An integrated ecological sanitation framework for water consumption reduction and energy generation, Capricorn District, Limpopo province, South Africa

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Thesis accepted in fulfilment of the requirements for the Doctor of Philosophy in Science with Transdisciplinary Environmental Science at the North-West University

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Examination: 3 October 2024

DECLARATION

I, **Luvhimba Tlhoaele**, declare that this thesis, **"***An Integrated Ecological Sanitation Framework for Water Consumption Reduction and Energy Generation in the Capricorn District, Limpopo province*"**,** is my own work and has not been previously submitted for a degree at this or any other institution. This is my work in design and execution, and all referenced materials contained herein have been duly acknowledged.

DEDICATION

To Kgatoentle, Sirai, and Mmathebe, my children, I send you all my blessings as you navigate your life journeys. This masterpiece was crafted for you, like I always say; you can never be a graduate of knowledge. The study was meant to complement the fountain of knowledge that my elder sister, Masindi Ramulongo, strongly encourages.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to the Almighty for granting me the opportunity to pursue my studies and for bestowing upon me the resilience to navigate this journey and persevere during the research process, “Philippians 4:13”. The crafting of the thesis could not have been possible without the guidance of many academics at various institutions. I extend my sincere gratitude and profound indebtedness to my supervisor, Prof. Lobina Palamuleni. Her patience, meticulous supervision, careful oversight, unwavering encouragement, continuous support, and invaluable guidance along with swift responses to the submitted drafts which were vital in the successful completion of this study. I would also like to thank Dr David Tinarwo for assisting me with the laboratory work, which was the main activity of the study, your efforts are very much appreciated.

My sincere thanks to my employer for the financial support that enabled me to complete my research work. I also acknowledge the cooperation and patience of my research assistants and editor, Victor Mlambo, Tshediso Serei, Glyn Pindihama, Mufunwa Muntsu, and Prosper Mhlanga, as well as the respondents from the sampled schools, particularly those that assisted with