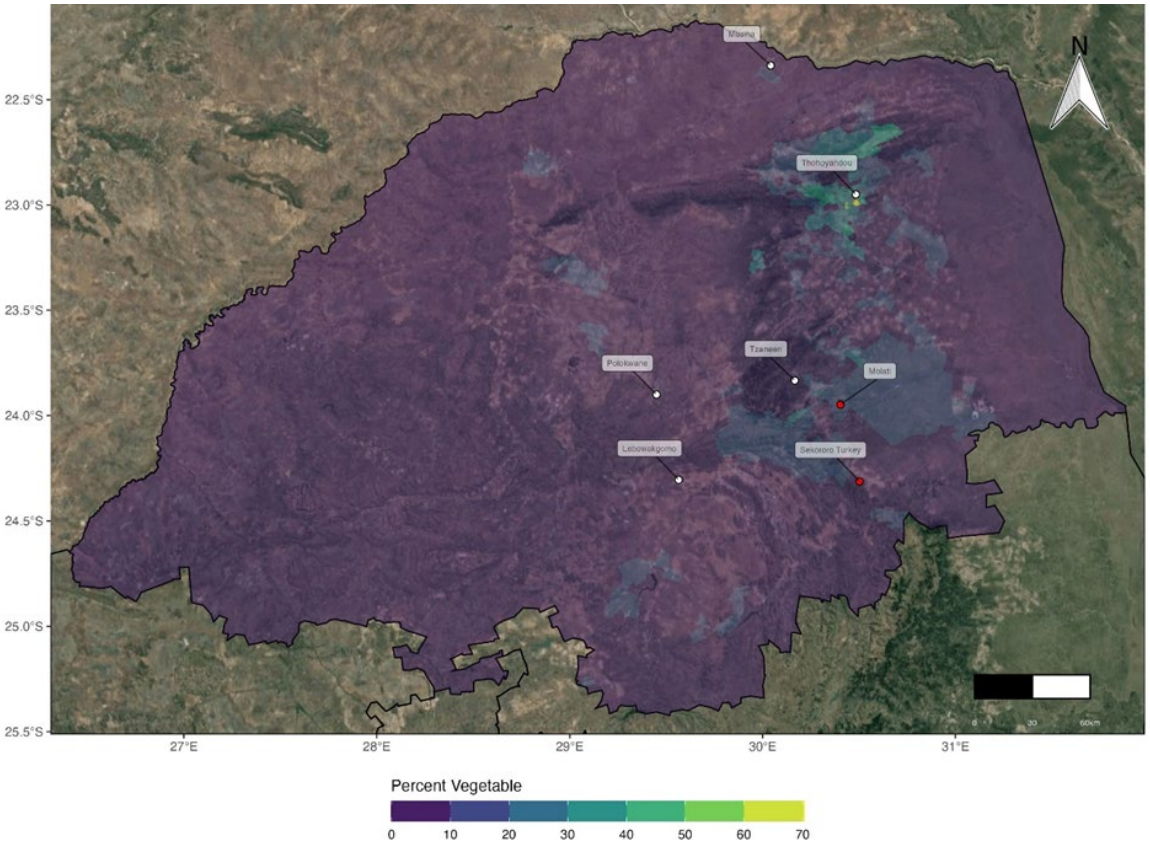

Figure 3-2: Vegetable production in the Limpopo Province

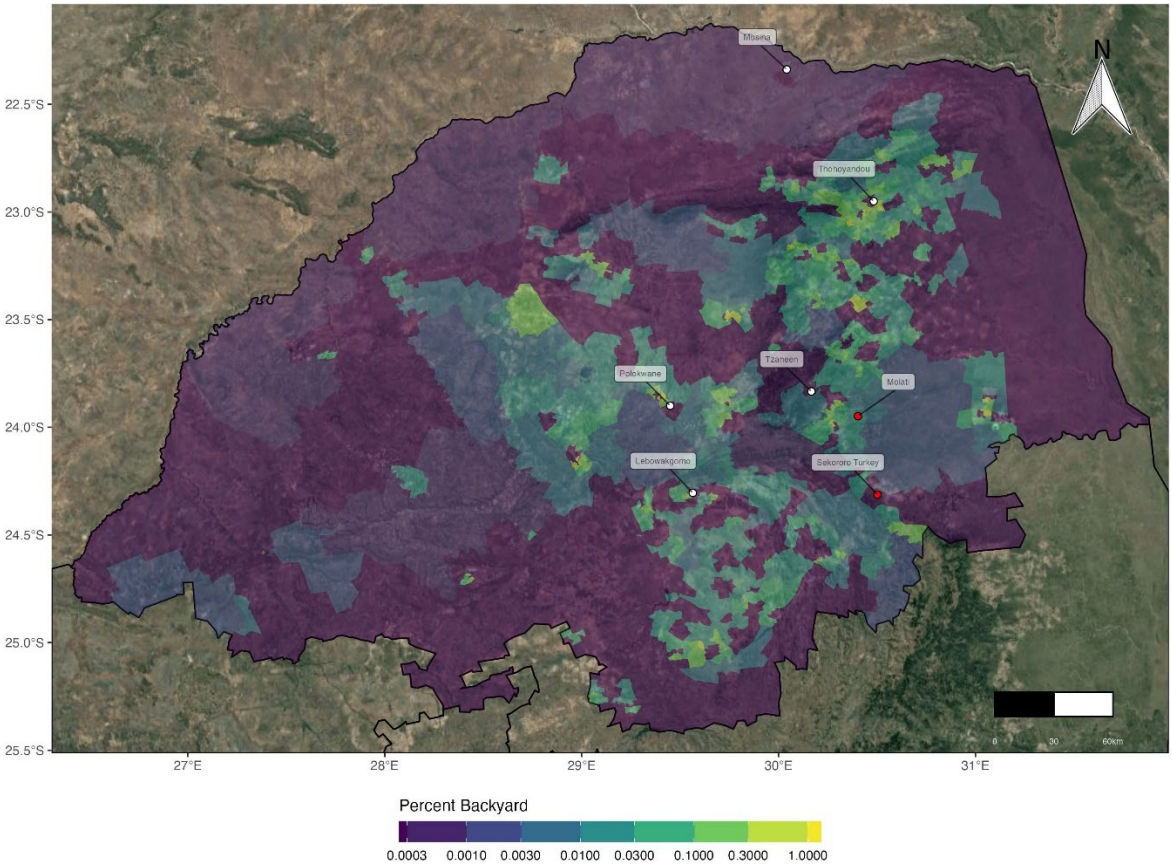

Figure 3-3: Percentage backyard farmers in the Limpopo Province

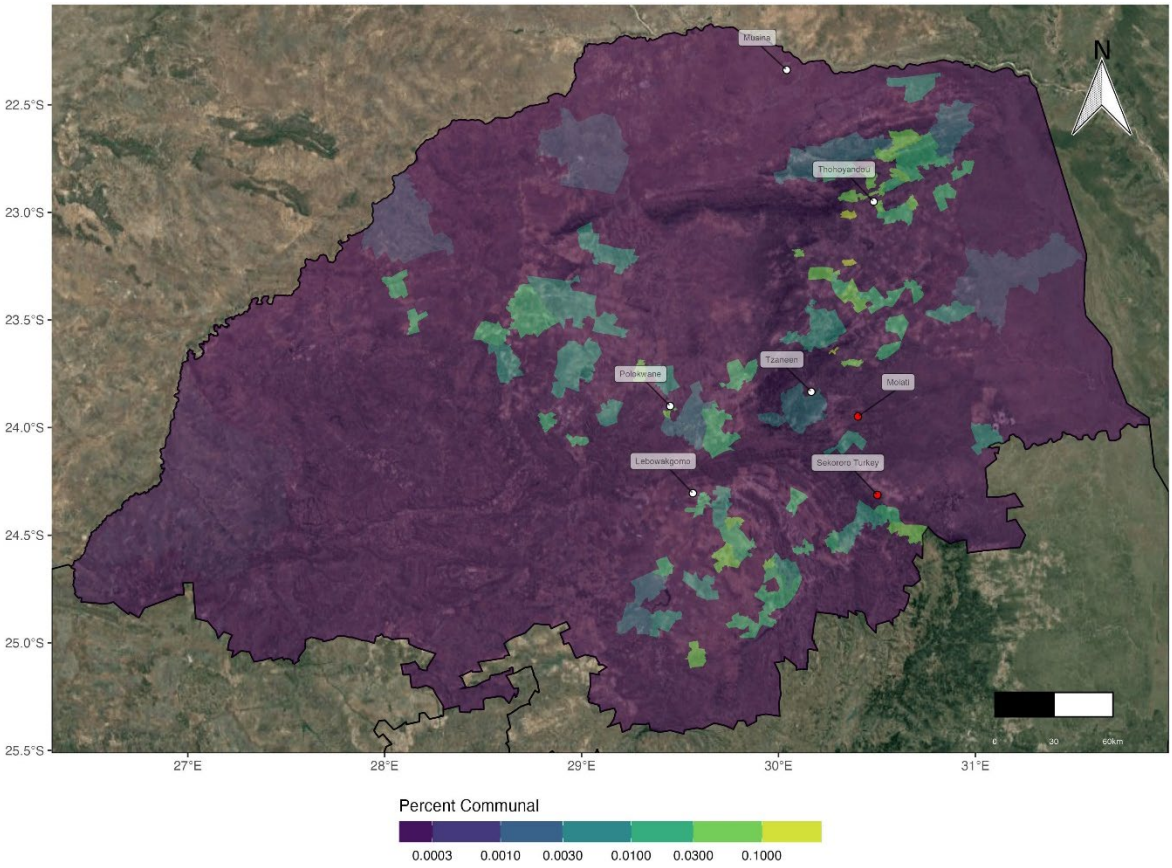

Figure 3-4: Percentage communal farms in the Limpopo Province

3.3.2 Water availability and sanitation

Figure 3-5 shows the majority plumbing infrastructure in each ward of the Limpopo Province, respectively. Most wards have a majority water access inside the yard, and second highest is water access inside the dwelling. Large sections in Limpopo have no majority, meaning that these areas have a mixture of indoor, outdoor or community water access. According to **Figure 3-6** the dominant water access in Molati is community stands within 200m of the dwelling, while the dominant water access in Ga-Sekororo is within the yard. The two selected sites therefore represent the two water access scenarios that are most dominant in the majority of the province, in particular within the subsistence farming communities (**Figure 3-1**).

Figure 3-7 shows the majority sanitation in each ward of the Limpopo Province. Most wards in Limpopo have a majority of normal pit latrines, while a majority in flush toilets are second highest. Relatively few wards have a majority of improved ventilated pit latrines (VIP). Areas without a majority means that the wards have a mixture of various forms of sanitation. According to **Figure 3-8,** the dominant sanitation in Molati is normal pits, while Ga-Sekororo falls just within the boundaries of a region where VIPs are most dominant. Thus, in terms of sanitation the two sites also represent two important and representative types of decentralised sanitation systems used in the Limpopo Province.

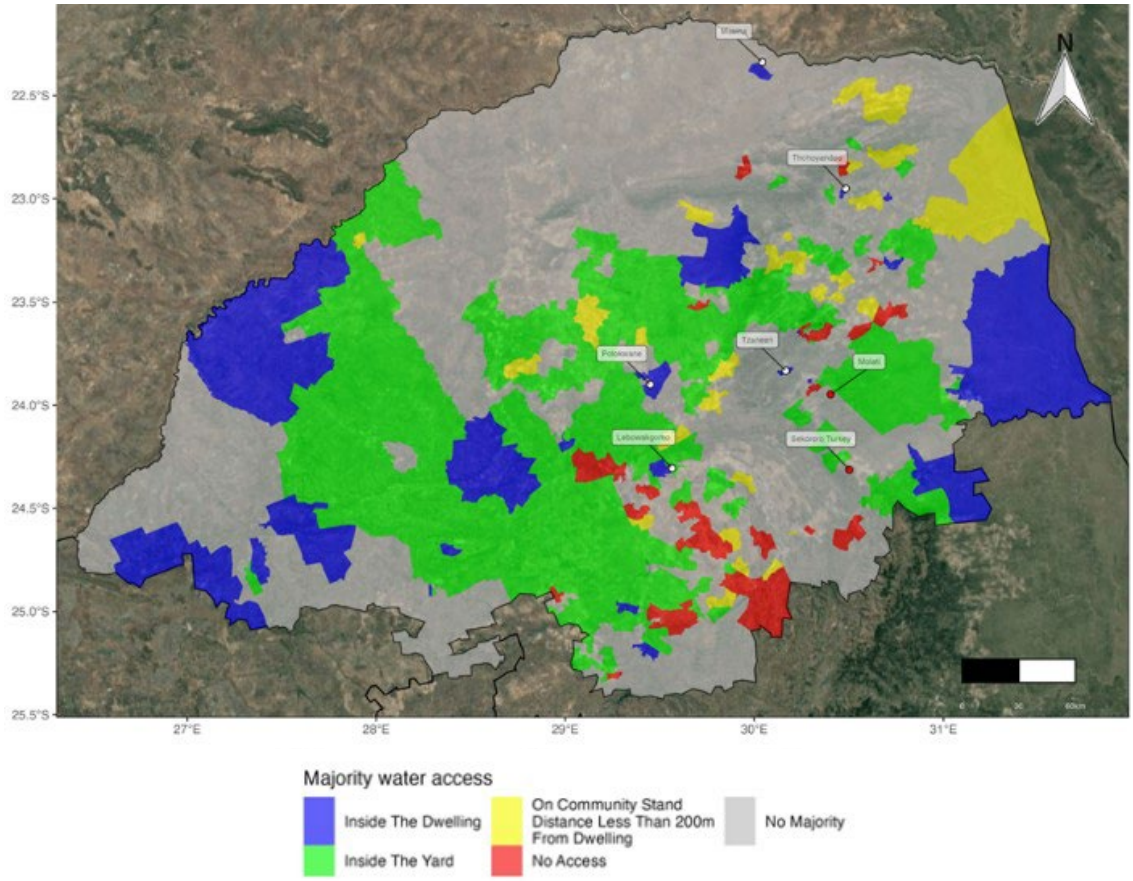

Figure 3-5: Majority plumbing infrastructure (above 50% of households) by ward in Limpopo

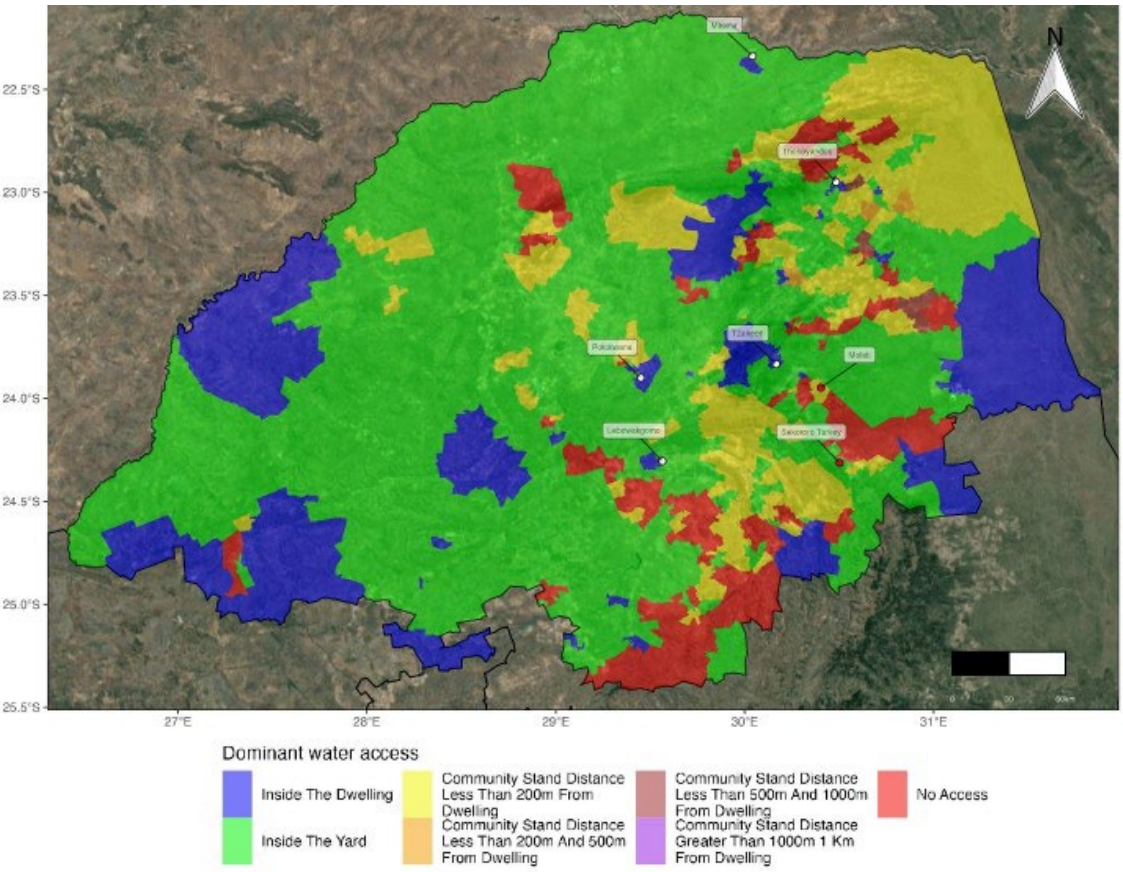

Figure 3-6: Dominant plumbing infrastructure by ward in Limpopo Province

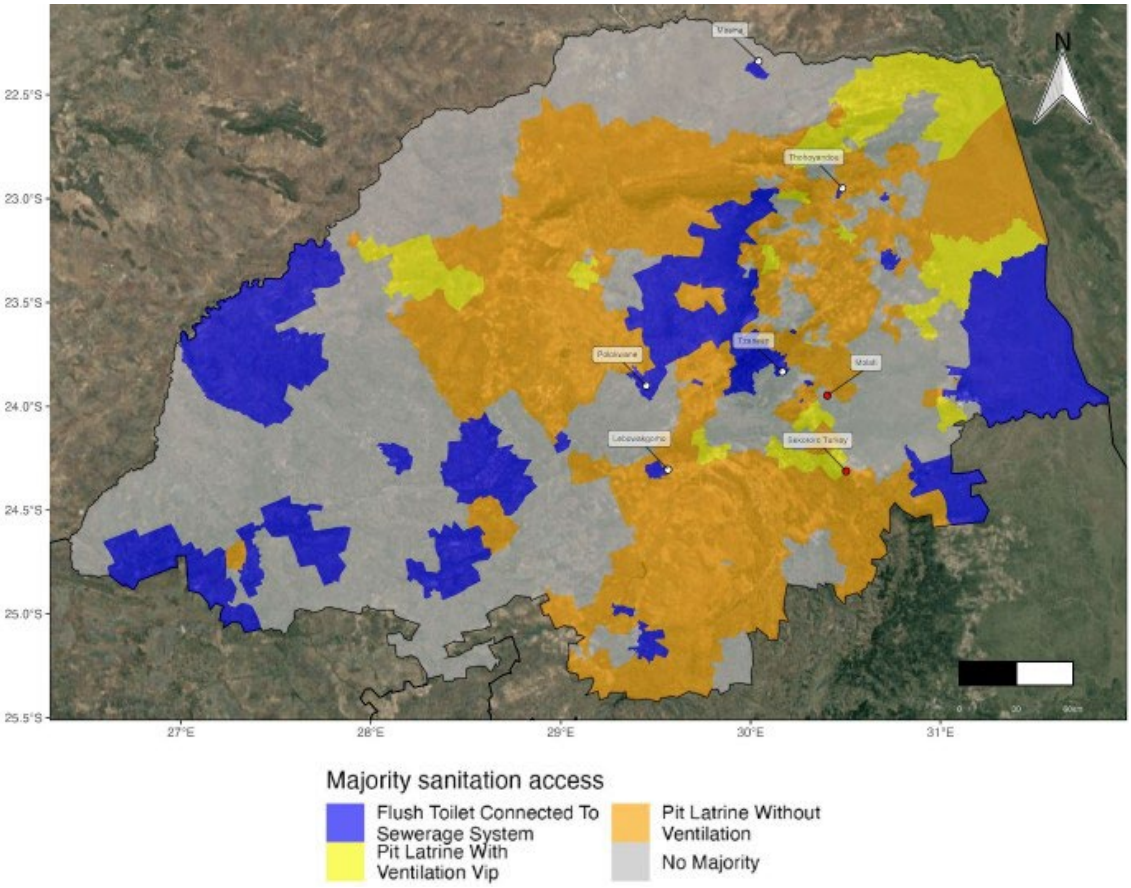

Figure 3-7: Majority sanitation access (more than 50% of households) by ward in Limpopo

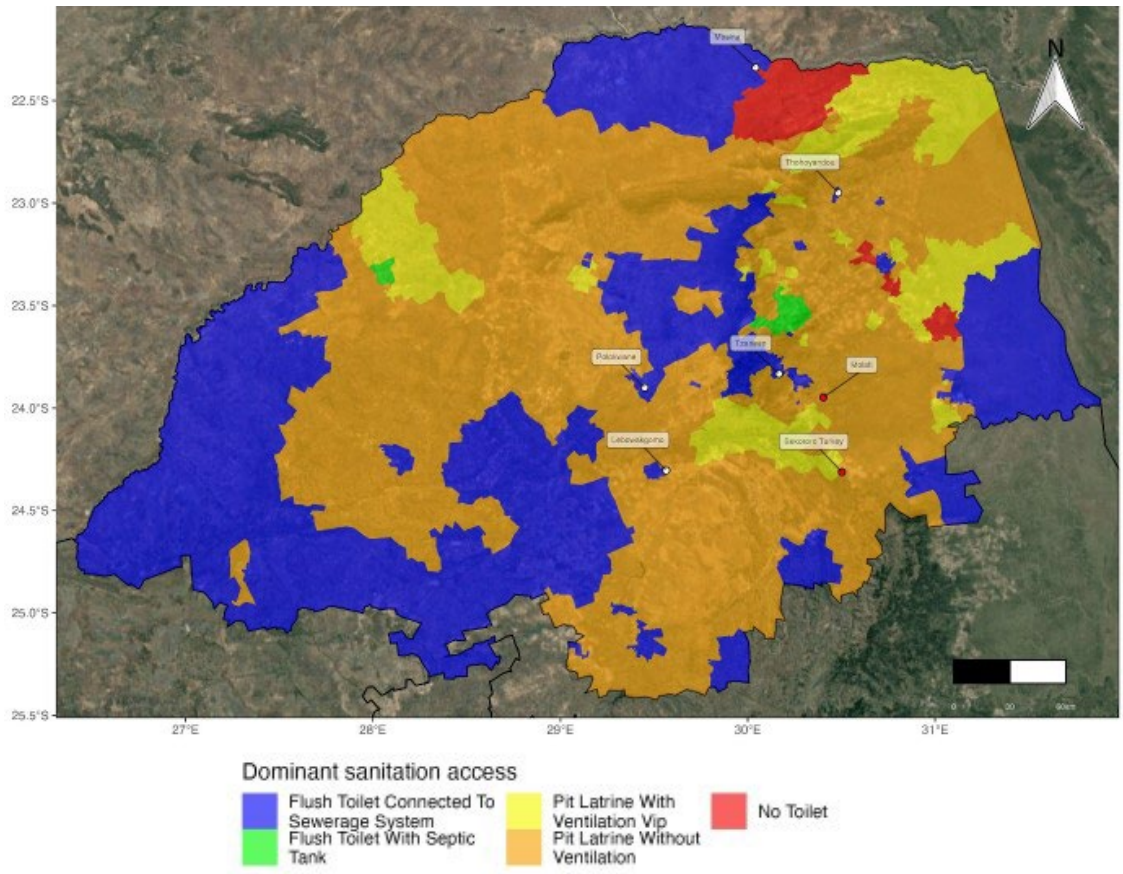

Figure 3-8: Dominant sanitation access by ward in Limpopo Province

Figure 3-9 indicates the relationship between indoor plumbing and dominant sanitation. The large blue circles show a correlation between indoor plumbing and flush toilets. Small orange and yellow circles show a correlation between dry toilets and a lower percentage in indoor plumbing. There is no clear correlation between the use of VIPs and normal pit latrines in relation to indoor plumbing. The choice between VIPs and normal pits is more likely due to various other factors such as municipal support.

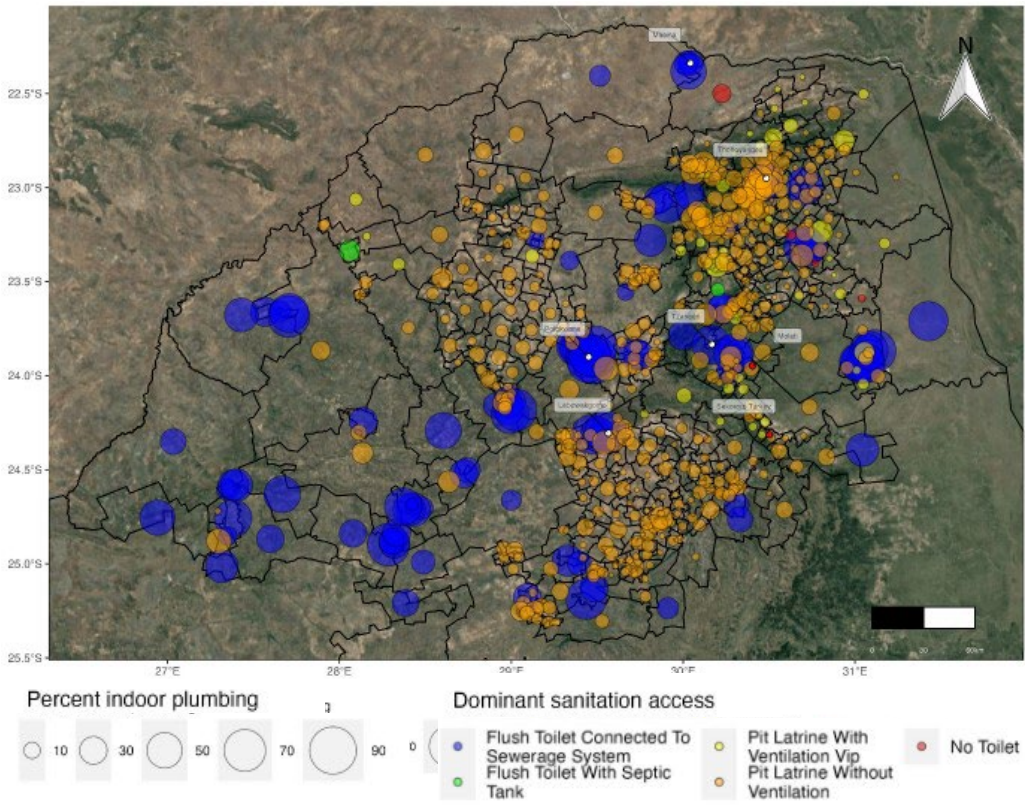

Figure 3-9: Dominant sanitation graduated by precent indoor plumbing by ward in the Limpopo Province

3.3.3 Population density

Figure 3-10 shows the population density of the Limpopo Province. The higher density areas that exceed 300 people per km^2, roughly coincides with larger cities or towns and with the areas of subsistence farming shown in **Figure 3-1**. Lower density regions then represent commercial farmlands and nature reserves. Molati and Ga-Sekororo have population densities of approximately 100 and 300 people per km^2, respectively. Based on this Ga-Sekororo can be classified as peri-urban and Molati is more rural.

3.3.4 Poverty

Limpopo is one of the poorest provinces in South Africa (Human Sciences Research Council Economic Performance and Development, 2014) where more than 30% of the population experienced hunger in 2013. Stunting among boys and girls 0-3 years of age was 26.9% and 25.9%, respectively (Human Sciences Research Council, 2013). According to **Figure 3-11,** large areas of the eastern and central parts of the Limpopo Province have an unemployment rate above 50%. There is reason to think that poverty and hunger has worsened as a result of Covid-19.

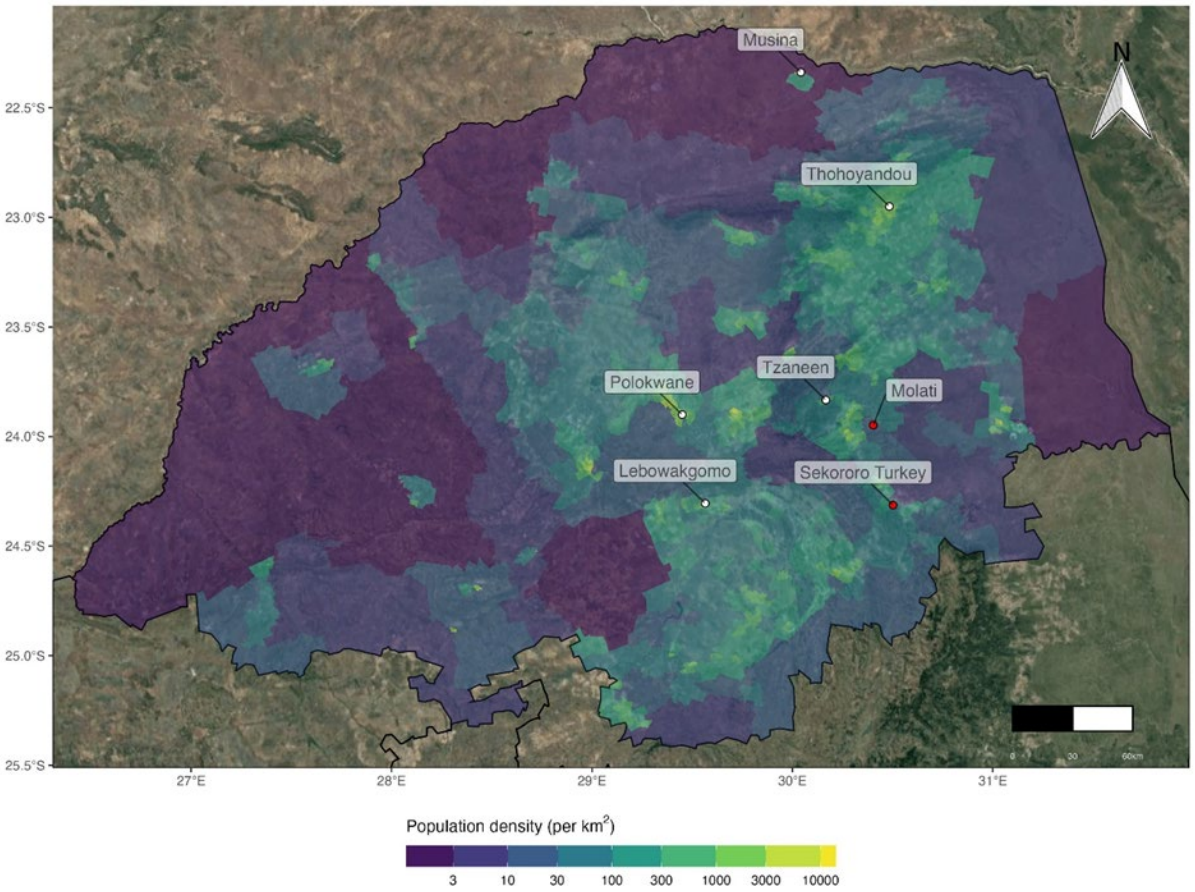

Figure 3-10: Population density in the Limpopo Province

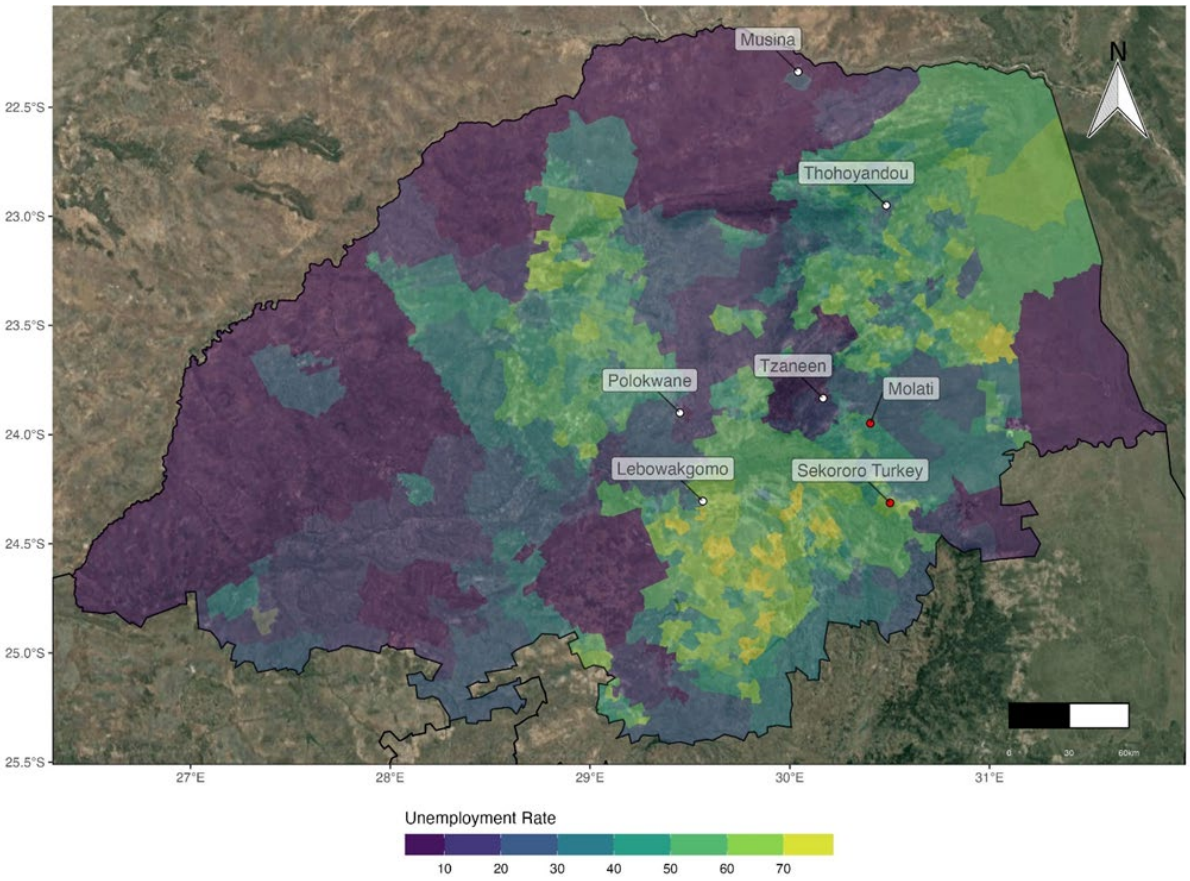

Figure 3-11: Limpopo unemployment rate

3.4 Discussion on the way forward

From the discussion above it is clear that the Limpopo Province in general and the Mopani DM in particular needs solutions for poverty, unemployment and poor service delivery. Current systems are not only failing in terms of poor implementation and backlogs, but also in terms of community cooperation. The typical model of centralised water treatment and supply seems not only to be failing currently, but unlikely to succeed in the future. There is a need for locally developed, 'indigenous' solutions that are better aligned with the needs, culture and capacities of the people.

Figure 3-1 shows that subsistence agriculture covers a significant portion of the Limpopo Municipality. The areas of subsistence farming also correlate with areas where backyard vegetables are grown, and where pit latrines and poor water access are dominant. These areas are the focus of this project. The two villages that were selected are considered well representative of these areas. Molati represents a large area in the province that has normal pit latrines and access to water is predominantly within 200m of the yard. Ga-Sekororo similarly represents another large portion of the province that uses mainly ventilated improved pit toilets and have water access within their yards. These similarities will improve our ability to upscale the decentralised sanitation practices in the WEF framework to be developed within Molati and Ga-Sekororo.

3.5 Conclusion

It can therefore be concluded that the two villages, Molati and Ga-Sekororo, properly represent a significant part of the most needy people in the Limpopo Province and will be suitable areas for co-designing the decentralised sanitation practices within a WEF framework.

4 Engagement with smallholder farmers

4.1 Introduction

A good understanding of the problems, opportunities, cultures, thought-patterns and behaviours of the SHFs is imperative. We report on the individual interviews with the SHFs, two focus group sessions with SHFs in Ga-Sekororo and two in Molati, and a deep analysis of the system in which the SHFs live and work. This analysis indicates the links between various problems that SHFs experience, as defined by themselves, and the environmental, cultural, economic and government constraints within which they operate, as, firstly, defined by the researchers on this team and then, secondly, by the SHFs.

4.2 Methodology

The engagement with SHFs was done through individual interviews and focus group meetings in both Molati and Ga-Sekororo. The individual surveys were done at the end of July 2022 and the first focus group meetings occurred on 6 September 2022 in Molati and on 7 September 2022 in Ga-Sekororo. Individual interviews were done with 9 SHFs in the Molati Village, and 20 SHFs attended the focus group meeting. In Ga-Sekororo 12 SHFs were interviewed individually and 16 attended the focus group meeting. A second round of focus group sessions were held with the same groups: in Ga-Sekororo on 7 March 2023, in Molati on 8 March 2023. Most of the SHFs that were interviewed also attended the meetings. These are the people that will participate in the co-design phase in future research. They will form part of the planned co-designing team.

The aim of the process was not to collect quantitative data, but to qualitatively characterise the groups of SHFs and to build a relationship with them as part of a transdisciplinary research team that will work together to solve their sanitation problems during future research.

4.2.1 Individual interviews

Questionnaires were designed to explore the understanding of sanitation and agriculture in these two villages. People were asked how they feel or think about the sanitation they are using, looking into six spheres connected to sanitation, namely cultural meaning, environmental meaning, economic meaning, safety, social/political meaning and potential uses (See **Appendix 2** for a copy of the questionnaire used). The SHFs volunteered to be interviewed at the introductory meetings – this is important, because in future research these volunteers will form part of the transdisciplinary team to co-design decentralised sanitation solutions that will be well integrated into their context and daily lives.

4.2.2 Focus group meetings

At the beginning of each focus group meeting a register was circulated and the aim of our project, to integrate decentralised sanitation into agricultural practices in a way that is desirable, was explained to the SHFs. We also informed the SHFs that the actual development of new systems may not start soon, because we are currently conducting a scoping study, and we are still looking for funding for the development phase. Once development starts, it will be done over three years to experiment with decentralized sanitation systems. There are a number of technical options, and we want to work with the farmers to determine what can work and how. The SHFs will use different technical options, and we will regularly discuss their experience and together find the best options for each issue.

The agenda for the first focus group meeting in September 2022 was as follows:

- Past, present and future of sanitation and farming in their villages, analysed separately
- How to integrate sanitation into agriculture in a way that can work
- Issues: Most pressing matters related to, for example:
  - Climate change
  - Stakeholders
  - Municipality – registration for sanitation, etc.
  - Present functioning of toilets

The second round of focus group meetings in March 2023 also started with an introduction to explain that we wanted to discuss the problems that SHFs experience in terms of agriculture and sanitation. The SHFs were given approximately two hours to talk about these problems. Apart from making notes on a flip chart that was displayed and visible to all who attended the meeting, the project team did not contribute to the conversation, in order to get a complete perspective from the SHFs.

4.3 Results

The results of the individual interviews and the focus group sessions have been integrated, because both methods are qualitative in nature, and the information from them often overlaps.

4.3.1 Basic information about the SHFs

A total of 21 SHFs in Molati and Ga-Sekororo were interviewed individually (7 men and 14 women). In general, SHFs have been living in their respective villages for extended periods, on average 43 years, and are well settled where they live. Yard sizes are around 2 000 m^2 to 2 400 m^2 in both areas. Further information on the SHFs is included in **Appendix 2.**

4.3.2 General impressions from the focus group meetings

The SHFs from Molati and Ga-Sekororo responded very differently to the concept of the project to develop decentralised sanitation systems that are integrated with agriculture, which we have presented during their respective first focus group meetings. The reason for this difference is probably because of the history that Ga-Sekororo has with the Mahlathini Development Foundation over the four years preceding the meetings. The group of SHFs in Molati has not recently been involved in successful agricultural projects that have improved their quality of life, while SHFs from Ga-Sekororo recently have had this experience.

The SHFs from Molati wanted assurance that it is safe to re-use human waste for compost. The project team indicated that the practices will be developed with them, to ensure that they are comfortable with the solutions that will emerge. At that stage we were not able to say what kind of solutions will be the result of our study yet, but if a solution had risks or is unacceptable to them, we would not implement it. The SHFs at Molati also indicated that they were happy with their pit latrines, and they only wanted the municipality to service and empty the toilets when they were full. Some SHFs in Molati, however, indicated that they are willing to cooperate in the project and that they had seen other people re-using human waste as compost.

At Ga-Sekororo, the SHFs indicated a number of problems that they experienced with pit latrines and indicated that they are willing and excited to participate with us in finding better solutions. They indicated that they are willing to pay for better alternatives and they are comfortable with re-using

human waste as compost, if it is safe. The solution that they saw for sanitation problems was that the municipality should empty the toilets regularly. At Ga-Sekororo the SHFs were much more realistic about their expectations of the municipality, and did not expect any services from them. They did not say that they were unhappy about it, and it seems as if they have accepted responsibility for improving their own lives. This is most likely due to the feeling of empowerment that previous development projects have given them.

4.3.3 Access to water and sanitation

4.3.3.1 Water access

All SHFs had access to electricity in their homes, but only approximately half of them had access to water through municipal water provision, mostly communal standpipes or central water access points. The larger proportion of the group of SHFs, especially in Molati, had individual boreholes in their yards that they installed themselves. In Ga-Sekororo the SHFs also relied on unprotected springs for water access. In Ga-Sekororo access to water is generally extremely limited and water shortages are a major concern. Households resort to buying water in times of scarcity and this means that water is used for drinking and household purposes primarily and not for irrigation. About a fifth of the SHFs in Ga-Sekororo use greywater to clean their pit latrines, due to the lack of water. A few of the SHFs in Ga-Sekororo were members of the local community water access borehole scheme and another group of 10 community members clubbed together to develop their own small scheme with a borehole they paid for. During the focus group meeting at Ga-Sekororo, people complained that water is hard and they had problems of scale deposits.

4.3.3.2 Current sanitation

Figure 4-1: An example of a typical pit latrine in Molati village, constructed by the Greater Tzaneen Local Municipality (September2022)

Almost all of the SHFs have dry on-site toilets or pit latrines that are situated at the far corners of their yards to limit bad odours inside the house (). Few houses, especially new houses, do not have a toilet, but these people would share toilets with their neighbours on a temporary basis if necessary. At Ga-Sekororo human waste is sometimes seen in the veld.

The pit latrines have either been constructed by the residents themselves or the municipality. Half of the SHFs have between 1 and 3 pit latrines on their properties that are in use. The trend is that new pit latrines are built before the old ones are full and usually if the functionality of the first latrine becomes limited due to decaying top structures or collapsing of the pits. The SHFs also mentioned that they prefer to have more than one pit latrine in use, sometimes with separate latrines for women and men in the household. On average seven people per household use a pit latrine at any given time. SHFs indicated that dry on-site toilets are more affordable and it is not expensive to construct one for themselves.

Old pit latrines are used for disposing general waste products, such as disposable nappies. At Ga-Sekororo the problem of full pits during floods was raised. This situation is a motivation for the SHFs to re-use their waste. Other SHFs indicated that their pit latrines were in operation for many years, for such a long time that most could not remember exactly when they had been built. As the area is

hot and quite dry and the soils are sandy, filling up of latrines is not a major concern for them. The problem is the smell and build-up of odour over time.

The SHFs all use toilet paper or newspaper for personal hygiene and although there is no water access at the toilets, all SHFs interviewed said they wash their hands after using the toilet. Most people do not have a problem with cleaning the toilets, but it is not easy to clean the pit latrines. All SHFs use cleaning materials such as Domestos, Jeyes fluid and Jik to clean their pit latrines on a regular basis (1-3 times per week). A few SHFs mentioned using decomposing granules in their pit latrines to increase the processing of the waste and reduce smells. They mentioned that these chemicals require a lot of water, and one is not allowed to use the toilet when the chemical is poured inside the toilet. They normally use the chemical at night. They do not throw foreign objects into the toilet that are still in use; old and unused pits are used for general waste disposal.

Most SHFs aspire to have good service delivery in the form of cartage to empty their pit latrines; they do not aspire to have on-site flush toilets because of the reality that there is not enough water for that. The SHFs are mostly willing to pay for having their pit latrines serviced. More than half indicated that they are willing to handle wet and dry forms of human waste and to use it for composting and growing crops.

One SHF at Ga-Sekororo has experimented with a septic tank, but currently it is filling up and he is unable to empty it. Only a few SHFs make use of cartage services for their pit latrines. Two SHFs have built flush toilets in their homesteads, and they make use of cartage services to clean out their septic tanks. A company in Hoedspruit, Drain Surgeon, is most commonly used for this service. Cartage is only done by private companies and individuals and the Greater Tzaneen or Maruleng LMs are not currently undertaking this service. The Maruleng LM apparently does not empty old pit latrines, but rather dig new pits when the old one is full. The SHFs from Ga-Sekororo, mentioned that there is a group of men led by Mr Sekgobela from Sophaya, who go around and empty VIP toilets manually and dispose of the waste, for an affordable fee*. A case study of this service provision is provided in* ***Appendix 3****.*

4.3.3.3 Problem with the pit latrines

At Ga-Sekororo, people mentioned insect pests that are a problem in the pit latrines. The toilets are very hot and there are many flies inside. When you enter the toilet the flies sit all over you, and the people fear that this could cause diseases. An SHF said that insects bite her legs when she cleans the toilet. Sometimes there are so many ants in the toilets that people are unable to sit on it. And there are also very big cockroaches. Some of the SHFs said that VIP toilets have an unpleasant smell that sticks to one's skin and clothes after using the toilet.

During the day the SHFs feel safe when using the pit latrines in their homestead, but because of crime some do not feel safe at night. They use a bucket inside the house at night. All SHFs said that they do not allow children to use pit latrines, because of the risk of children falling into the pits and some of the structures are unsafe, therefore, children practice open defecation. There are no rules about open defecation, but most people will clean up after the child, and most of the adults only use a toilet, rather than practice open defecation. They indicated that toilets at schools are safe, because they now have flush toilets with seats that fit the children.

4.3.3.4 Present situation and aspirations

The SHFs were asked which type of sanitation they would prefer. In both villages most of the SHFs that were interviewed and those who attended the focus group meetings, indicated that they prefer pit latrines with cartage services (Figure 4-2). They admitted that everyone aspires to flush toilets, although few indicated flush toilets to be their preference, because they were realistic about the high costs and the amount of water needed. It was generally agreed that dry toilets should be outside of the house. People are willing to share toilets with their neighbours, but sharing over the long-term is a problem.

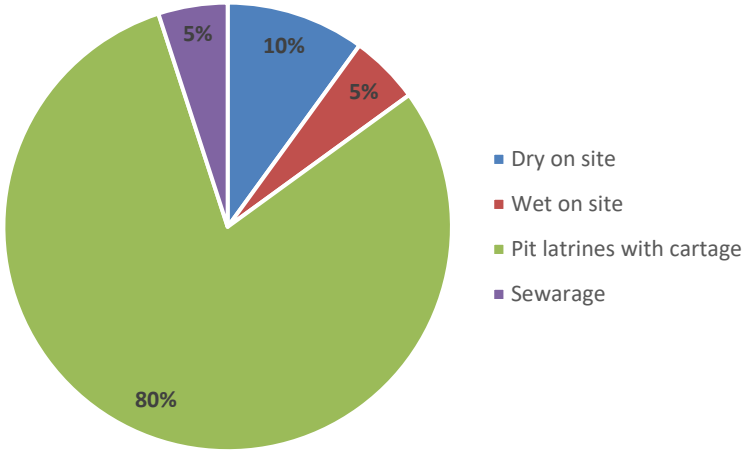

Figure 4-2: Types of decentralised sanitation systems preferred by the smallholder farmers that were interviewed or attended the focus group meetings.

Another SHF at Ga-Sekororo indicated that he would prefer a toilet that does not store the waste where it is visible from above. The SHFs, especially those in Ga-Sekororo said they are willing to contribute up from 30% to 50% of the costs involved for improved sanitation.

During the interviews and the focus group meetings some SHFs indicated that they are aware that human waste can be used for agricultural purposes, however they do not know how to use it. An SHF in Molati indicated that there is a man from Nobody, close to Polokwane, who makes manure from filtered human waste. In Ga-Sekororo some participants indicated that they buy waste from wastewater treatment works in Phalaborwa, which is used as compost.

The SHFs were asked how they feel about handling human waste and what kind of waste, i.e. urine, dried human waste, or wet human waste, they are most willing to handle and re-use for agricultural purposes. Six of the 21 SHFs that were interviewed indicated an aversion in handling any form of waste. They considered it to be a disgrace and they feel that they would never eat or sleep if they were to handle it. They would not use it for agriculture, because they have to sell their crops. Five SHFs said that they are willing to handle urine, wet human waste and dry human waste and if taught to do it safely, they will use the waste to make compost. Seven SHFs are willing to handle urine and dry human waste. Most of the SHFs that indicated willingness to work with human waste and to re-use it in agriculture indicated that they will only do it if they can avoid health risks through better knowledge, wearing protective clothing or managing the pathogens.

4.3.4 Environmental characteristics

The SHFs indicated that both areas are reasonably flat, but that there is considerable run-off when it rains. The few SHFs who have problems with pit latrines temporarily flooding when it rains were all in Ga-Sekororo. Most SHFs have found ways to lead run off water away from their pit latrines or have built them at higher elevations for this purpose. They believe there is contamination from their pit latrines in their environment, but could not clarify exactly how this occurs.

Approximately 180 m east of Molati a large erosion gully has formed during a flood several year ago. This gully has naturally started to stabilise in some places with some vegetation along the edge, but in many other places the soil is still eroding. This gully is used by the community for solid waste disposal, specifically of baby nappies.

4.3.5 Agricultural practices

All the SHFs that were interviewed practice agricultural activities, primairly backyard gardens, which all respondents mentioned having. Dryland field cropping is also undertaken by many of the SHFs and almost half of them own livestock (poultry, goats, pigs and cattle) (**Figure 4-3**).

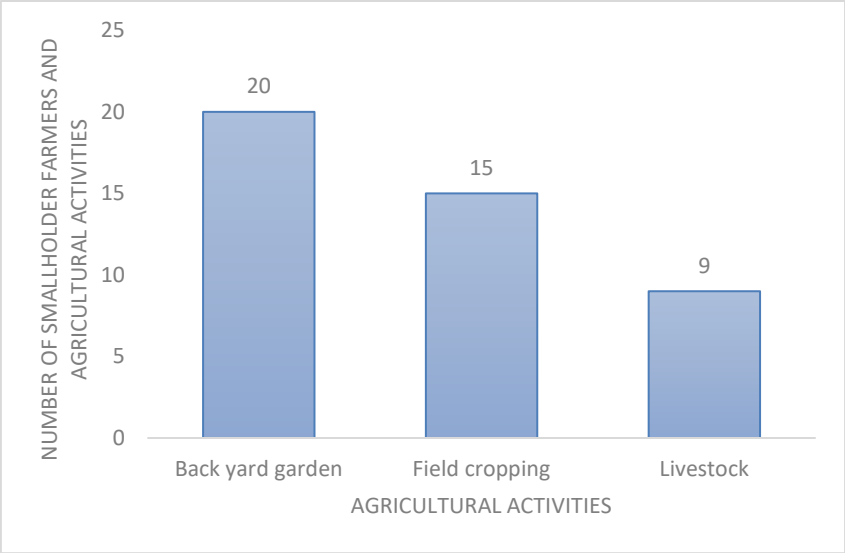

Figure 4-3: Distribution of farming activities among survey respondents.

Backyard gardening is more prevalent (**Figure 4-3**) as this is easier to manage and they can use available water in their household for irrigation, for example in Ga-Sekororo there are times where they go days without water and they use filtered greywater to irrigate their gardens, while it would be difficult to maintain field crops if it does not rain. Respondents from Molati are still doing field cropping because rainfall in that area is better and more predictable than in Ga-Sekororo. In Ga-Sekororo, most respondents have abandoned their large fields due to lack of rain, extreme heat, soils with low fertility and an inability to afford expensive external inputs. About two thirds of the SHFs involved in this project that have livestock, mainly cattle and goats, are based in Ga-Sekororo. There are larger communal grazing areas available for extensive livestock grazing than in Molati, which lacks grazing.

Figure 4-4: Vegetable garden in Ga-Sekororo and Molati

Figure 4-4 shows homestead garden in Ga-Sekororo (Photos 1 and 2) and Molati (Photos 3 and 4). Photo 1 shows mustard spinach grown in deep trenched beds and a drum of liquid manure in the foreground. Photo 2 is an example of furrows and ridges, intercropped with herbs such as rosemary and lemon grass and a micro-tunnel with drip irrigation in the background in Ga-Sekororo. Photos 3 and 4 shows vegetable production undertaken in Molati. The layout of these gardens in Molati is more traditional for the area, with a lot of bare ground between rows. The raised jo-jo tanks indicate the storage of water from individual boreholes used to irrigate these gardens. There is a difference in soil types, with the sandy, infertile hydrophobic soils common of Ga-Sekororo in Photos 1 and 2 and the much more fertile deep red Hutton soils in Photo 3 and 4, common to Molati.

In Molati, the SHFs with backyard gardens are also those who have their own boreholes, to facilitate irrigation. In Ga-Sekororo, the majority of respondents have been working with Mahlathini Development Foundation, and they have been introduced to a number of soil and water conservation practices, as well as rainwater harvesting to improve their access to water for gardening. Greywater management and use have been promoted and drip irrigation, using a greywater system, has been introduced in the micro tunnels promoted in this area. Practices such as compost making, deep trench beds, furrows and ridges, mulching and green manuring have assisted in improving water holding and crop production significantly. People in Ga-Sekororo use grey water and soil moisture conservation practices, which have improved their lives, because they are now also able to produce crops in winter. In Molati most of the farmers have been working on their own with the little help they get from the Department with tractors and pipes, and most are also using drip irrigation in their gardens. Here greywater is used for watering flowers and ornamental plants, unlike Ga-Sekororo where it is treated either through filtration or ash and then used on crops.

4.3.6 Culture and traditions

Communities are grounded by beliefs and traditions, including taboos and social and religious customs restricting particular things, actions and people. Through the interviews conducted, it was clear that in both villages there are no rules or traditions for building a toilet and that people are behaving according to general practices. The SHFs indicated that they have used toilets that were poorly constructed in the past; some used to share toilets with their neighbours or practiced open defecation.

The SHFs confirmed ancient believes that traditional healers may access human waste, including faeces or blood, and use it for malevolent purposes. Therefore, they believe that when someone practices open defecation it is important to clean up the waste. Female respondents indicated that in the past they used cloths during their menstruation cycles, which had to be washed after use and hidden inside the house. These cloths are only disposed of in the toilet when they are damaged. Most women continue with their daily routines during their menstrual cycle, but those who attend the ZCC church are not allowed to do certain things like going to church or touching their church attire until after a 7-day waiting period.

During the interviews various practices around toilets were mentioned. Out of the 20 respondents, 2 respondents have separate toilets for male and female and the rule is followed by everyone in the household. The other SHFs share toilets with the same gender and they also allow strangers who pass by the street to use the toilet when they ask.

The SHFs know that worm eggs exist, but most of them think it is caused by the flies inside the toilets. They admit that they are not sure how worms can cause health issues. Children with intestinal worms are normally taken to the clinic for treatment. One respondent in Ga-Sekororo said she uses Nkaka leaves (*Momordica balsamina*) to treat children with intestinal worm egg (**Figure 4-5**). She crushes the leaves to extract the juice and apply it on a child's anus.

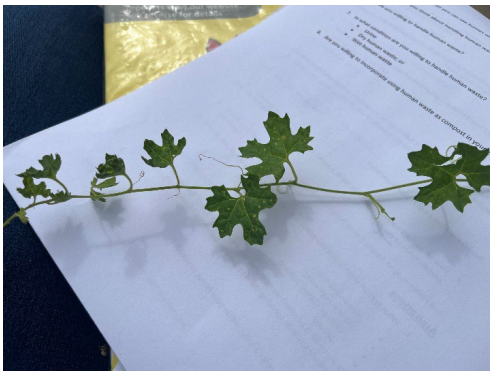

Figure 4-5: Momordica balsamica used for treatment of intestinal worms

4.4 Deep systems analysis

After the first meeting with the SHFs in Ga-Sekororo and Molati, a deep systems analysis was done by the researchers, based on the information we had at the time, to identify the main problems and drivers in the system. The system in which the SHFs live and work has been analysed as indicated in **Figure 4-6**. The green rectangular cells indicate the primary drivers of the systems, including a lack of water (environmental factor), poverty (economic factor), meeting of western and African cultures (social factor) and the lack of services (government role).

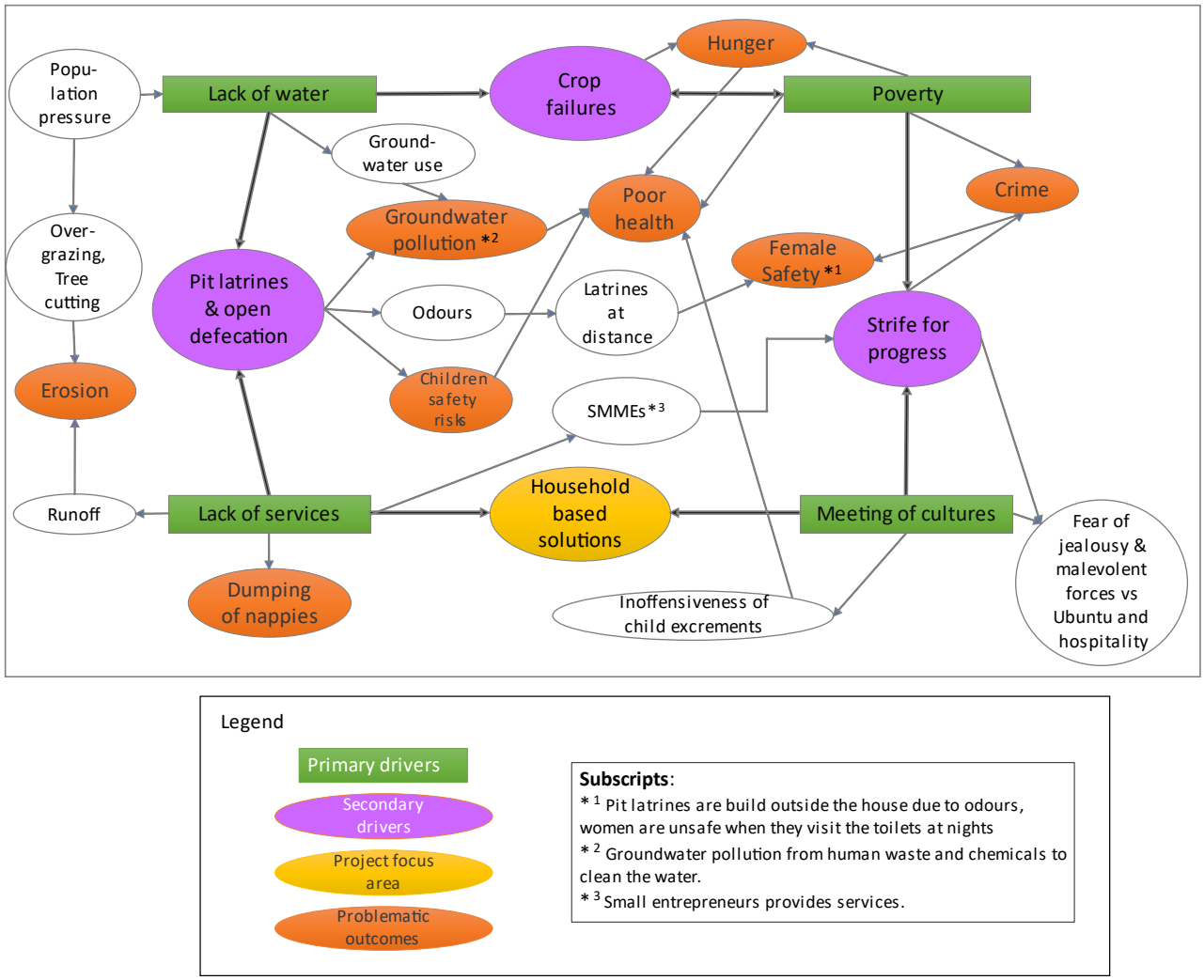

Figure 4-6: Deep systems analysis of the smallholder farmers in Molati and Ga-Sekororo as compiled by the researchers after consultation with the SHFs

The following interactions are indicated in **Figure 4-6**:

- The lack of water together with poverty result in crop failures and hunger, which reinforce poverty.
- Pit latrines are the result of a lack of water and the lack of services. Pit latrines are constructed at a distance from the house, to reduce bad odours in the house. This, together with crime, has safety implications for women at night. The pit latrines are also not safe for children, who are encouraged to practice open defecation, which may impact on the health of the community. Pit latrines also potentially pollute groundwater, which is used for drinking, thus also impacting on health.
- Erosion is caused by the population pressure, causing over-grazing and tree cutting, together with a lack of stormwater drainage services that causes runoff.
- The African culture is characterised by their hospitality and Ubuntu. During our meetings this hospitality has been confirmed by the SHFs who said that they allow neighbours who do not have toilets to use their toilets, or that they sometimes have specific toilets that are only

used by guests. However, partly due to the influence of the western culture that promotes individualism and the strife for progress, this hospitality and Ubuntu is sometimes replaced by jealousy and fear of malevolent forces.

The focus of our study is to find household-based practices that can solve the problems that are caused by a lack of water and services. These practices must be in harmony with the current culture of the people and their current social and economic environment. Small companies can play a vital role to provide the necessary services.

The system analysis shows that the problem is not simple, but it consists of various factors that are interconnected in a complex way. Addressing the problem of one factor in isolation, according to the reductionistic approach, will not produce a solution that is well integrated into the entire system, and is likely to fail. Our approach of transdisciplinary research aims to include the SHFs in the design process, because they understand the full context within which they will use the solution. However, we do not merely want the SHFs to assist us with solutions that *we* develop. The process that we follow in our interaction with the SHF is designed to allow a context and process in which the SHFs do not see us as the experts that they must consult, but to ultimately, see a certain solution as a possibility for themselves and to become the drivers of the design process. This solution does not have to be something that we present, it must rather be something that emerges from the interaction between the SHFs and the researchers from outside.

The analysis in **Figure 4-6** reflects the outcomes of the focus group meeting, but it was compiled afterwards from the point of view of the researchers. In the second focus group meeting the team further engaged with the SHFs to get a deep systems analysis from their viewpoint (**Figure 4-7** and **Figure 4-8**), which differed notably from the one in **Figure 4-6.** An important difference in our analysis in **Figure 4-6** and the analysis of the SHFs (**Figure 4-7** and **Figure 4-8**) is the focus on detail in those that were done from the SHFs' perspectives. The SHFs are confronted with all the details of their messy reality, while the research team were classifying more general patterns in the system. Another difference is the importance of agriculture, from the SHFs' point of view, where from our perspective, sanitation was the central problem. We believe that the analysis from the SHFs' perspectives is more useful and complete.

At Molati, the concept of community relations was more prevalent in the discussions, but these were mostly influenced by money. The need and lack of money was also mentioned more explicitly in Molati, compared to the farmers in Ga-Sekororo. In Ga-Sekororo participants indicated more concern about the natural environment, and pollution of the river. In both communities, agriculture and water were main problems, and sanitation were only discussed later on during the conversation. They did not connect sanitation to other aspects of their lives.

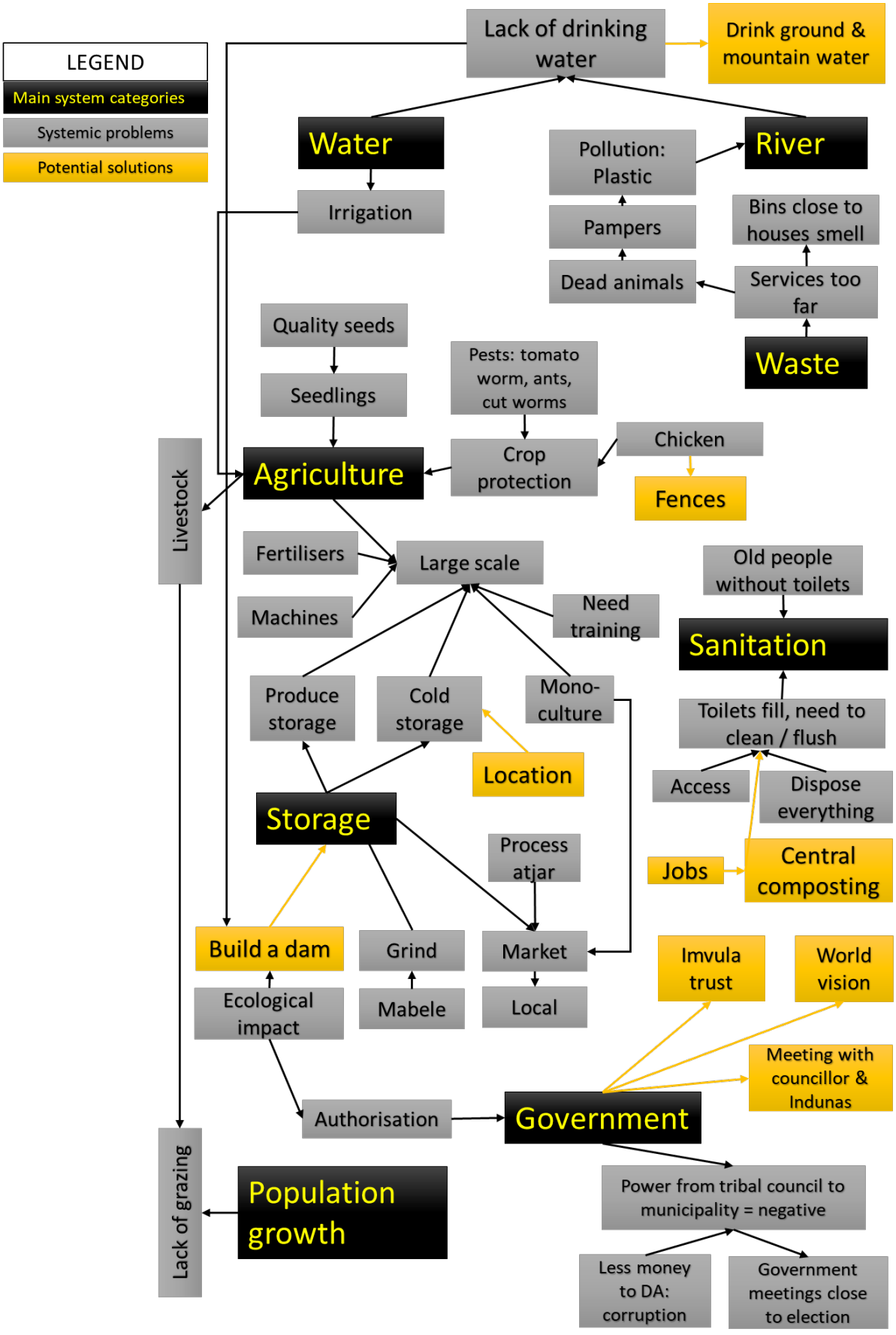

Figure 4-7: Deep systems analysis from farmers' perspectives at Ga-Sekororo

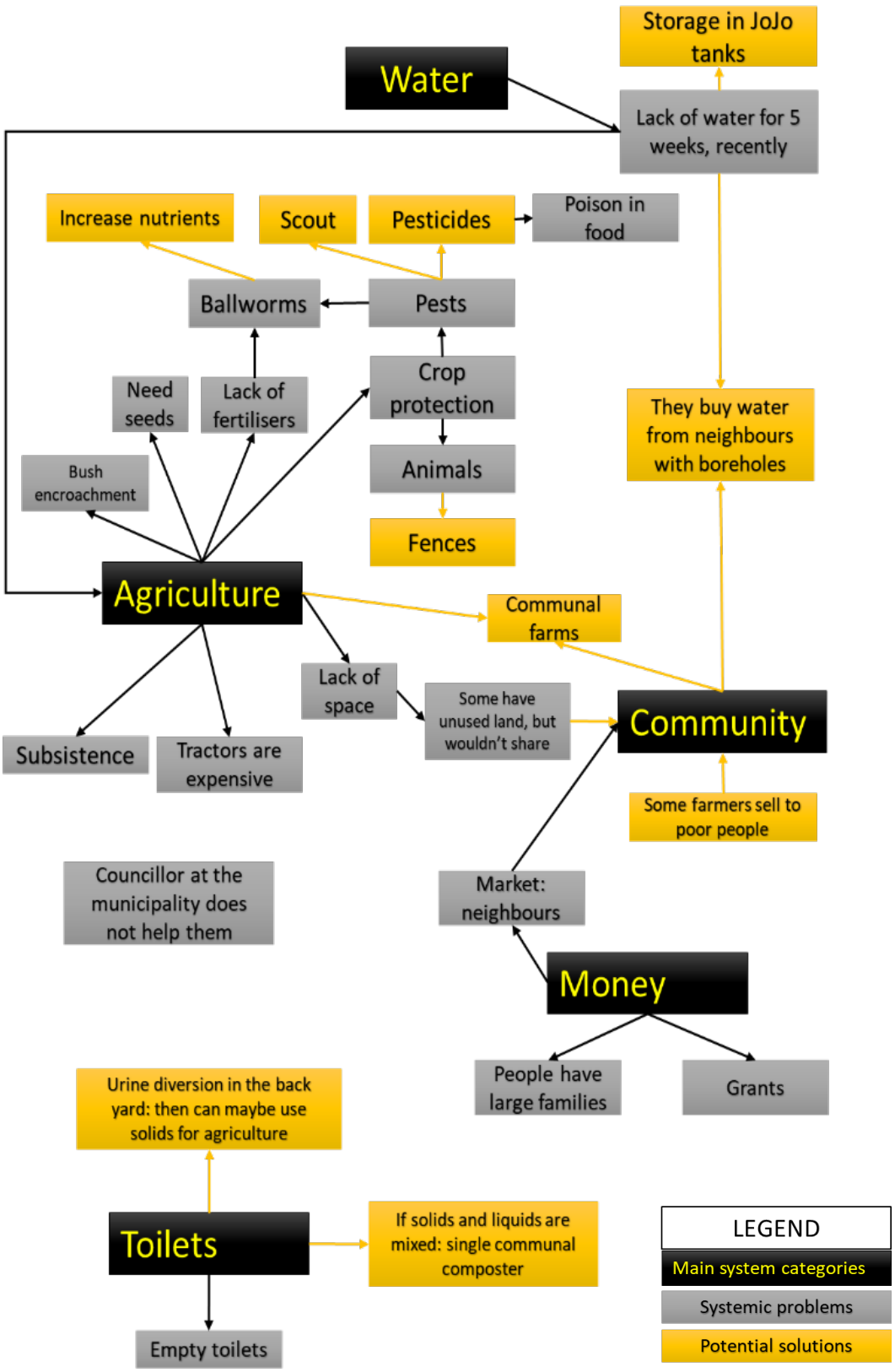

Figure 4-8: Deep systems analysis from the SHF's perspectives at Molati

5 Stakeholder engagement

5.1 Introduction

The previous section reported on our discussions with SHFs; in this section we report on our engagement with various other role-players and stakeholders. These role-players include the Mopani DM, the University of Limpopo, as well as other entities that are involved in the field of non-sewered sanitation in South Africa and internationally.

5.2 Mopani District Municipality

Mopani DM has five local municipalities (LM) (**Figure 5-1**). This study was conducted in two sites under two LMs, Greater Tzaneen and Maruleng LMs.

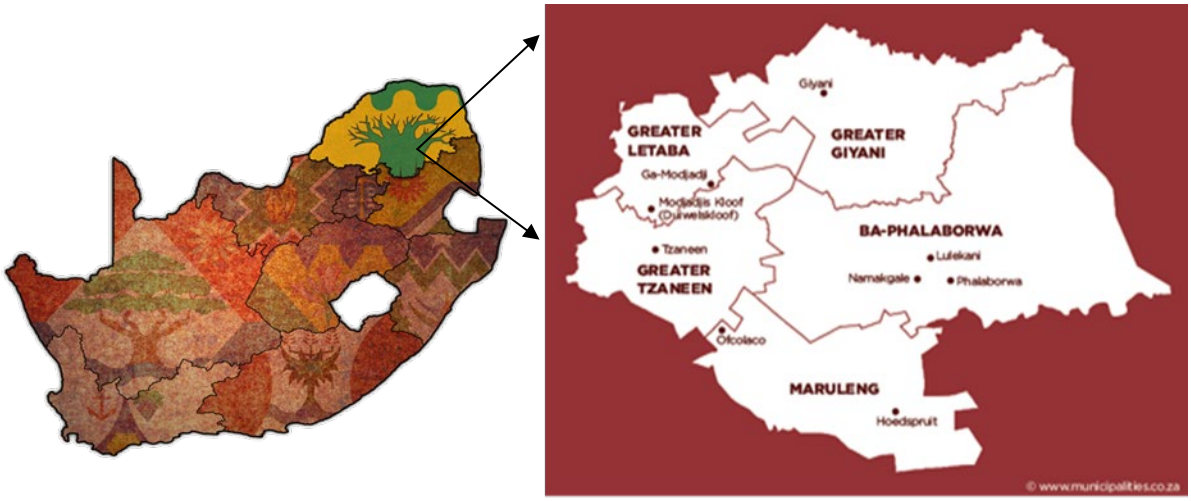

Figure 5-1: Local municipalities of the Mopani District Municipality

5.2.1 Sanitation services

The sanitation systems fall under the Mopani DM. The project team worked with the AWARD team on the final reviewed Integrated Development Plan (IDP) of Mopani DM to gain more insight into the sanitation systems that have been done over the years by the DM and other private entities. The IDP still uses census data that was collected in 2011, which means that there is now a backlog that needs to be investigated. The IDP also indicated the kinds of sanitation services currently in the municipality, which are:

- Flush toilets connected to a sewage system
- Flush toilets connected to a septic tank (mostly self-constructed services)
- Chemical toilet
- Pit latrines with ventilation (VIP)
- Pit latrines without ventilation
- Bucket latrines

The IDP further indicated that there are households with no sanitation services, which in Greater Tzaneen municipality was 13,2% and in Maruleng municipality was 7%; the data was taken from the 2011 census data, the current situation is unknown. The two municipalities are not the only ones with

backlogs: the Greater Giyani municipality has the highest percentage with 23.9% of households with no sanitation services. In the district there are still schools and clinics that are without sanitation. In addition, the IDP indicated that the high backlog in the RDP level sanitation in villages constituted a major risk in terms of groundwater pollution (Mopani District Municipality, 2022-2023).

5.2.2 Waste management

Mopani DM integrates waste management plans for all five local municipalities under the district. In the five local municipalities in the district, only two local municipalities, Greater Tzaneen and Maruleng LMs have authorised waste management facilities/landfill sites. Hazardous wastes are transported to disposal facilities in Gauteng province by private contractors. The Department of Health also hire private consultants to collect and transport medical waste from hospitals and clinics in the district to waste disposal facilities in Gauteng (Mopani District Municipality, 2022-2023).

According to the IDP of the Mopani District Municipality (2022-2023), many rural communities in the district use pit latrines, only a few houses with readily available water supply have flush toilets. The IDP states that The Department of Environmental Affairs, under their Social Responsibility Programme (SRP), in 2007/2008 awarded Ba-Phalaborwa LM with R1,5 million benefits for the establishment of a composting project for the management of its garden waste (this was not confirmed as none of the interviewees knew about this).

Greater Tzaneen municipality, in which one of the sites (Molati) is, is on course with managing waste in its area of jurisdiction and has a licensed landfill site. The municipality has contracted out the waste removal services to a private company and has further extended its waste management services to rural areas where transfer facilities are located at schools and where a number of villagers put out their household refuse for further collection by the Municipality (Mopani District Municipality, 2022-2023).

Maruleng LM in which Ga-Sekororo site is, has been providing waste collection services in three management areas which are Hoedspruit, Kampersrus and Drakensig, for a total of 660 households; they also have a licenced landfill site, called the London landfill site. This accounts for collection from about 3% of households in both commercial and residential areas. There is no refuse removal provided in some of the villages (23 in number) and the households rely mostly on backyard dumping, burial and burning. These pollutants put people at risk of contracting diseases such as cancer, and respiratory related illness (Mopani District Municipality, 2022-2023). This data used in the IDP was collected in 2011 from the census data.

5.2.3 Interviews conducted

Interviews were conducted with two Mopani DM officials. Solomon Tshabalala Modjadji (Waste and Water Superintended plant manager) and Albertina Rammalo (Water and Waste Management manager), both agreed to have a meeting with our team member, Betty Maimela, from MDF (Mahlathini Development Foundation) and Tebogo Mathebula (Local government facilitator). **Table 5-1** shows the questionnaires and answers from the interviewed personnel from the Mopani DM. Albertina Rammalo requested a formal written communication outlining the project, purpose and benefit of the project also including the duration of the project.

Table 5-1: Outcomes of the interviews with officials from the Mopane District Municipality

Questions	Answers
1. What is the method/criteria used to select sanitation facilities that are constructed in and around Mopani DM? a) Where and how is funding secured? b) How are service providers brought on board? c) What are the annual budgets for DM/LM for sanitation?	Sanitation facilities are chosen using the RDP programme, which is a standard service, and they also investigate the availability of water; most areas have no access to 24 hours tap water and rely on stand taps or delivered water from the DM. a) Sanitation funding is secured from the Municipality Infrastructure Grant (MIG) and sanitation revenues from tariffs that are approved by the district in consultation with locals. b) Service providers are brought on board through tendering processes that adhere to supply chain regulations. c) Annual budgets are reviewed every year in the middle of the financial year, which might change the budget, depending on the progress of a project. It might be due to overspending/less spending on certain sanitation programmes that will lead to adjusting the budget.
2. What are the planning constraints and considerations in choosing designs and sanitation processes in the rural areas?	Availability of water. The Mopane DM is embarking on water availability to ensure that every household ends up with a stand tap that will have water running through to allow them to introduce other sanitation facilities and now they are only looking into the systems that they have, which mostly in the villages are the VIP latrines and pit latrines in rural areas. The criteria for sanitation services are done by The Department of Water and Sanitation.
3. The IDP indicates that Greater Giyani has about 54% of households with no sanitation system, census data collected in 2011, what is the case now? Has the percentage decreased or increased?	A lot has been done between 2011 and 2023. There had been new recipients of sanitation systems and there might have been an increase in the backlog due to an increase in population. Several developments around the district and census are not done by the Mopane DM, hence they are still having the data from 2011 in the reviewed IDP with the knowledge that a lot has changed.
4. The IDP also indicates that a bucket system sanitation was rolled out but in low numbers per local municipality, why was the roll-out in low number? Were they trying it out?	Mrs Albertina explained that the Mopane DM has never done bucket system sanitation services.
5. Do they allow private individuals to come to the treatment plant for dried sludge?	Previously they allowed individuals to collect dried sludge in the treatment plant, to use for agricultural process, because the system was properly maintained. Due to poor maintenance of the treatment plant, they have stopped that from happening, not knowing if it is user friendly or not.
6. How do the Mopane DM know the number of households in need of a sanitation facility? And how do they keep track of households that have been rendered a sanitation facility?	In rural areas recipients register for sanitation services at the ward council, that submits it to the local municipality, then to the district. The local municipality does keep track of all information of the recipients.

Questions	Answers
7. How do the Mopane DM help recipients when their sanitation facility is full?	The VIP sanitation is designed in a way that, when the pit is full, one can move the latrine to a new pit. The district doesn't help with emptying VIP latrines nor with building or moving the available structure to a new pit.
8. For those using septic tanks in the district, does the municipality help with emptying that tank when it is full? And how often do they help them?	The district does help with emptying private septic tank when a call for help is made, but there are charges. Firstly, transportation fee is charged for the distance travelled to their homestead and the load that was emptied. All the money is paid to the Mopane DM.
9. Are there any tests done to check the effect of leaching to the water table to see if there is any contamination to underground water or not? And if yes when last was the test conducted?	Tests are not done to check for leaching per se, for every borehole drilled a survey is first done, drilled and water quality test are done. It will be determined from the water quality test whether they equip the borehole or not. They only use a reverse osmosis plant for the borehole when they find a contaminated borehole, but this plant is expensive. They also avoid having water facilities near cemeteries and sanitation facilities as they know underground water might be contaminated.
10. What are the recipients' views on sanitation facilities that are constructed for them?	There are concerns from the recipients; they are not happy using VIP latrines, pit latrines and flushing toilets. VIP and pit latrines smell, flushing toilets have sewer blockages that run across recipients' households or streets with a horrible smell.
11. In terms of chemical toilets, that are shown to be one of the sanitation services that is privately owned, how does the Mopane DM monitor the disposal of waste from these services?	Private services providers that have mobile toilets have communicated with the DM asking to empty the waste at the waste treatment plant, but due to the high volumes received by the plant already it was not allowed. As alternative they have landfill sites that are dedicated for the local municipality so that waste that is disposed there can be monitored to avoid environmental pollution. Some local municipalities are still underway of getting a licenced dumping/landfill site.
12. How does the Mopane DM help schools and clinics that are without sanitation or with poor sanitation?	The Mopane DM does help schools with emptying latrines with septic tanks only when communication is done by the Department of Health and Education to the Mopane DM. The Mopane DM is not responsible for schools and clinics sanitation facilities, for schools it is the Department of Education and for clinics it is the Department of Health.
13. With the increase of sewage volumes received in the treatment plant, what is done to ensure that the effluent that is eventually released into the streams/rivers does not contaminate the rivers/streams?	To ensure and avoid contamination of rivers/streams the Mopane DM has two programmes for water quality: Blue drop programme for testing water quality for consumption before it is released to the public. The Green drop programme checks the quality of effluent before it is released into the rivers /streams. All these programmes are from the Department of Water and Sanitation, and they are published.
14. The IDP indicated that the RDP sanitation has helped to reduce the backlog in sanitary facilities, what is the RDP sanitation programme? And how has it reduced that backlog?	RDP sanitation are VIP latrines, they are RDP standard and are widely used in the Mopane DM since water is an issue in rural areas.

During the interviews detailed in **Table 5-1,** it is clear that water availability is a problem, it was indicated that most of the budget of the DM is allocated towards water and towards providing potable water to the people. It was also clear that most of the sanitation services that are available are under pressure and the demand for sanitation services are increasing with increasing concerns because of the failing of the system. Normal pit latrines and VIPs are currently the only sanitation solutions where water is not available. The DM is not responsible for the management of the toilet waste from decentralised sanitation solutions. They clean septic tanks if their transport costs are covered, and they build VIP toilet structures which the household can move, if the pit is full. There is a wastewater treatment facility, which is currently not operating efficiently due to poor maintenance.

5.3 University of Limpopo

The project team visited the University of Limpopo (UL) on 9 March 2023. The Departments of Water and Sanitation and Geography was present at the meeting. During the meeting it was agreed that the two departments will each provide one honours student to participate in this project. A signed agreement from the University of Limpopo to participate in the project is shown in **Appendix 5**. The following arrangements were agreed upon:

- The geography student was to engage with the people and collect data through interviews, the water and sanitation student was to collect data on potential groundwater contamination through pit latrines.
- Both students were to collect qualitative data
- The students were to be accompanied by Ms Betty Maimela, who was the field coordinator, when visiting the sites
- The UL was to supervise the students during data analysis and report writing
- Nova was to pay the subsistence and travel costs of the students for a 2-day site visit.

5.4 Decentralised sanitation projects in eThekwini Municipality

The team has also visited the decentralised sanitation projects at the eThekwini Municipality to get a better understanding of what solutions have been implemented, what worked, what did not work so well and what problems they have encountered. The results of this visit are summarised in **Appendix 4.** Their research is valuable and will inform our own project and the kind of technologies that we will experiment with. Different people at eThekwini have mentioned that the aspects that are lacking in their current projects are:

- Developing suitable solutions for the back-end of the toilet system – i.e. to use, treat or manage the waste appropriately
- Co-designing solutions with the end-users
- Involving politicians, tribal councils and local government during the development stages.

5.5 Connections with International Partners

We have developed an international network that will work together to look for funding to continue with the co-design phase of the programme. The network includes:

- Prof Dr Michael Burkhardt and Dr Dorothee Spuhler from the Eastern Switzerland University of Applied Sciences (OST), Institute of Environmental and Process Engineering (UMTEC), who acted as the Swiss project coordinator for the SNIS and SOR4D applications.

- Me Cornelia Haueisen, assistant to prof Burkhardt at Eastern University, Switzerland
- Prof Elizabeth Tilly, Chair of Global Health Engineering, Department of Mechanical and Process Engineering (D-MAVT), ETH Zürich
- Ms Jacquelene Friedenthal from the Swiss embassy, who is especially interested in our results, because they implement sanitation services in Venda. She advised us to include Venda as a future site for upscaling our solutions, because their network of development actors and researchers can benefit from our research and can support us there.
- Mr Edmore Kori, Lecturer (Geography and Geo-Information Sciences) and PhD candidate at University of Venda
- Mr Buhle Dube, Senior lecturer at Urban and Regional Planning, Lupane State University, Zimbabwe
- Dr Elisa Matola, Lecturer at Instituto Superior Politècnico de Manica, Mozambique;
- Dr Antoinette van der Merwe, post-doctoral fellow at SDG Hub, University of Pretoria and consultant at Nova Institute. Affiliated with ETH Zurich.

Various international organisations provided Letters of Interest (LOI) for our project including:

Worldwide Fund for Nature / World Wildlife Fund (WWF): This Swiss-based International Organization has operations on environmental conservation worldwide, including in South Africa. The WWF is also involved in numerous projects regarding water protection including the Journey of Water project which focus on three rivers within the Limpopo Basin. The WWF is interested in following our project and being updated on important findings. We will consider future research to scaling our solutions to the Mpumalanga and KwaZulu-Natal Provinces, to include their strategic water areas.

The International Federation of Environmental Health (Africa Regional Group) indicated their interest in being updated on the results of our project, due to the potential of improving sustainability and health through better sanitation.

The Bowier Trust Foundation Switzerland (BTFS) indicated interest to follow the project progress and use the outcome since a proper faecal waste management concept is still lacking in Liberia. (https://www.bowier-trust.org/en_us)

5.6 Conclusion

It is critical that the authorities are involved from the beginning of the co-design process, to ensure that they support the outcomes that are developed. Good collaboration with the authorities is critical for the success of the project. The support of the eThekwini Municipality in KwaZulu-Natal was key to the success that they have achieved.

We have expanded our network internationally to find the necessary support (in terms of funding, knowledge and technical support) to continue with the next co-design phase that will follow on the current WRC project.

6 Discussion

6.1 Evaluation of readiness of this project to proceed to the next phase

Projects of the Nova Institute usually go through several phases before they can be implemented on a large scale. At the end of every phase, the team evaluates the outcomes off the phase to decide whether it is ready or not to transition to the next phase.

It can also be called gate decisions. Stratton (2003) explains project gate decisions as key points decided upon during a formal evaluation of the project after the implementation of each phase. Gate decisions are made during phase transitions. Following every gate decision at the end of each project phase, one of the decisions may be whether the project proceeds, or is delayed, altered or cancelled.

In this project gate decision, attention will be given to following key points:

- Existing knowledge: Possibilities and gaps
- Need for a solution at the research sites, and potential to upscale
- Existing potential to co-create a suitable solution in the local context

This research study has been conducted to plan and prepare for a longer-term programme to co-design, with SHFs, a decentralised sanitation system(s) that is integrated with agricultural practices. We have investigated possibilities and identified gaps in the current knowledge. During this planning phase, it was confirmed that the rest of the programme will be a viable undertaking, i.e. there is a need for such a solution, there will be potential to upscale the solution to a community and municipal level and there is a potential within the local and broader contexts to develop a solution.

6.1.1 Existing knowledge: Possibilities and gaps

The literature review in **Section 2** summarises the variety of technical possibilities available for decentralised sanitation systems. However, despite the variety of technical possibilities, relatively little effort has been made to find solutions that will be acceptable to the end-users. The literature review indicated that cultural and religious thought-patterns regarding sanitation and food production will likely influence the uptake of decentralised sanitation technologies and the integration of these technologies into agriculture. While it is widely acknowledged that issues such as health risks and safety are important considerations, few projects have taken these cultural and religious thought-patterns into account.

We consider decentralised sanitation practices integrated with SHF practices to be a complex socio-ecological system, which implies that the success of solutions to any problems is highly dependent on the context, including culture, climate, ecology, populations sizes, and incomes.

During a site visit to various non-sewered sanitation projects in the eThekwini Municipality, Kwa-Zulu Natal, the local project leaders identified the following gaps, confirmed by the literature, on sanitation:

- The focus has been on developing front-end solutions for decentralised sanitation rather than on ways to manage the waste (back-end).
- The approach is mainly on developing and implementing good technologies, rather than co-designing technologies and practices with the end-users.

- In the past local politicians and tribal councils have not been included in the project, which caused conflicts and even project failures at later stages.

We have also encountered a lively interest in the idea to co-create decentralised sanitation into SHF practices from Swiss researchers, using a socio-ecological system (SES) complexity approach. This interest should lead, eventually, to support from that area.

6.1.2 Need for a solution at the research sites, and potential to upscale

There is a need for new approaches and technologies that support alternative sanitation efforts (Austin and Duncker, 2022). However, user acceptance is the main unsolved problem in many technology-transfer projects in many parts of the world. Technical concepts imported to another region without considering the socio-cultural context have too often caused failure. Education of and demonstrations to ensure the sustainable use of the given technology seldom succeed. A key prerequisite for end-user acceptance in micro-contexts is that the new technology must become part of the daily practices of the end-users. End-users should not only be consulted, but must be supported to become active role-players during the development of the solutions.

The impact of societal and cultural aspects related to the use and the reuse of water and to human excreta should be further researched. Indigenous knowledge systems, local beliefs, traditions and practices, but also gender and generational differences must become a decisive factor in the planning and operating of water and sanitation solutions. The importance of considering beliefs and traditional practices becomes even more evident when promoting the treatment of excreta for further use, as outlined by sustainable sanitation and integrated water resource management (IWRM) concepts. Different groups of people have varying, culturally determined relations to human excreta, which affect the acceptance of their treatment (Schelwald-Van der Kley and Reijerkerk, 2009). Therefore, we have to acknowledge that solutions which are co-developed and maintained by the local people themselves stand the best chance of long-term success of water and sanitation systems and sustainable resource management.

In the profiling of SHFs in Limpopo, as detailed in **Section 3**, we have found that large parts of the province are inhabited by subsistence farmers, who often practice vegetable production in their backyards. These communities do not have flush toilets or indoor plumbing, but they use pit latrines and use taps in their yard or communal taps within 200 m from their homesteads. The study areas that were selected are representative of a notable area within the Limpopo Province, and successful practices in these households can likely be applied in many other similar households.

These results indicate that many people in the province will benefit from improved management of toilet waste, while a notable number of backyard farmers could potentially use the waste for agricultural purposes. This confirms that there is good potential to upscale practices that are successful within our research sites.

6.1.3 Existing potential to co-create a suitable solution in the local context

The research team has found much potential within the research sites to develop decentralised sanitation solutions.

Firstly, we found a group of motivated SHFs who take responsibility for solving their own problems. Many of these farmers have previously experimented with agricultural solutions. They have indicated

that sanitation is a problem, some have tried various things to manage toilet waste in their pit latrines, and they are willing to cooperate to co-design a suitable decentralised sanitation solution.

Secondly, it was found that the local people in rural areas have already developed different solutions for managing human waste from their pit latrines, which could possibly be refined to become feasible practices for converting the waste to compost. According to the complex systems theory, these practices can be considered as 'emergences', because they are phenomena that have naturally arisen from a complex system and are well integrated within the context of the complex system (Preiser, 2019). An example of emergence with much potential, which was identified during this study, was that small companies were established by community members to empty the pit latrines with spades and transport the waste away to be dumped. We call them the 'pit latrine pickers'. This service is very valuable and affordable for the people whose pit latrines are full, but it is not done in an organized, dignified, effective and structured way. Through collaboration with local people, such a practice can be further developed so that human waste is:

- Collected and stored more safely and easily (e.g. with improved equipment)
- Transported more efficiently (e.g. dehydrating the waste might be important to reduce the mass to be transported and reduce the health risk)
- Converted to compost in a safe way (e.g. through managing water content and temperature in composting containers)
- Removed in a more comfortable and dignified way

We consider a sustainable and dignified sanitation practice to reduce groundwater pollution and provide sanitation that is hygienic, safe and with limited nuisances such as odours and insects. If such a solution can be developed with the end-users and the local entrepreneurs, it will create employment opportunities for local people, which will be a strong driver for implementing the solution.

6.2 Development of the DSP-WEF Framework

6.2.1 What is the WEF Framework?

Through this research we have developed an alternative approach to decentralised sanitation in rural and peri-urban communities, which is outlined by a DSP-WEF Framework. This framework consists of (i) our strategy, (ii) our aims, (iii) critical role-players and (iv) the conditions and drivers of the system that is necessary for success. These four aspects of the DSP-WEF Framework are discussed below. A schematic illustration of the DSP-WEF Framework is given in **Figure 6-1**.

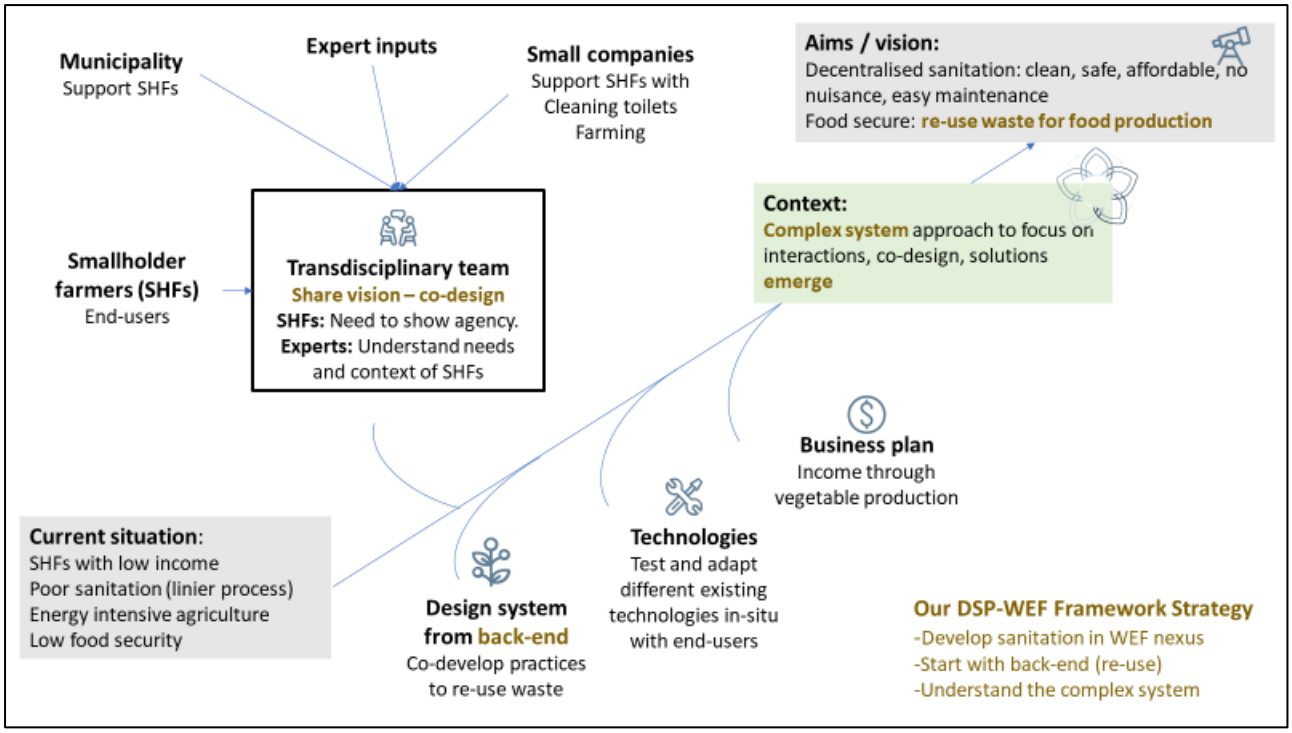

Figure 6-1: A schematic illustration of the approach towards developing a decentralised sanitation practice in the context of the Water-Energy-Food nexus, DSP-WEF Framework

6.2.2 What is our strategy?

We have identified several changes to the normal scientific approach that we believe are necessary for the successful outcome of a decentralised sanitation programme:

- Sanitation should not be developed in isolation, e.g. when sanitation is managed as part of the WEF Framework, it is possible to divert human waste from polluting water resources and develop it as a resource for food production.
- A suitable sanitation system should first develop practices to re-use the waste, working from there toward a suitable front-end that will produce the waste in the needed form.
- The DSP-WEF Framework is essentially a complex system, as is all living systems. It differs from a mechanical system, in that outcomes are unpredictable and uncontrollable. This does not mean that one cannot have a desired outcome, it means that one must engage with the system in a different way. The way of engaging with a mechanical system is to control it. The way of engaging with a complex system is through relationships. Healthy relationships can have positive outcomes, while a relationship where one party controls or ignores the other seldom has good outcomes. To have good outcomes, our approach focusses firstly on developing a shared vision with the end-users, and then, through our interactions and experimentation with various options, on evaluating various options until a solution emerges which we all consider to be satisfactory and which the end-users see as a possibility for themselves.

6.2.3 What are our aims?

- To develop with poor households and SHFs in rural and peri-urban communities in Limpopo, affordable, clean, safe, ecologically sustainable, decentralised sanitation systems that are easily maintained.

- To develop safe ways to re-use the human waste for agricultural production. Therefore, our target group of people should already practice agriculture, or be willing to start a form of agriculture.

6.2.4 Role-players

6.2.4.1 Smallholder farmers

In this study we have engaged with the SHFs at several opportunities. We have a preliminary assessment of what they need and what they aspire to in terms of sanitation and agriculture. Some key outcomes are highlighted here.

SHFs in the study areas would all like a water-borne sanitation system, but they do not aspire to it, because of the high costs and water requirements. They said they just wanted toilets that are affordable, safe, clean, easily maintainable, and ecologically sustainable (they had concerns about water quality impacts). Nuisances such as smells and insects should also be eliminated. There is a preconception that people in rural and peri-urban areas always aspire to have what people in urban areas have and will therefore not be satisfied until they get, for example, flushing toilets. We have observed this tendency of aspirations with people in peri-urban communities in Gauteng, who plant lawns and flowerbeds, instead of vegetables. The SHFs in the study areas, however, do not seem to aspire to the urban way of life so strongly. For example, they do not plant lawns and flowerbeds, but vegetables in their gardens. In term of sanitation, we also did not observe these aspirations to flush toilets.

The SHFs are much more concerned about problems with their agricultural activities, compared to problems with sanitation. By linking sanitation with agriculture, therefore will have a positive impact on the agricultural problems, which are a bigger priority for them. Some SHFs are willing to re-use the waste for food production. Several others would consider it if it is safe. A small number did not feel comfortable with that at all.

Through our conversations with the communities, we have determined that they are able and willing to pay about R300 p.a. for a company to clean a full pit latrine. We assume therefore, that they are not able to pay more than R300 per year for improved sanitation solutions.

6.2.4.2 Small companies

We foresee that small local companies will be involved in the process. There may be a need for companies who can assist with toilet maintenance, and for trained individuals to assist with farming practices in people's houses (either provide extension services, or to farm in the yard for a fee).

6.2.4.3 Authorities:

The authorities are currently unable to solve the sanitation problems in the study areas. If a solution emerges from this study, their role must be defined.

6.2.5 Conditions and drivers of success of the DSP-WEF Framework

While it is not possible to control a complex system, it helps to understand the drivers and necessary conditions that will contribute to the successful achievement of the aims, for example:

- The key to success is that the end-user is actively involved in the development of the solution. They must see a solution as a possibility for themselves, and then perfect it for their own

requirements. They must show agency and willingness to work together on a solution. ***Through our study we have united two teams of motivated SHFs in two areas that will cooperate with us in the co-design phase***

- Some functional role-players are needed to make the solutions work, i.e. small companies. ***In our study we have identified existing small companies that provide certain services.***
- Solutions must emerge from the community: **We have identified existing practices that have already emerged from the communities in the study areas, which is a good indication that more solutions are likely to emerge through interactions with the necessary specialist**
- Business plan: a business plan is necessary to ensure the sustainable uptake of the practise. ***We have determined that SHFs in our study area are unable to pay a monthly fee for services, the business plan should be based on potential incomes from vegetable production, enabled by fertilisation with human waste.***
- The availability of possible technologies, which could be used or adapted to suit the needs of the SHFs. ***In this study we have identified various technologies that could potentially be used or adapted to fit into daily sanitation and agricultural practices of the SHFs in the study areas.***

6.3 Future research: Plan for going to scale

From this research, we have developed a strategy for the way forward.

The aim is to co-design a solution to decentralised sanitation systems with SHFs in rural and peri-urban areas, who are unable to pay for the service, who do not have water available for flushing, and who are / want to practice agriculture in their homesteads.

Nova's phased approach (**Figure 1-2**) can be slightly adjusted and applied as follows to the present project:

- **Scoping study** (current report, done): Determine viability of integrating decentralised sanitation into SHF practices and provide guidelines for going forward
- **Co-creating phase** (next step): When the current project is completed the co-designing phase is planned during which the project team will test the most promising technical solutions with approximately 20 selected participants, 10 from a more rural community (e.g. Molati) and 10 from a more peri-urban community (e.g. Ga-Sekororo). An iterative process of testing and adapting the technologies should be followed until a solution emerges that complies with the needs of the end-users and is fully integrated into their daily practices. It will extend over a three-year period.
- **Roll out 1**. Community scale: Co-designing practices with selected community members: how to upscale to one community? A high level of uptake is needed to make a significant environmental impact
- **Roll out 2**. Municipal scale: Co-designing practices with municipality and community members: how to upscale to one municipality
- **Roll out 3**: National scale: how to upscale to other municipalities

6.3.1 Value proposition

Table 6-1 outlines the value proposition for various beneficiaries in the decentralised sanitation sector. The beneficiaries include households and SHFs, small companies, municipalities and the WRC. Key activities required from each beneficiary are indicated.

Table 6-1: Value proposition for beneficiaries in the decentralised sanitation sector

BENEFICIARIES / PARTNERS	GETTING BUY IN & SUPPORT FROM BENEFICIARIES	VALUE PROPOSITION	KEY ACTIVITIES (ALL BENEFICIARIES ARE INVOLVED THROUGHOUT THE PROJECT)
Two groups of **smallholder farmers (SHFs)**, who mostly produce vegetables in their yards, are ready to proceed with the programme. They represent the conditions in which the majority of households in the Limpopo Province live	The two groups of SHFs are ready to proceed with the programme and to work together to find solutions.	**Households** Sanitation solutions. Better food security **SHFs** Access to fertiliser Sustainable agricultural practices	Households and SHFs take part in the planning, they use the potential solutions, evaluate them, discuss ways in which they can be adjusted with the rest of the team, and iterate the whole process until a suitable solution emerges.
There are **small companies** in the community who clean pit toilets for a fee	These entrepreneurs will be involved in the co-creation of practices for cleaning the pit latrines	More income Dignified practices More jobs to be created	Entrepreneurs take part in the planning, they use the potential solutions, evaluate them, discuss ways in which they can be adjusted with the rest of the team, and iterate the whole process.
Local municipalities are unable to provide all the residents with water and sanitation services	Municipalities are involved from the beginning in the activities of the project, to ensure their understanding and support, and to prevent resistance in later phases	Solutions for sanitation services	Municipalities take part from the point of view of implementing a solution, not from the point of view of the end-users (households, SHFs and entrepreneurs).
The Water Research Commission (WRC) is looking for viable ways in which decentralised non-sewered sanitation can be provided in rural and peri-urban areas	Keep buy-in and support through well managed execution and robust impact measurement and reporting	A contribution is made to the WRC's search for solutions for decentralised sanitation	The WRC guides the project by receiving and evaluating milepost and annual progress reports.

6.3.2 Elements of up-scaling practices

The main elements of the plan for going to scale are:

1. Horisontal extension of sanitation-plus-smallholder farming practices
2. Bottom-up extension of sanitation-plus-smallholder farming practices
3. Communication with local and International development organisations (top-down approach)
4. Academic peer-reviewed publications
5. Podcast / videos

6.3.2.1 Horizontal extension of sanitation-plus-smallholder farming practices

The horizontal extension of solutions is done by;

- Taking the co-designed solutions to a large number of end-users who live in similar contexts within the same community. A high percentage of residents must use the solutions, to ensure that the impact of pollution on water resources and ecological systems is reduced significantly. The way in which this is done is also co-designed with local role-players.
- The solutions are then taken to other communities

6.3.2.2 Bottom-up extension of sanitation-plus-smallholder farming practices

Bottom-up or vertical extension of solutions is closely related to the horizontal extension. It is done by taking the results of the research to higher levels of authority and larger organisations, starting below and working up to the top, e.g.: the local municipality and the larger district municipality are already involved in the co-creation phase to ensure their understanding and support. It is then implemented in the whole municipality. From there it will be taken to other municipalities. The authorities will play a key role in taking it from end-users to end-users, from community to community, and from municipality to municipality. At this stage a business case and a business plan will be drafted.

6.3.2.3 Communication with local and international development organisations (top-down approach)

This is called a top-down approach, because here the project team communicate with the leaders and experts, both in government and Non-Government Organisations (NGOs), who manage development initiatives, design strategies and take decisions about policies and implement them in the communities.

In this study we have made connections with several International Organisations who showed a keen interest in this topic.

- We have contacted Ms Jacquelene Friedenthal from the Embassy of Switzerland to South Africa, Botswana, Eswatini, Lesotho, Mauritius and Namibia. She indicated that our research would be most beneficial to them if we include the Venda region in Limpopo, South Africa, to our study. We have therefore included a scoping of Venda to determine the potential of upscale our co-designed solutions.
- The World Wildlife Fund (WWF) indicated a particular interest in the research that we are undertaking, however, the Limpopo Basin is not part of their strategic water areas. We will consider future research to scaling our solutions to the Mpumalanga and KwaZulu-Natal Provinces, to include their strategic water areas.

These organisations can be given opportunities to provide inputs to the co-design phase, through online discussions where the planning and progress of the work are presented (at the beginning of the co-design phase), after year one and year two, and the final results at the end of year three, including plans for the next phase.

The following organisations will also be invited: Savanna Science Network and the parallel African Research University Alliance Water Centre of Excellence; the Global Water Partnership and relevant agricultural organisations.

6.3.2.4 Academic peer-reviewed publications

Results should be published in academic peer-reviewed articles, to inform the scientific community of the outcomes and to stimulate cooperation.

6.3.2.5 Podcasts / videos

Project outcomes should be communicated to a non-scientific audience, including policymakers and a general audience. Policy briefs can be published on one of the participating universities' outlets. The Sustainable Development Goals (SDG) Hub at the University of Pretoria created the South African Policy Support Initiative, a platform that aims to disseminate research findings in a format that is easily digestible for policy makers. Depending on the results and findings, one or more policy briefs should be written that could help policy makers to implement the findings in other contexts.

Outcomes can be communicated though publishing podcasts and short videos that explain the project and main results could be distributed on social media and within the research group's network. Since problems regarding sanitation is frequently mentioned in Southern African news outlets, viable solutions to improve sanitation can be published in South African newspapers or other online outlets, such as The Conversation (https://theconversation.com/africa), News24 (news24.com), Mail and Guardian (mg.co.za/).

7 Conclusion

There is a clear need for the development of decentralised sanitation which is integrated with agriculture, but the problems that the SHFs deal with in terms of food production and sanitation are very complex. The household becomes a very important place for solutions to emerge, because this is where sanitation problems, the culture, the environment and the economy meet. The household is a key place where the lack of services can be overcome, and where Ubuntu can be restored.

In **Section 6.1**, *Evaluation of readiness of this project to proceed to the next phase,* it was confirmed that there is potential to develop the DSP-WEF Framework, based on our interactions with the SHFs in the two study areas. The SHFs confirmed their need for a solution and their willingness to work together towards a solution. Several potential solutions to the management of human waste have already emerged from the communities in the study area. The potential to co-create a suitable solution in the local context, and to upscale the solution to other communities is such that we can conclude that it would be highly recommendable that the project proceeds to the co-creating phase at a minimum of two sites, namely Molati and Ga-Sekororo in the Mopane DM, Limpopo Province.

There is agreement within the team on the way to go forward. The co-designed project will center around intensive cooperation between the experts on the team and other team members, specifically two groups of 10-20 SHFs, in each of the selected rural and peri-urban communities, to co-design innovative practices that use the most suitable decentralised low water, energy and carbon sanitation technology(ies) and/ or practices that have emerged from the community. Practices for composting human waste will also be developed. These new practices will be functionally integrated with existing smallholder agricultural practices. In other words, it will be a real and sustainable option for SHFs.

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8.2 Photo references

African girl and boy stunted growth: Image by Freepik;
Woman at homestead farm: Image by <a href="https://www.freepik.com/free-photo/full-shot-smiley-woman-holding-tablet_34240843.htm#query=homestead%20farming&position=8&from_view=search&track=ais">Freepik</
Tractor: a>; Image by Racool_studio on Freepik
African woman carrying water sunset: Image By vecstock
Country woman holding leavy crops: Image by Freepik

9 Appendices

Appendix 1: Decentralised sanitation solutions for rural and peri-urban communities

Decentralised wastewater treatment systems (DEWATS) incorporate a various technologies with the primary focus on local treatment, simple operation and reuse of the treatment products (Truyens et al., 2018). It is for this reason that DEWATS are gaining more widespread use in developing countries as a means to provide sanitation services to informal, peri-urban and rural communities where large-scale sewerage systems are not feasible.

DEWATS technologies include systems such as ventilated pit latrines (VIP), septic tanks, composting toilets, etc. Lourenço and Nunes (2020) classified the different systems into dry and wet systems (**Figure 9-1**). This literature review considers the main aspects of the key technologies and how the products of such technologies can be used as input to agricultural processes.

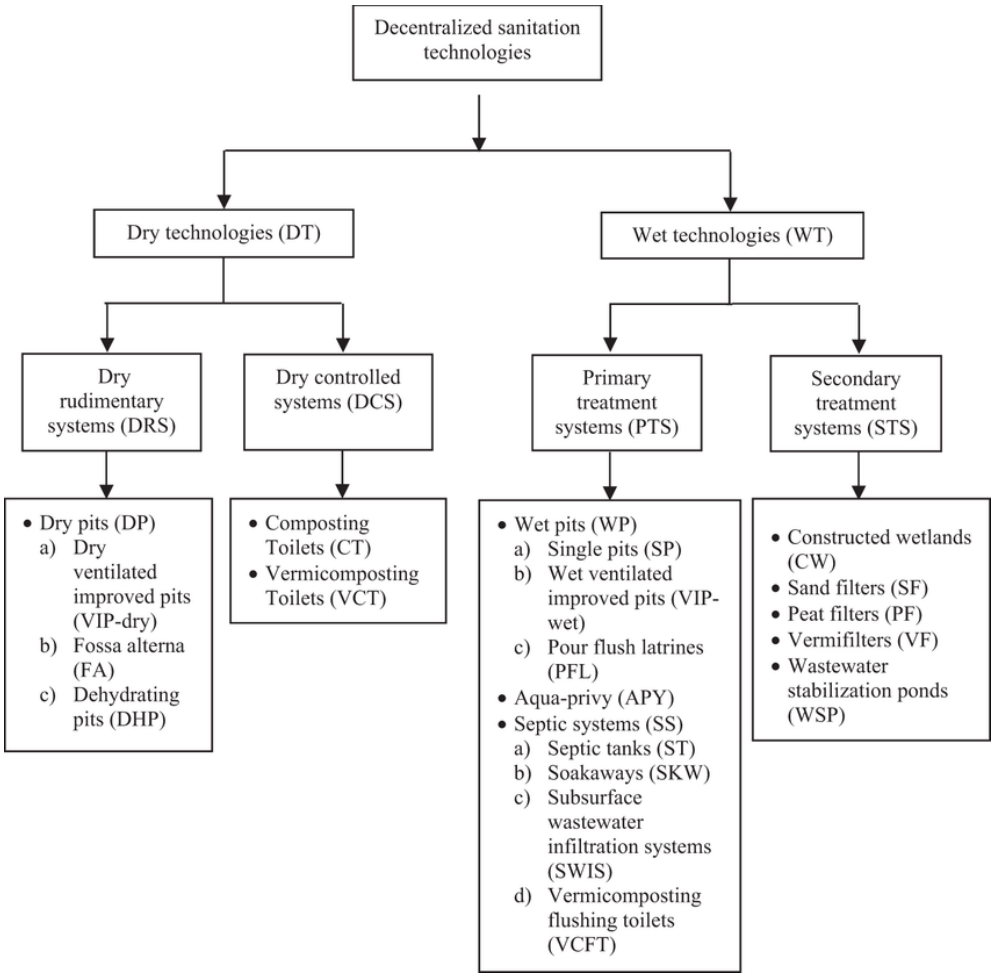


Figure 9-1 Decentralised treatment technologies (from Lourenço and Nunes (2020))

Evaluation of dry technology toilet systems

Pit latrine

Pit latrines consist of a hole in the ground to contain human excreta. The hole may be unlined or lined (Orner et al., 2018). Once the pit latrine is full, it is either closed or emptied. The basic inputs and outputs are presented in **Figure 9-2**. The outputs from the pit latrines cause concern. Gases cause odours, liquids can potentially contaminate soil and groundwater, and solids provide a medium for micro-biological and helminth growth.

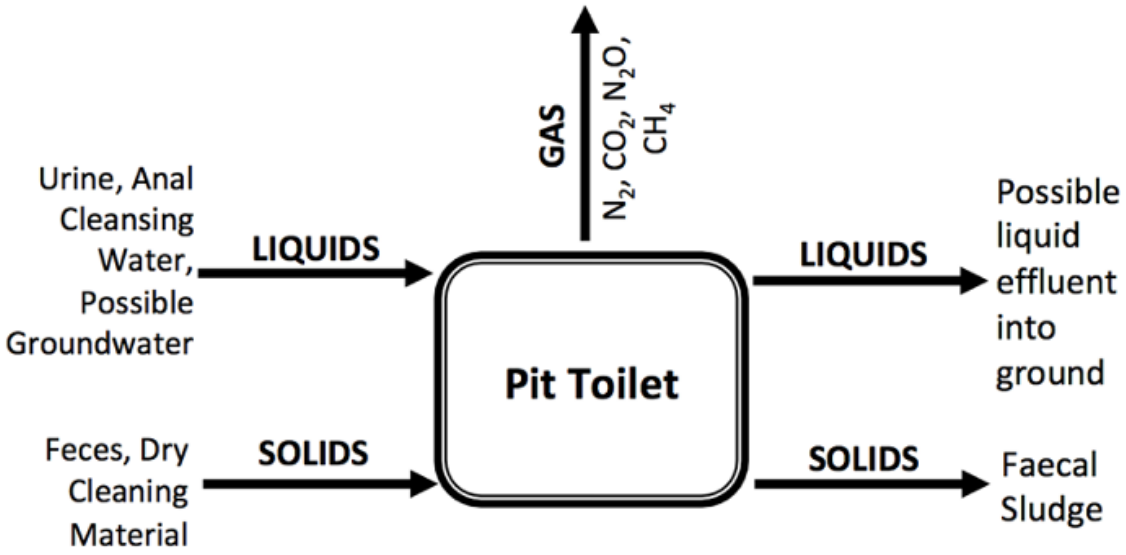


Figure 9-2: Basic inputs and outputs in a pit latrine (from Orner et al., 2018)

Malodours from pit latrines typically comprise methane, carbon dioxide, nitrogen, ammonia and hydrogen sulphide (Nakagiri et al., 2015). A study by Lin et al. (2013) using gas chromatography-mass spectrometry and olfactive analyses identified 198 volatile constituents including isobutyric, butyric, isovaleric, 2methyl butyric, valeric, hexanoic and phenylacetic acids, which are responsible for the rotten, cheesy odour in pit latrines. A combined effect of phenol, p-cresol, indole, skatole, and some carboxylic acids caused the manure, horselike odours that are typical of pit latrines. The rotten egg odours are caused by dimethyl sulphide, dimethyl disulphide, dimethyl trisulphide, methyl mercaptan, and hydrogen sulphide.

Pit latrines also become breeding grounds for flies, mosquitoes and bacteria (Dzwairo et al., 2006, Nakagiri et al., 2015) and may also contain large amounts of pathogens (Orner et al., 2018). Pit latrines are used to contain faecal matter to reduce health risks through reduced exposure, and not specifically to remove pathogens. Over time, pathogens in the pit latrine can be inactivated or removed in different ways. The residence time in the pit is believed to have the largest impact on pathogen reduction due to unfavourable temperature and moisture levels (Orner et al., 2018).

Nwaneri et al. (2008) divides the solids in a pit latrine into 4 layers. (i) At the top is a small sludge layer with biodegradable components that rapidly degrades aerobically. (ii) The second layer is also an aerobic section of the pit, where aerobic degradation of hydrolysable organic material occurs. The rate of degradation is limited by the aerobic hydrolysis of complex organic molecules to simpler compounds. (iii) the third layer is anaerobic because oxygen is blocked by the top layers. Anaerobic digestion is a much slower process, which is controlled by the rate of anaerobic hydrolysis of complex organic molecules to simpler molecules. (iv) The lowest layer contains inactive, stable organic material which accumulates over time until the pit is full. At this point the pit latrine must be emptied or closed.

Liquids accumulate in the lower levels of the pit latrine, and eventually the area becomes saturated. This becomes a pathway for pathogens to migrate out of the pit into the surrounding soil and groundwater (Orner et al., 2018). Bacteria and viruses can move vertically or horizontally with the liquid from the pit into the soil. The hydrogeology and the size and type of the pathogens determines the rate at which the pathogens move away from the pit (Orner et al., 2018). Bacteria and viruses generally travel the furthest and helminths and protozoa travel the least.

Ventilated Pit Latrine (VIP)

The Ventilated Pit Latrine (VIP) is the same as a normal pit latrine, with a ventilation pipe as shown in **Figure 9-3**. The ventilation pipe that extends 0.3-0.5 m above the highest point of the toilet's roof is installed and is capped with a screen. This improves airflow out of the pit, which reduces both odour and the presence of insects (Orner et al., 2018).

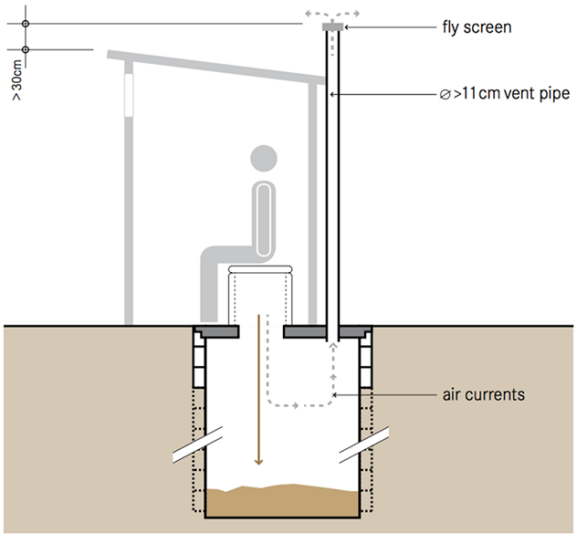


Figure 9-3: Ventilated Pit Latrine (from Orner et al. (2018))

Apart from the added benefits that the ventilation provides, the VIP is still the same as the pit latrine and has to be periodically cleaned or closed and a new latrine dug. Unless there is a separate treatment process in place to treat the sludge from the pit latrine, the material is generally not available for use in agriculture.

Compost toilet

Composting toilets were originally commercialized in Sweden in the 1970s (USEPA, 1999). The composting toilet provides an oxygen-rich environment where solid waste is broken down into compost by aerobic bacteria and fungi that occur naturally (Krosofsky, 2020, USEPA, 1999). Composting toilets are suitable alternatives in areas where water is limited, because they require little or no water to function (Kubba, 2017).

A composting toilet has a container that is well ventilated, to create a suitable aerobic environment in which moist, unsaturated human excrement can decomposed through biological and physical processes (USEPA, 1999). Larger units may have to be installed in a tank below ground. Small units can be placed on the floor inside the bathroom. A suitable cover material such as sawdust or grass clippings is required. The compost produced is potentially available for use in agriculture.

There are two main types of composting toilet systems (Tilley, 2022):

(i) Continuous or single composters which contain only one chamber. With this self-contained compost toilet, all excrement and composting materials go into the top and are removed from the bottom in a continuous fashion.
(ii) Double or batch composters consist of at least two or more containers. With this type of system, the composters are filled and allowed to age some before additional excrement and other materials are added.

Urine dehydration diversion toilet (UDDT)

Urine diversion toilets are usually constructed as part of a composting toilet or flush toilets. The UDDT separates liquids and solids at the source, which has the following benefits:

(i) It does not require water;
(ii) It produces no odours if it is used and maintained correctly;
(iii) The treated faecal matter is dry, odourless and less offensive;
(iv) It does not attract flies or other vectors;
(v) The treated faecal matter is partially sanitised and safer to handle;
(vi) The toilet design makes it easy to empty;
(vii) There is a minimal risk of contamination of ground and surface water resources;
(viii) It can be constructed aboveground in challenging environments;
(ix) It can be inside of the home for security and convenience of the users (Mkhize et al., 2017)

Evaluation of wet sanitation systems

Wet sanitation systems usually start with a standard flush toilet. The low-flush or pour flush toilets are some variations to the standard flush toilet design. Once the waste material is mixed with water, there is an additional problem of cleaning the water again. Therefore, the various treatment options available become more relevant with wet sanitation systems.

Wet sanitation systems often require primary and secondary treatment (Krekeler, 2008). Primary treatment includes systems incorporating settlers and anaerobic digesters (such as septic tanks) and

secondary treatment systems include soakaways, French Drains, constructed wetlands and ponds (Krekeler, 2008, Truyens et al., 2018).

Low-flush and pour-flush toilets

A Water Research Commission project initiated in 2009 investigated the use of pour flush toilets to be adapted for South Africans. The pour flush toilet looks like a conventional flush toilet, but it is flushed with water that is poured into the pan by the user. A low-flush toilet has a mechanical flush. Both pour-flush and low-flush toilets need less than 2 litres of water per flush, as opposed to 5 to 7 litres used in conventional toilets (Van Vuuren, 2014). Apart from the water savings, advantages of pour – and low – flush toilets include its low-cost installation, safety for woman and children, reduction in odours and flies, and it can be used in households without water reticulation. They can also be used inside the houses, and greywater can be used in pour-flush toilets (Van Vuuren, 2014, Water Research Commission, 2014). In 2018 a total of 16 000 pour-flush toilets have been installed in South Africa (Pillay and Bhagwan, 2021). Although users have given good feedback on the pour- and low-flush toilets, the technology has not yet been widely taken up by municipalities (Pillay and Bhagwan, 2021).

Ventilated anaerobic treatment systems (Septic Tank Systems)

Septic systems are underground wastewater treatment structures that are commonly used in rural areas where sewer systems are unavailable. They combine natural processes with technology to treat sewage and grey water from the household (USEPA, 2021). A septic tank system consists of a partitioned tank with an inflow chamber where the wastewater can settle and undergo anaerobic digestion. Scum accumulates on the surface of the tank and sludge is deposited at the bottom. Usually, 60% to 70% of solids, oils and grease are retained in the septic tank (USEPA, 1999). The tank also has an outflow chamber where the effluent is discharged from the system (**Figure 9-4**). The flow rate through the septic tank can be controlled with baffles that promote settling (USEPA, 2021). Once the effluent is discharged from the septic tank it can be further treated by passing it through a trench with gravel into a soakaway. As the effluent is treated by microbes as it filters through the gravel and reaches the soil below. The septic tank is ventilated via a small vent.

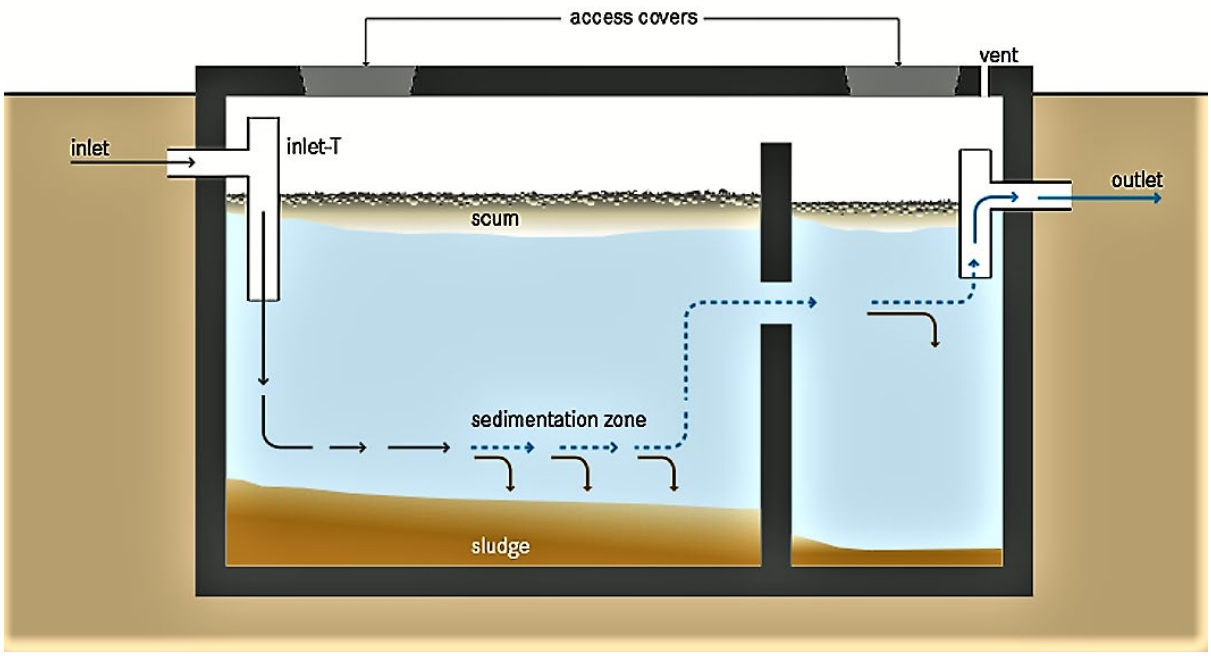


Figure 9-4: Septic Tank (from USEPA (2021))

The septic tank is an underground, impermeable tank that reduces the risk of sludge contaminating the soil and groundwater. Periodically the tank must be pumped out and the sludge must be disposed or treated. The sludge can also be composted and used as fertilizer. The main drawback of these systems in rural areas is the availability of water.

A lower-cost variation to the septic tanks is an aquaprivy toilet with a soakaway, or underground drain. The aquaprivy is a small watertight septic tank underneath the toilet. The toilet is flushed with up to 3 litres of water, which sometimes has to be added manually by the user. A water seal is created in the tank to reduce flies and odours. The solids remain inside the tank and has to be removed by a vacuum tanker and properly treated. The effluent from the tank is drained into a soakaway before being discharged into the surrounding soil. Aquaprivy toilets has operation and maintenance costs, it cannot be installed inside a house or in dolomitic areas, as there is a risk of leakages. These toilets are widely used in Gauteng, but problem occur due to inappropriate construction and use (Martin and Pansegrouw, 2009).

Unventilated anaerobic treatment systems (Biogas production)

In an unventilated septic tanks system, design changes can be made to capture the gas produced through anaerobic digestion, to be used for biogas. Biogas comprises methane, carbon dioxide and other trace gases which is a source of energy that can be converted to heat, electricity or light (Tilley et al., 2014). There are small biogas reactors that can produce biogas at the household or community level in rural areas. Animal manure, kitchen and garden waste can also be added to the reactors (Tilley et al., 2014).

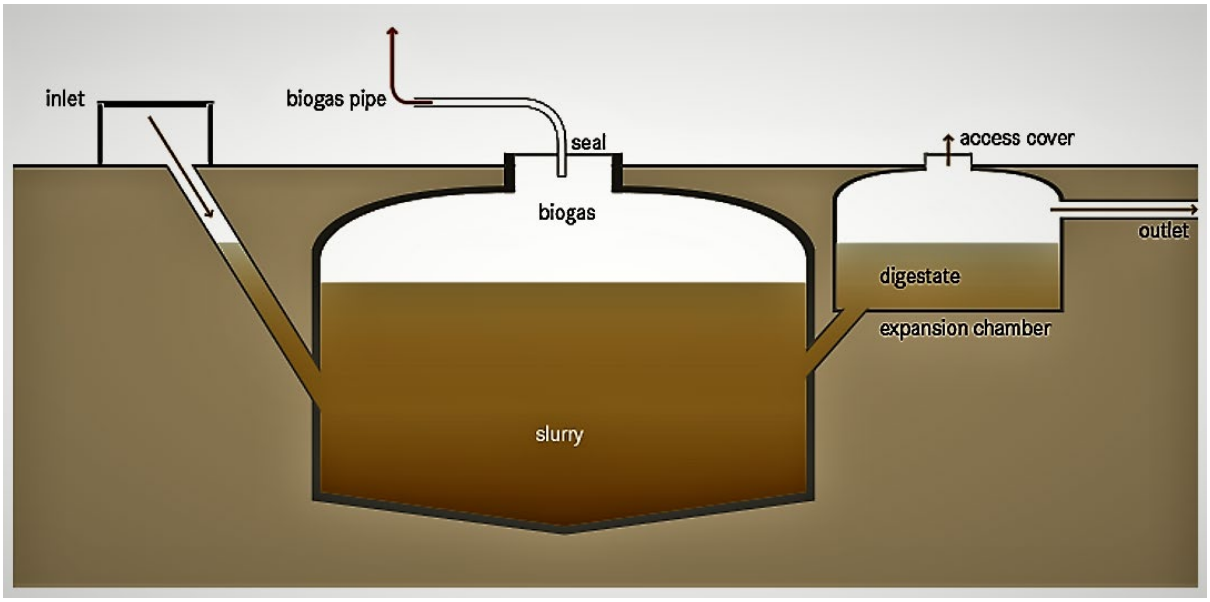


Figure 9-5: Anaerobic Digester (from Tilley et al. (2014))

Small-scale biogas reactors **Figure 9-5** consists of an inlet, a sealed reactor chamber, a vessel to collect biogas (e.g. upper part of the reactor, floating drum, plastic balloons, see below), and an expansions chamber (Tilley et al., 2014). There are three general types of biogas reactors designs: rubber-balloon biogas plants, floating-drum plants and fixed-dome plants.

Rubber-balloon biogas plants

The rubber-balloon biogas plants are the easiest and cheapest to construct. It has a large plastic bag (e.g. PVC) containing the waste material. Inside the bag sludge settles at the bottom and the gas accumulates at the top from where it is withdrawn **Figure 9-6**. The inlet and outlet are attached to the plastic layer of the balloon. The pressure that builds up inside the elastic bag provides the energy to transport the gas to where it will be used. The pressure can also be increased by adding weight on top of the balloon. This is a low-cost system, but are temperature sensitive and because the gas is at a relatively low pressure it must be close to where is will be used. The bags can also easily be damaged and has to be cleaned regularly (Tilley et al., 2014).

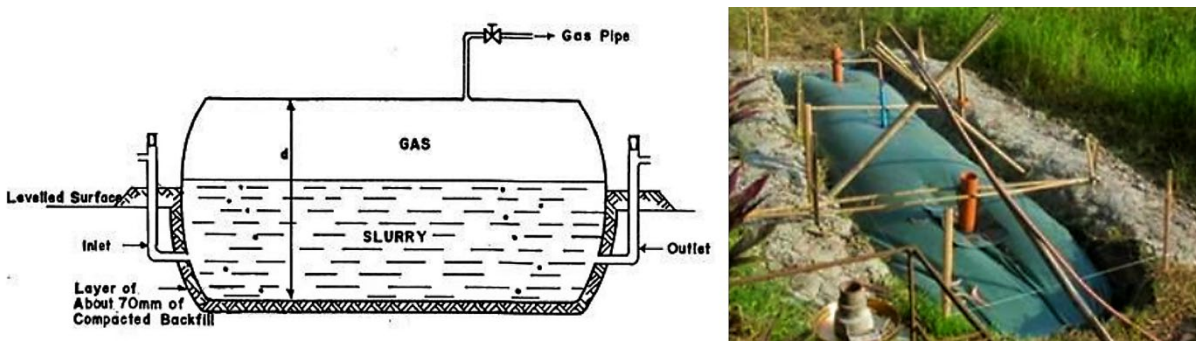


Figure 9-6: Plastic bag anaerobic digester (from Tiley, 2014)

Fixed-dome reactors

The fixed-dome plants have a non-movable gasholder on top of a digester. When gas production starts, the slurry is displaced into the compensation tank (**Figure 9-7**). The gas pressure is a function of the volume of gas stored and the difference in height between the slurry levels in the digester and compensation tanks (Tilley et al., 2014). The advantages of the fixed-dome biogas plants to rural and peri-urban areas include relatively low construction costs and a long lifespan due to material that do not rust. However, leakages through the brickwork gasholder or cracks requires management and the construction requires the supervision of experienced technicians. Another potential disadvantage is the variation in gas pressure that can affect its ease of use (Tilley et al., 2014).

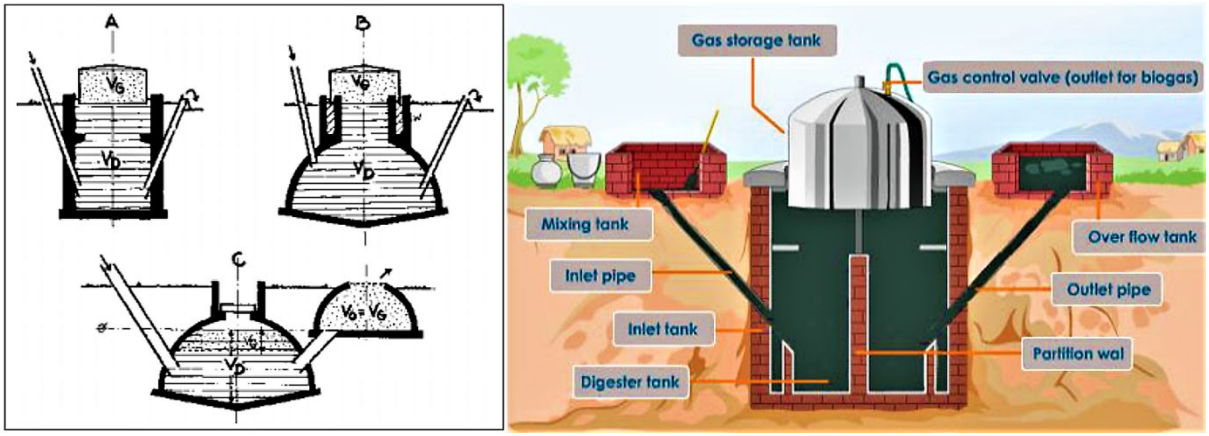


Figure 9-7: Fixed dome anaerobic digester (from Tiley 2014)

Floating-drum reactors

A floating-drum reactor has an underground digester and a gasholder that either floats directly on the slurry or in a separate casing fill with water (Tilley et al., 2014). The gas is collected in a drum that moves up or down depending on the amount of gas it contains. A guiding frame prevents the drum from tilting.

The advantages of the floating-drum reactor are that the gas pressure is constant (depends on the weight of the gasholder), construction is relatively easy and it is robust, because it can function and produce gas even when there are construction mistakes. Solids build up in the digestor, which must be removed from time to time, but can be used for fertilizer. The disadvantages include high cost of the material of the steel drum and all the steel parts are susceptible to corrosion. Therefore, floating-drum reactors have a shorter lifespan than fixed-dome plants, and the drums must be painted regularly (Tilley et al., 2014).

Aerobic Treatment Systems

Many of the processes used in Aerobic Treatment Systems (ATUs) are similar to those used in municipal sewage plants, only on a smaller scale (USEPA, 2021). Oxygen is injected into the treatment tank, which increases natural bacterial activity that removes nutrients from the effluent (**Figure 9-8**) (USEPA, 2021). The water can also undergo pre-treatment and / or final treatment. The final treatment includes disinfection to further reduce pathogen levels. The disadvantage is that it requires

regular maintenance, the aerators require electricity and breakdown of the aerator cause failures of the system.

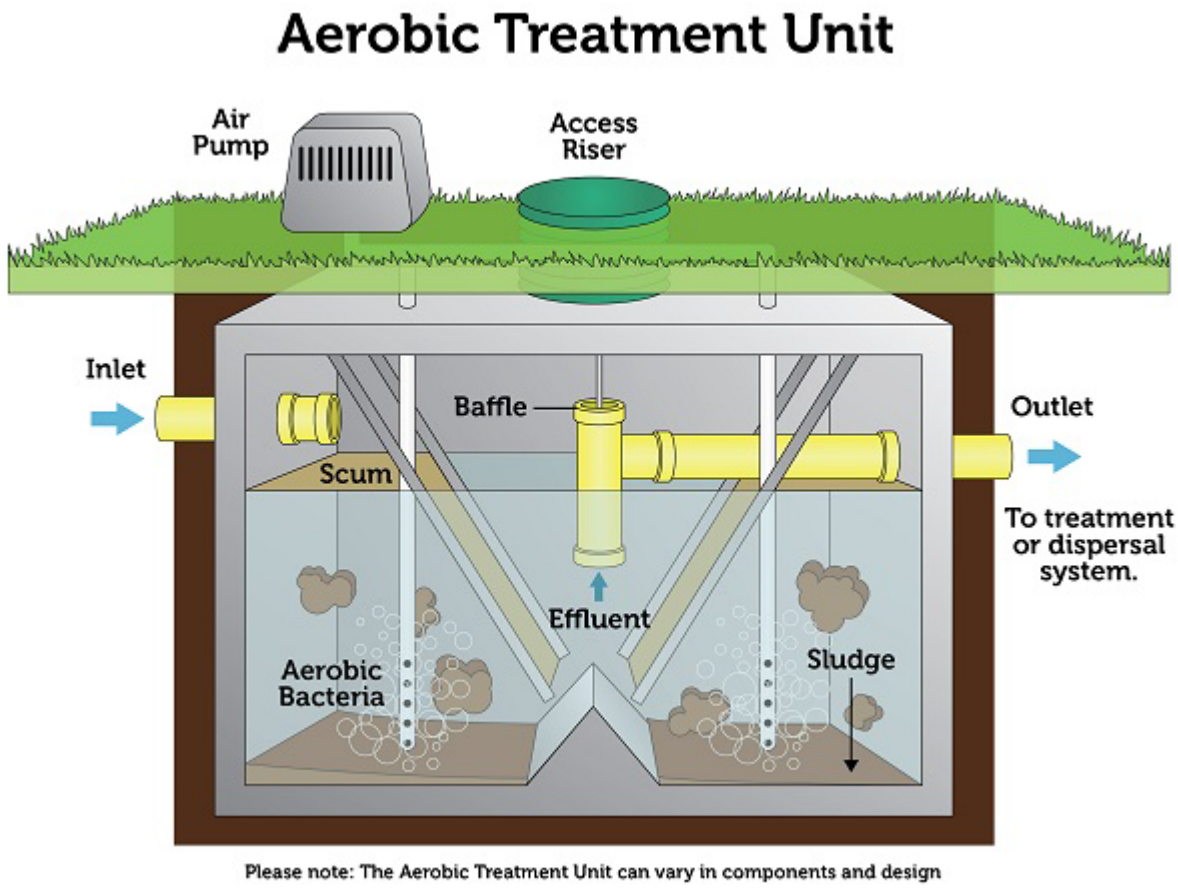


Figure 9-8: Aerobic treatment unit (from USEPA (2021))

Secondary treatment systems

Wet sanitation systems produces both effluent and solids that need to undergo secondary treatment. The increase in water:solid ratio in these systems means more effluent requires treatment before it can be re-used. In many cases, a number of secondary treatment systems are used to treat effluent from wet sanitation systems.

Recirculating Sand Filter System

Sand filters are connected to a septic tank and can be place above or below ground (**Figure 9-9**). The sand filter is an impermeable container that is filled with sand. Effluent is pumped from the septic tank, via a pump tank, to the top of the sand filter and undergoes secondary treatment as it percolates through the sand. The sand filter is very effective in removing nutrients, and also safe in areas where groundwater pollution is a potential problem. The main disadvantage is the high cost in construction, compared to the usual septic tank system (USEPA, 2021).

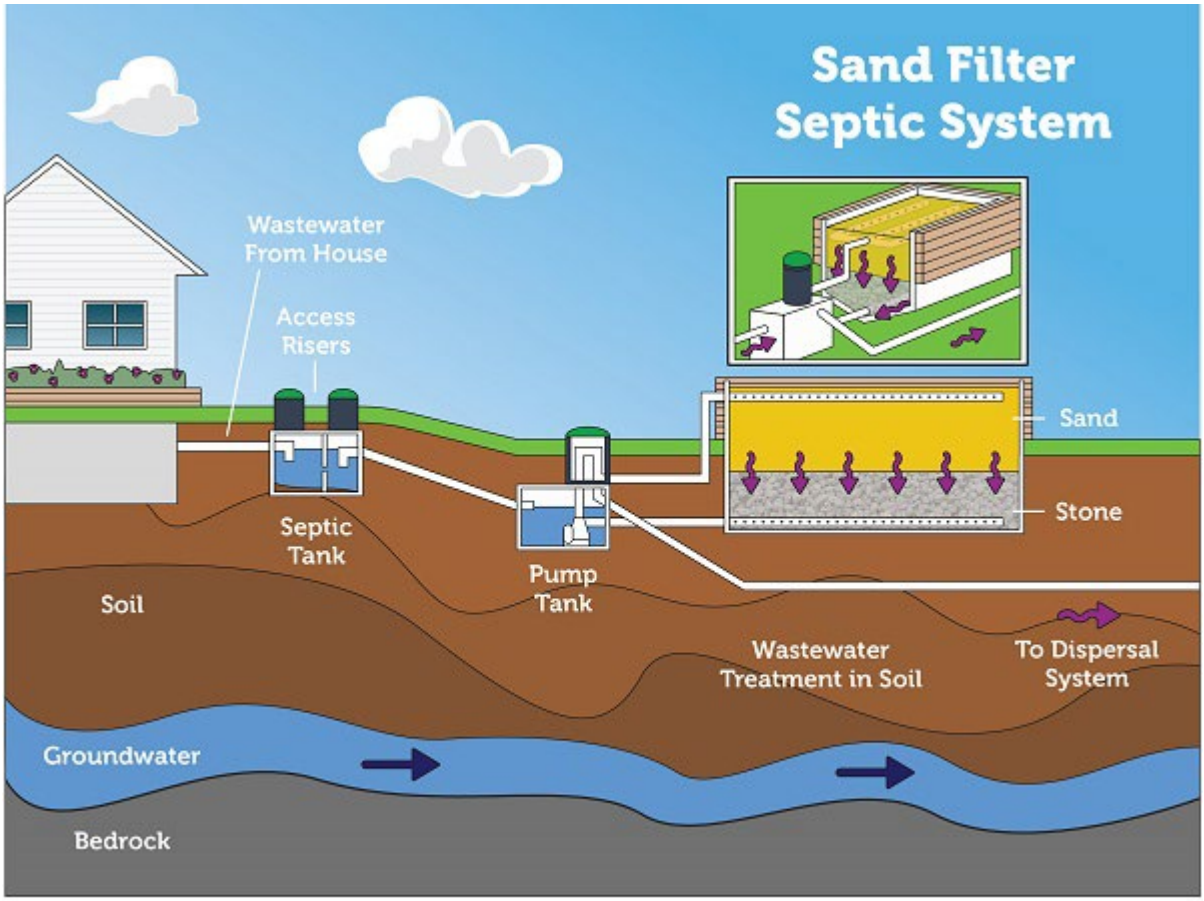
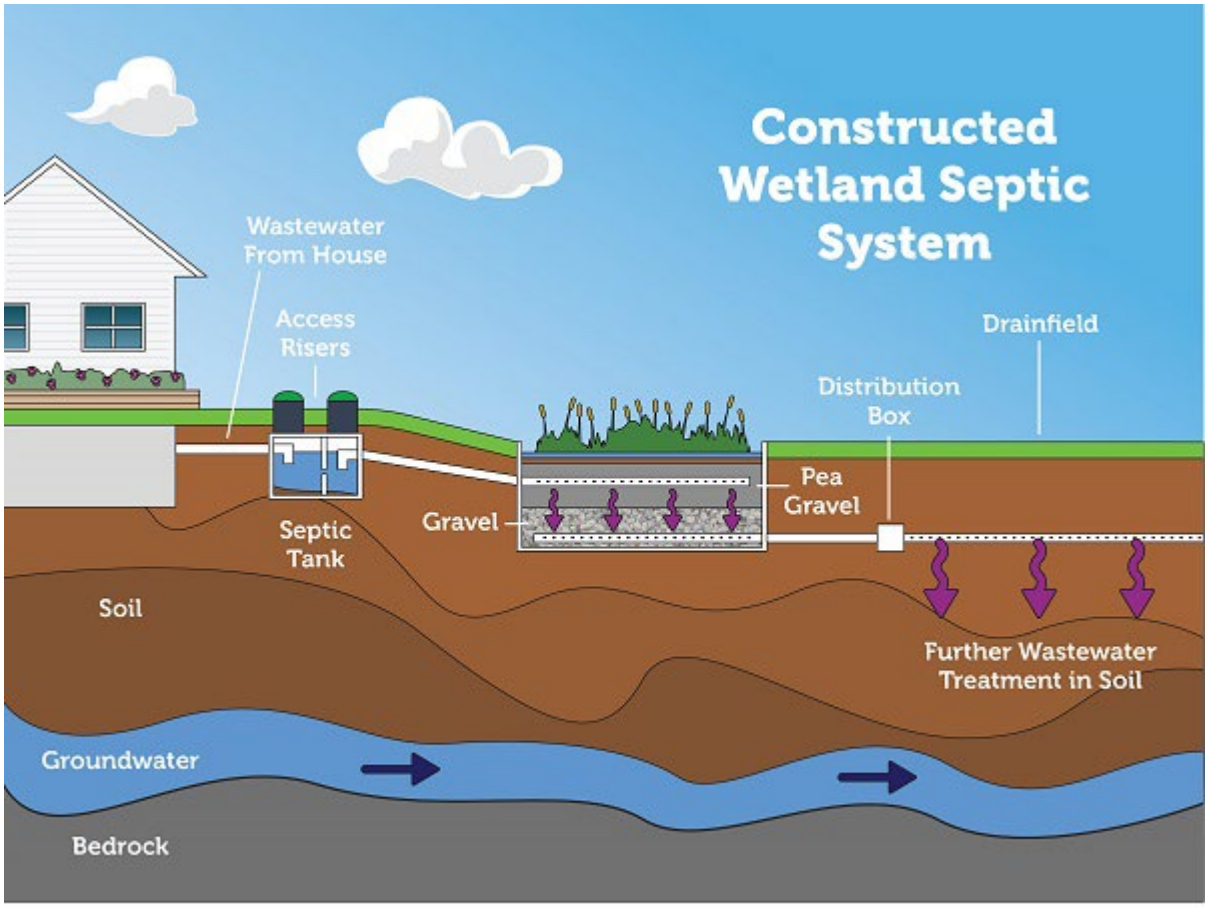


Figure 9-9: Sand filter system (from USEPA (2021))

Constructed Wetland System

Wetlands have a natural function to clean water, and this process is reproduced in constructed wetlands. The constructed wetland will be in an impermeable cell, with gravel and sand in which wetland plants grow. The plants that are used must be adapted to survive permanently saturated conditions (**Figure 9-10**). Effluent from the septic tank is directed into the constructed wetland, or wetland cell, where is flows through the soil and comes into contact with micro-organisms and plants that removes nutrients and pathogens (USEPA, 2021).



Please note: Septic systems vary. Diagram is not to scale.

Figure 9-10: Constructed wetland (from USEPA (2021))

Pond System

A pond system typically consists of a lined open water dam similar to a maturation pond in a municipal waste water treatment plant. Natural processes in the pond and the availability of free water further treat water from a septic tank system.

Packaged Water Treatment Plants

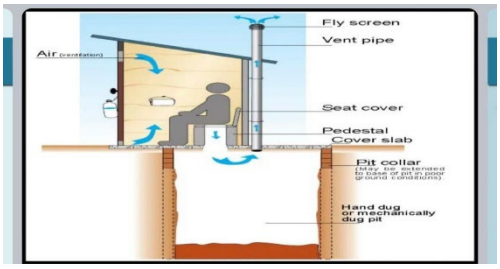
Van Niekerk et al. (2009) define a package plant as: "any onsite, waterborne, domestic wastewater treatment system; whether it consists of one or many modules; with a total capacity less than 2 000 m^3 /day. It typically includes equipment largely constructed and packaged off site and brought onsite for installation". The most common types of package plants in South Africa are the activated sludge or extended aeration plants, trickling filters, submerged bio-contactors and rotating bio-contactors (Van Niekerk et al., 2009). Anaerobic systems like septic tanks, pond systems and constructed wetlands are often used for pre-treatment step or for the final polishing step.

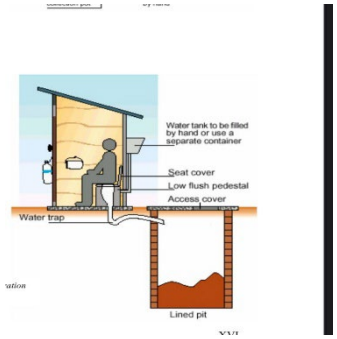
Appendix 2: Engagement of with smallholder farmers in the study area

Questionnaire used for individual interviews

1. What is your name?
2. What's the name of the village?
3. Under which municipality does your village fall?
4. How long have you been a resident in your village?
5. Do you have access to water? If yes which? (tick as many as are applicable)
    - Borehole water
    - Municipality truck water
    - Unprotected spring water
    - Protected spring water
    - Other; describe
6. Do you have clean water to drink?
7. Do you have access to electricity?
8. What do use for cooking? Electricity or firewood? Or a combination?

9. What type of sanitation do you use in your homestead?
    - Dry on-site toilet (pit latrine and VIPs)

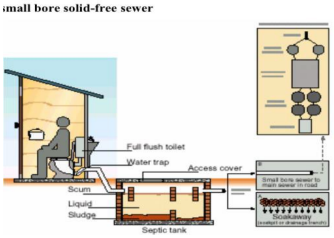




    - Wet on site toilet

    - Cartage (honey suckers)

    - Sewage



10. Where is your toilet located in your homestead?
11. How long have you been using the toilet?

12. What happens when the toilet is full?
13. Those using toilet inside the house, how big is the flushing point, and how long do they use before it fills up?
14. What other foreign objects are you adding to the toilet?
15. What do you use for cleaning after using the toilet?
    - Toilet paper
    - News paper
    - Water
    - Other; describe
16. How do you clean your toilet and how often do you clean it in a week?

Agricultural characteristics

1. What agricultural activities are you doing?
    - Back yard garden
    - Field cropping
    - Livestock
2. How long have you been farming?
3. What farming practices are you using?
    - Composting
    - Mixed cropping
    - Mono cropping
    - Conservation Agriculture
    - Furrows and ridges
    - Tractor
4. Do you have any agricultural projects in the community assisted by the Department of Agriculture?
5. Are you farming for household consumption or for selling?
6. What type of irrigation system are you using?
7. Do you get any support from a government organisation/NGO?

History and culture

Communities are grounded by beliefs and traditions. Among these beliefs and practices were taboos the were seen as social and religious customs placing restriction on particular things, actions and people.

1. What is the tradition/rules towards building a toilet in the village?
2. What were you using for sanitation in the past?
3. What are the rules/beliefs with regards to people helping themselves outside in the bushes?
4. What are the taboos/beliefs related to women during their menstrual cycle? What kind of pads do they use (disposable / reusable), how or where do they clean / dispose them? Do woman continue their normal daily routines during menstruation?
5. What are the rules related to toddlers/children using pit latrine toilets? How do you feel about the toilets at the school? Do you let your children use the same toilet as you?
6. Do you feel safe when using your toilet?
7. Do you share a toilet with:
    a. Only people in your household of the same gender as you?

b. Everybody in your household?
c. People in the streets?
d. People in the neighbourhood?

How do you feel about this arrangement?

8. How aware are you about worm eggs in the environment and the toilet you might be using?
9. Do you think people are the reason to worm eggs?
10. What are the health issues related to worm eggs to human?
11. Have children experienced worm eggs problems? And how were they treated?

Environmental characteristics

1. Do you have access to roads?
2. How far is the nearest town? And how do you get there?
3. Do you have a job? If yes, what job and where?
4. How big is your household in the village?
5. What's your soil type?
6. What's your soil depth?
7. How often does it rain?
8. What happens when it rains?
9. Where does most of the rainwater run to when it rains? Does it impact on your latrines and sanitation?
10. What do you do with greywater and 'black water' in your household?
11. Are they living in a flat or hill environment?
12. Do you think your current toilets are polluting your water?

Present situation

1. How many pit latrines (old and in use) in your yard?
2. Do you have a toilet that was done by the municipality? And how do they choose households that will get the toilet?
3. How many people are using the toilet?
4. Have you ever seen / heard of other kinds of toilets that you would like to use in your house?
5. What are the issues related to the toilets with regards to their children using the same toilet?
6. What happens when the toilet is full? Does the municipality arrange any honey suckers to drain the toilet? And who pays the municipality or individual?
7. Do you have a tap in your household?
8. How often does water run from the tap in a week? Does the water in the tap ever dry up at certain times of the day?

Aspirations

1. What type of toilet would you prefer in your household in future?
   - Dry on site toilet
   - Wet on site toilet
   - Cartage (honey suckers)
   - Sewage
2. Are you willing to spend some money towards a better toilet? And how often can you contribute towards spending money towards a better toilet? How much?
3. Would you prefer a toilet inside your house or outside?

4. Do you know that you can use human waste for agricultural purposes?
5. What do you think about handling human waste for agriculture purposes?
6. Are you willing to handle human waste?
7. In what condition are you willing to handle human waste?
    - Urine
    - Dry human waste; or
    - Wet human waste
8. Are you willing to incorporate using human waste as compost in your garden?

Table 9-1 shows the responses of the SHFs who were interviewed individually.

Table 9-1: Summary of information from sanitation questionnaire SHFs - Limpopo September 2022.

Category	Description	Molati	Ga-Sekororo	Rating: Low (0%-33%) / Medium (33%-66%) / High (661115-100%
No of SHFs: 7 men,14 women		9	12	
Average years living in the area		51	37	
Access to Water:	Individual Boreholes	6	9	
	Unprotected springs	0	9	43%
	Protected springs	0	0	0%
	Municipal trucks	0	0	0%
	Other: standpipes, communal water points	2	8	48%
Current sanitation	Dry, on site	9	12	100%
	Wet, on site	0	0	0%
	Cartage	1	1	10%
	Sewage	0	0	0%
Preferred future sanitation	Dry on site toilet	1	1	10%
	Wet on site toilet	1	0	5%
	Cartage (honey suckers)	7	9	76%
	Sewage	0	1	5%
Willingness to contribute to sanitation	Yes:	9	9	86%
	30% of cost	6	5	52%
	50% of cost	3	4	34%
	No, can't afford	0	3	14%
Preparedness to handle human waste	Handling:			
	- Urine	5	7	57%
	- Dry waste	7	7	67%
	- Wet waste	3	2	24%
	Incorporation of human waste as compost in gardening or farming	7	7	67%
Number of pit latrines	Old:			
	0	2	9	52%
	1	3	2	24%
	2	2	1	14%
	3	2		10%
	In use:			
	1	7	3	48%

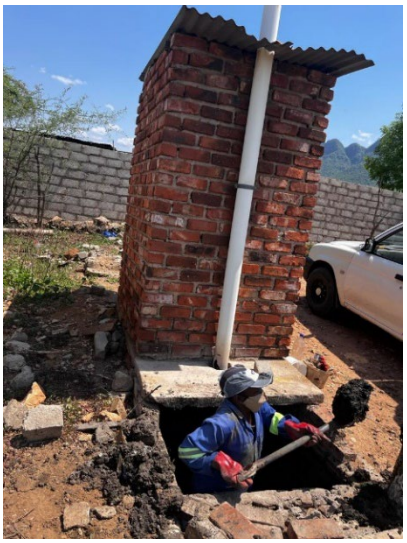
Category	Description	Molati	Ga-Sekororo	Rating: Low (0%-33%) / Medium (33%-66%) / High (661115-100%
	2	2	4	29%
	3	0	5	23%
Use of toilets	Number of people per household on average	7	7	7
Position of toilet	Outside at corner of plot	9	12	100%
Management	Add chemicals to promote waste breakdown	2	0	10%
	Dig another when full	9	12	100%
	Time before digging new toilet (years)	9	20	14,5
	Municipal removal for full pits	0	0	0%
	Private 'honeysuckers": e.g. Drain Surgeon or local contractors	2	2	19%
Foreign Materials	Paper (newspaper, toilet paper)	9	12	100%
	Pampers	2	0	10%
	Greywater from laundry and washing	0	4	19%
	Cleaning materials; Jeyes fluid, Handy Andy, Domestos (1-3x/week)	9	12	100%
	Other – only when full, then the toilet is used for general waste disposal	9	12	100%
Rainwater	Temporary flooding of toilet due to runoff in the yard	2	2	19%
Municipal pit latrines	Yes	4	8	57%
	Registered, but waiting	2	2	19%
	No	3	2	24%
Past practices	Use of bushes and grass	1	2	14%
Cultural	No rules regarding open defecation	9	12	100%
	Use of toilets for whole life – no other practices	8	10	86%
Women and menstruation	Taboos: Not allowed certain activities: gardening, church, handling food due to belief of being unclean	0	4	19%
	Use of washable cloths	4	8	86%
	Use of disposable pads	0	1	7%
	Women's safety at night a concern	1	3	19%
Toddlers	Don't use pit latrines, open defecation and adults clean this up	9	12	100%
Awareness of health issues	Worms and worm eggs transmission through human waste	4	9	62%
	Health issues due to worms - don't know/unsure	7	10	81%
Treatments	Worms in children – taken to the clinic	8	7	71%
	Buy deworming medication	0	3	14%
	Don't know/unsure	1	2	5%
Energy	Electricity	9	12	100%
	Cooking: firewood only	4	4	38%

Information on participating farmers

Farmers who volunteered to form part of the project team were interviewed individually and attended the focus group meetings.

Appendix 3: Study on entrepreneurs that clean the pit latrines in Ga-Sekororo

Stakeholder engagement and field visit with VIP latrine drainer service providers in Ga-Sekororo area



18 November 2022

Me Betty Thobeka (Maimela) visited one of the schools, to meet the principal in request of contact details for sanitation waste drainers. Cleaning sanitation waste at schools is done by local service providers, through a subcontract with the municipality. Locally people have seen that sanitation is causing issues in the community because people are not certain that a latrine would be given to them or not. The criteria used by the municipality to select people who have registered for latrines are unknown to the community.

Mr Sekgobela is from Sofaya, a village in Ga-Sekororo. He started as a pest controller, dealing with pests in households and latrine cockroaches. When his business started, many households complained about latrines filling up, and they wanted chemicals to reduce the volume of the waste. Mr Sekgobela then started experimenting with chemicals, but had not been able to develop a solution yet.. Then he decided to work on ways to empty a latrine manually without getting sick. Currently, he is working with more than ten young people from his village to drain latrines manually around Ga-Sekororo and Ga-Mametja.

Mr Sekgobela started draining latrines manually around 2017 in his village and neighbouring villages at an amount of as little as R150 to 210 L per tank. He continued with this work on a part-time basis. He now uses a bucket system to take out the waste inside VIP latrines and fill a 210 L tank for R300. According to Mr Sekgobela there is competition in this business, especially for draining school latrines, but so far around Ga-Sekororo and Ga-Mametja he seems to be popular and these people contact him for help. He mentioned that people are not used to draining pit latrines yet, but he thinks the costs, materials and labour needed to build a new pit latrine, and because of the limited space in their homesteads, people will resort to emptying their latrines instead.

He also indicated challenges when emptying the pit latrines. Firstly, these structures are built in different ways: those built by the municipality are easy to empty as they are constructed to allow one to open them at the back for draining. However, self-constructed pit latrines do not have an opening at the back to drain them easily with a bucket. Draining these self-constructed latrines are messy and hard – but they have found ways to do so.

A visit was paid to the dumping site by the researcher, Me Betty Thobeka, Mr Sekgobela and one of the SHFs, Mr Isaac Malatji. The site is near a village called Peace-Mark and Meetse. The dumping site is not controlled, it is open for the public and accessible to anyone to dump whatever they want, being homestead dirt, plastics, bottles and nappies, etc. All the waste that are drained from the latrines are dumped in the same dumping site.

Figure 9-13 below shows the dumping site where the pit latrine cleaners dump all the waste that they take out of the latrines. In the dumping site the human waste gets mixed with different types of waste from the households. This site is accessible for livestock to look for food, which is dangerous because the edible waste is mixed with human waste and plastics.

Figure 9-11: Waste dump site where content from pit latrines is disposed by the pit latrine pickers

Figure 9-13 shows images of the waste dump site where the content of pit latrines are disposed by the pit latrine pickers A: waste they dumped the day before the visit; the waste is still wet; B: Waste that had been dumped a week ago; it is starting to dry; C: Waste that had been dumped over a month ago; it is dry and blown by the wind; also visible are nappies that had been disposed inside the pit latrines; D: Part of the dumping site, with different types of waste that had been disposed on the site.

Mr Sekgobela invited Me Thobeka to accompany them when they were emptying a municipal pit latrine at Peace-Mark. A household owner heard about him and asked him to empty his pit latrine. They used a bucket, spade, gloves, mask, and boots; however, their protective clothing was old and worn out. They filled three 210 L tanks on a bakkies at a time, then drove to empty them until the pit latrine was empty. The waste was black and solidified, even fresh faeces from the day before. There are worms at the top of the waste pile, while other waste that was disposed in the pit was at the bottom. Mr Sekgobela said that most of the latrines he has emptied are old and he noticed that waste layers differ according to the years. Old waste at the bottom look like ash, as was seen on the dumping site. The latrine they were draining was moist at the bottom, but with no water, and watery at the top.

Figure 9-14 shows the process used to manually drain the latrine. They have to go into the pit to be able to drain it, using a spade to fill a bucket. One VIP in **Figure 9-14 A** was constructed by the municipality, and has enough room to empty the pit, the other was self-constructed, with no room for emptying.

Figure 9-12: Process of cleaning the pit latrines

Figure 9-14 shows the process of cleaning the pit latrines. A: Two VIP latrines, one constructed by the municipality with bricks around 2015, and one under construction by the household owner. B: Seat of a full pit latrine C: Protective boots, Jeyes fluid that they use when there's a smell and gloves for protection. D the inside of the pit after the first load had been taken out for dumping; less fresh faeces is seen, where everything is dark, and plastics and nappies are also visible E: Entrepreneurs are taking out waste using a spade to fill the buckets and fill a 210 L tank in the bakkies F: Fresh faeces taken out, they might have used the toilet in the morning.

Mr Sekgobela wants to use all the waste he is disposing of to fertilise the soil and farm crops like sweet-corn, maize and fruits, basically crops that won't come into contact with this waste. He went to Ga-Sekororo tribal authority to ask for land where he could farm. He managed to get a place and he is cleaning it up and will start to dispose all the waste at his farm, but he also has to educate people not to throw plastics, hair, bottles and nappies inside the toilet, which will be a long process. The waste he drains at schools mostly contains no foreign objects.

Conclusion

Mr Sekgobela was happy that there are people interested in wanting to look into what one can do with human waste to fertilise the soil, this for him will bring awareness of their work in various villages all around Ga-Sekororo and Ga-Mametja, and people will start thinking of emptying their pit latrine instead of building poor structures; this will also reduce pollution of underground water but there is

a need to know how to use the waste because mere disposing adds to pollution that might lead to unknown diseases to both villagers and livestock.

Appendix 4: Visit to KZN sanitation projects

The project team, including Attie van Niekerk, Betsie le Roux, Mike Howard, Erna Kruger and Betty Thobela, visited various projects on decentralised sanitation systems in eThekwini, KwaZulu Natal, on 1-3 August 2022. The aim of the visit was to build a network with potential partners in eThekwini, to see what they have done previously and to understand what has worked and what did not work so well. **Table 9-3** shows the schedule and projects that were visited in eThekwini over the three days in August 2022.

Table 9-3: Schedule for site visits to and meetings on decentralised sanitation projects in eThekwini, 1-3 August 2022

Site and location	Projects	Facilitator
Monday, 1 August 2022		
Newlands Mashu Research Site 71 John Dory Drive, Newlands East	DEWATS, Pour Flush toilet, UD Toilet	Lungi Zuma (eThekwini Municipality), Preyan Arumugam, Travis Kunnen
Tuesday, 2 August 2022		
Thandanani Informal Settlement 71 Parkington Grove, Kenville	NEW Generator Community Ablution Blocks	Bonginkosi Ndwandwe Lungi Zuma
Khanyisa Projects 246 ZK Mathews Road, Glenwood		Nick Alcock and Teddy Gounden
UKZN Howard College	Feedback on user perceptions on innovative sanitation	Cathy Sutherland
Wednesday, 3 August 2022		
Household visits		

Newlands-Mashu

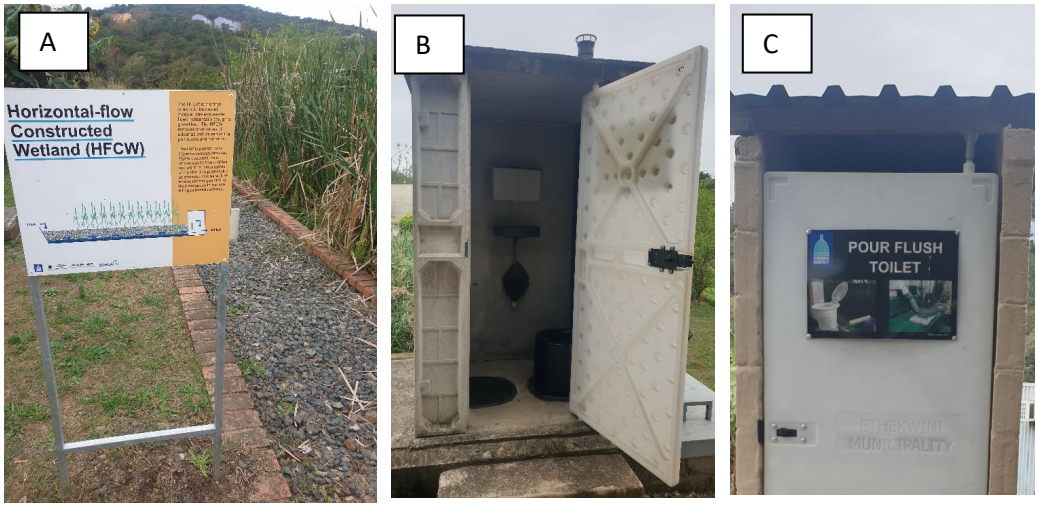


Figure 9-13: Decentralised sanitation toilets and treatment system at Newlands-Mashu research station: A: Horizontal flow constructed wetland; B: Urine diversion toilet; C: Pour flush toilet

Urine diversion toilet

eThekwini has installed 80 000, many use it but do not like it, it becomes a pit toilet that is not deep enough

Urine Diversion Challenges:

- People don't want to handle human waste;
- Requires more regular emptying than pit latrines;
- Foreign objects still a problem;
- Urine diversion doesn't happen so the waste is 'wet' defeating the purpose of the UDD.

Pour flush and a low flush toilet

It may be one step up on the ladder, because people want a flushing toilet, but it is a schlep to have water available all the time, but some take ownership of it and decorate the building

Pour flush challenges:

- Too much effort to fill up the water bucket
- The addition of cisterns failed because of technical issues (leakages) and too much water in the pit;
- Household is responsible for maintenance which often doesn't happen;
- Breakages are not fixed;
- Not many people are using grey water possibly because of lack of training by the contractors;
- However, eThekwini are replacing the UDD toilets with low flush as the current preferred option.

Wastewater treatment

They have an extensive facility for the back-end, where they get the sewage from 84 households higher up on the hill.

- There are different ingredients – scum from fat and oils, etc.
- They are treated in phases
- The scum is scooped off at the beginning
- Urine and faeces (sludge) are separated step by step
- The nutrients are in the urine – they do nothing with the sludge, the remove it from the bottom of the pit and throw it away (or bury it?)
- Ammonia must still become nitrates before it is a fertilizer that plants can use – that happens in the later phases
- They have a wetland through which the effluent goes before it goes into the river
- Preyan has just complete her Ph. D. on this facility

DEWATS System challenges:

- Skimmer required up front to treatment because of the high levels of oils and grease due to diet (an important consideration in design);
- Existing problems with wetland systems primarily as a result of mixed size gravel in beds. Causes short-circuiting, aeration, ponding and incomplete bacterial breakdown. If this can be fixed, a wetland is useful as a polishing process.

Community Ablution Block (CAB) in Thandanani

Figure 9-14: A: Community Ablution Block (CAB) in Thandanani; B: Community people outside the CAB in Thandanani; C: Decentralised waste water treatment system behind the CAB in Thandanani

The CAB at Thandanani was very interesting and deserves further attention. It is very expensive, and must be maintained by the municipality. For example, they must ensure that toilet paper is available at all times to prevent people from flushing inappropriate cleaning materials into the toilet. This means that a dedicated person has to go to the facilities everyday to supply toilet paper, which has time and traveling cost implications. However, larger expenses are necessary to maintain the facility especially the treatment of the waste, or also known as the 'backend' of the system. If we merge this model with another one in Kwa Mashu where a resident put a toilet on a biogas digester, and got

enough nearby residents, plus cow / chicken manure, to use it so that he had free energy at home, such a person will have the incentive to maintain the ablution facility. It has different advantages:

- According to Lungi Zuma from the eThekwini Municipality, the CAB brings the small community together: it is something that belongs to all of them, children play there and people put up shops, like a town square
- According to Cathy Sutherland from the UKZN Howard Collage, it provides privacy: you go into the facility, where you can wash, shower, or use the toilet. That is in contrast with a public toilet where everyone can see you go in and out. Thus, the showers and basins are important
- If it is managed by a resident who benefits from it, maintenance may by more sustainable. One has to get one person in that small community who fits the role, you do not have to get every household to do certain things, such as in the pour flush and low flush toilets

Khanyisa Projects

Khanyisa Projects have two models of toilets that they are developing. This first high-tech flush toilet with an EOOS pedestal that diverts urine and processes the faeces in a complicated backend, reducing it to negligible amount of dried powdery material that can be disposed normally. This kind of toilet is not suitable for low-income households, because it will be very expensive and may need maintenance. The other toilet wraps the whole waste content of the toilet, urine and faeces, in plastic to be disposed. Our project team does not consider this toilet as a possibility for low-income households. At the front end, the plastic must be purchased, which will be problem considering how many people are unable to purchase toilet paper. At the back end, the wrapped-up waste will not be able to degenerate, due to poor waste management in rural areas it will be disposed of improperly in a similar way that disposable nappies are disposed of in rivers, and the breakdown of this material in plastic, i.e. under anaerobic conditions, will lead to methane production, thus becoming a climate change issue.

Visit to Khanyisa: Ted Gouden said that the people accepted the technology, but the politicians made them more negative about the technologies. They made them feel that the solutions are degrading and a lower standard compared to the flush toilets. This highlights the importance of involving the municipality, politicians, tribal leader, etc. in the development process.

Nick Alcock suggestion as best option for rural areas is pour flush with a soakaway for liquid fraction and dry out and deep trench for solids.

UKZN Howard College

We had a meeting with Cathy Sutherland on 2 August 2022, and she made the following important comments:

- They can draw up a framework with key things that must be considered in all cases, like the following:

  - Principles that sanitation must comply with (safety, comfort, privacy, space, e.g. distance from other houses for odour, near the house but not in the house (5 m), do not position it in way that it heats up, effective, sustainable/robust, quality, it must be pleasant to use, nice technology)
  - Risks – a certain substance may have value for soil, but it could contain pathogens,
  - Impediments, e.g. physical constraints such as soil type and availability of water; what plants can be used
- The idea that human waste can be a resource is more common than one may think
- People will not handle waste unless it is very dry
- Pyrolysis – make charcoal/biochar, to get energy or purify water, no one wants to take responsibility – wish it was someone else's problem urine is much more valuable and the risk is low, that may be why they focused on it so far – Dublin team focuses on this. Cathy mentioned that the community is afraid of fires, so burning may not be acceptable.
- The flush toilet is considered to be the ultimate solutions that people want, they may express positive feelings about a toilet solution now, which they compare with their current toilet, but after a few years of using this new toilet, they start to compare it with flush toilets or the next toilet on the sanitation ladder
- Cathy made mention of Rocla, Deslo and Soundrite systems (three kinds of low-flush toilets)
- She also works with Johan Sacks who is in Switzerland.

Low-flush and urine diversion in rural community

Figure 9-15: Urine diversion toilet in rural community

Visit to rural community on 3 August

a. Fanele took us to one household, but the people were not there and the low-flush toilet was locked. A urine diversion toilet next to the low-flush was not locked, but the door was broken. There were people in a shack on the premises, but we were not allowed to talk to them, because if we talked to them, it would have been research and we did not have permission for that.

b. It seems that the new toilet, with two pits at the back-end, may not be used regularly. The nearby UD-toilet is used regularly, but the male urinal and the place where the urine is collected within the toilet itself, is full of toilet paper. The male urinal was not completely blocked by the paper and could still be used

c. Fanele thinks that the people lock the door of the pour flush, because it is next to the road and any person can use the toilet if it is unlocked. If there is no water in the toilet for this person to flush, or the person makes a mess in the toilet, it will be the owner's problem to clean it up. However, the lock on the door may be the reason why the toilet seems not be used. Another reason for the toilet not being used may be that often people keep these toilets for guests.

Conclusion

1. In different meetings people mentioned two shortcomings in their programme so far, that are the: two things that we focus on, co-creation and what happens at the back-end, e.g. somebody would say there may have been better acceptance if they co-created a specific solution
2. It seems that the two things that we want to concentrate on, what to do at the back-end of the toilet and co-creating the solutions, are the two things that they feel are lacking in what they have done so far
3. Did we see a toilet that will work? Low flush? Urine diversion 2nd version at Nick Alcock (EOOS pedestal for flushing urine diversion)? The latter seams the most successful idea to test. The pedestal can be use on different types of toilets.
4. Two important programmes:
    a) SANS35000 compliance required for sanitation systems – we will need to ensure compliance;
    b) WRC Sanitation Technology Advisory / Testing Programme – we should engage with this programme to see what other systems are available, not just the ones in KZN.
5. There is a general problem that the traditional authority gives people permission to do things that are not permitted by the municipality, e.g. to build in ecologically sensitive terrain
6. Prof Odindo is in Maritzburg, he focuses on the backend of the sanitation system, with possibilities for agriculture. Our program did not allow us to travel to meet him, but he is a valuable contact.

Notes on the CAB (community ablution block):

7. A place to feel at home

a. Mass housing in the USA
b. Amankwah-Ayeh: traditional community-creating spaces were replaced by isolated spaces, that brings evils of the city.
c. African literature: place to feel at home
d. Thandanani (CAB): love one another
    i. Lungi: it promotes sense of community: children play there, others do washing, you can shower and use the toilet
    ii. Cathy: people do not want the public toilets, everybody can see you go in and come out. The CAB is different: there are various activities. You first go into the safe space of the facility, where you can do different things, and from there you go into the toilet. A clean toilet with enough space is perhaps the one place where you have privacy

Appendix 5: Agreement with the University of Limpopo

University of Limpopo
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Head of Department: Tel: +2715 268 2527, E-mail: izelque.botha@ul.ac.za

28 April 2023

RE: Scoping study towards developing a WEF framework for decentralised sanitation in rural and peri-urban communities in Limpopo

Dear Dr A.S Van Niekerk,

This letter serves to confirm that the Department of Geography and Environmental Studies agree to collaborate with the NOVA Institute on the scoping study funded by the Water Research Commission (WRC) from 1 April 2023 to completion of the scoping study. As per the proposed service level agreement the "long-term vision of the programme is to co-design, with smallholder farmers, decentralised sanitation which is integrated in their agricultural practices, for example by converting human waste into compost as a way of managing the waste and improving agricultural outputs. The scoping study is being conducted in Mulati (area of Letsitele) and Ga-Sekororo (area of Hoedspruit) in the Limpopo Province."

We also confirm that we will identify two undergraduate students that will work alongside the NOVA team on the scoping study as per the proposed service level agreement.

We hereby confirm our commitment to the collaboration and to the expectations involved. We will submit the signed service level agreement as soon as possible.

Kind regards,

Izelque Botha
Head of Department
izelque.botha@ul.ac.za/ +27152682527

Appendix 6: Capacity building

This project contributed to the capacity building of institutions, rural and peri-urban communities, and postgraduate students.

Institutional development

Several small companies worked together in this project, including the Nova Institute, Food and Water Research, Mahlathini Development Foundation, and Horizon Environmental. Further institutional involvement includes the preliminary discussions with the Mopane DM, and these discussions will continue in future research, to ensure that they support and benefit from the research.

Community development

Approximately 20 residents from each of two communities were involved in this project and will continue to participate in the co-design of sanitation solutions in their own homestead. The expertise of the experts in our project team will be shared with these participants in a way that will enable them to apply the knowledge to their everyday lives. The interactions between the participants and the project team should eventually help them to see a solution as a possibility for themselves. If this stage is reached, the participants are empowered and generally become the drivers of the development.

Postgraduate student development

Two honours students from the University of Limpopo became involved in the project. Their information and abstracts of their research is summarised below.

Mr Koketso Carl Boroko

Institution: University of Limpopo

Department: Department of Geography and Environmental Studies

Degree: BSE01 (Honors)

Progress: Mr Boroko is making good progress. He has completed his fieldwork and has submitted a draft report with his results.

Title of assignment: Assessment of the impacts of pit latrines on groundwater in rural areas: A Case Study of Ga-Sekororo, Limpopo province, South Africa

Research summary: This study examines the impact of pit latrines on groundwater quality and accessibility in Ga-Sekororo. The survey findings reveal a lack of boreholes in households, with pit latrines being a prevalent sanitation option. Residents have limited awareness of the potential impact of pit latrines on groundwater quality. Out of 19 surveyed houses, only 3 have boreholes, but these boreholes suffer from water quality issues, including the salt levels and the mud that comes out of the boreholes. The soil composition, primarily clay, shows groundwater contamination concerns. Despite clean water from the mountain, water accessibility remains a challenge due to financial

constraints. The research highlights how clay soil, pit latrines, and groundwater quality are related in the area, underscoring the need for sustainable water management solutions.

Ms Sibongile Hlophe

Institution: University of Limpopo

Department: Department of Geography and Environmental Studies

Degree: BSE01 (Honors)

Progress: Ms Hlope is making good progress. She has completed her fieldwork and has submitted a draft report with her results.

Title of assignment: An assessment of community perception on the use of human waste material from pit latrines for compost in rural village: A case study of Ga-Sekororo, Limpopo province, South Africa.

Research summary: The use of pit latrines is common practice in developing countries in avoidance of open defecation. This is no exception in Turkey village in Ga-Sekororo Maruleng Local Municipality Limpopo South Africa. The use of pit latrines is an unsustainable practice for the people of Turkey because they do not have any pit latrine drainage services and are forced to have multiple pit latrines. Digging new pit latrines takes up space and may be costly to build if the services have to be outsourced. The location of Turkey village is an advantage for substance farming because of the large land space and as with any agricultural practice there are challenges of sustainability and fertilizers could be the solution. This study aimed to find out what is done with the full pit latrines and to find out if the community would be interested in learning how to convert pit latrine waste into fertilizer and use it for their vegetable gardens. This was achieved through questionnaires administered to nineteen (19) household heads in Turkey village.

Appendix 7: Publications from this study

The results of the Literature Review were submitted for publication as Chapter 10 of the book: "**Advances towards sustainable socio-economic transformation through circular and transformative approaches**", Editors: Luxon Nhamo, Sylvester Mpandeli, Stanley Liphadzi and Tafadzwanashe Mabhaudhi. The book will soon be published.

Chapter 10: Enhancing socio-ecological interactions to achieve sustainable decentralised sanitation systems: why people are not using technical solutions.

Authors: Betsie le Roux a,d *, Attie van Niekerk b,d, Erna Kruger c,d, Betty Maimela c,d

a Food and Water Research
b Nova Institute
c Mahlatini Development Foundation
d University of Pretoria

Abstract

Universal access to water, sanitation and hygiene (WASH) in many peri-urban and rural villages has not yet been achieved. There are various technical solutions available to solve the problem, but end-user acceptance of sanitation solutions is the main unsolved problem. Education of and demonstrations to ensure the sustainable use of the given technology seldom succeed. Apart from some obvious problems such as safety risks (particularly for women and children) and environmental pollution to be considered in the design of a sanitation system, there are also more invisible problems such as religious and cultural thought-patterns that affect the use of technologies. A survey was conducted on scientific peer-reviewed literature about these African religious and cultural thought-patterns in relation to sanitation. The literature review has revealed potential factors that must be considered in the development of sanitation solutions. Ecological sustainability is also a very important component of developing a sustainable decentralized sanitation solution, which will be incorporated during the co-development phase, but falls outside the scope of this review. The complex systems theory presents a suitable approach to develop decentralized sanitation solutions, because it recommends that the researcher approaches the end-users with a learning attitude, and obtain multiple perspectives from all role-players. The eventual solution must emerge out of the interaction between all role-players. This approach is similar to trans-disciplinary research. Finally, the project team and the end-users must agree on a common vision. The solution should be implemented on the correct spatial scale (i.e. household, street or village scale). The outcome will be a technical design which is embedded into the daily practices of the household, e.g. a decentralized sanitation practice in the water-energy-food nexus (DSP-WEF).

Keywords: Water-energy-food nexus; Socio-ecological systems; complex systems theory; circular economy.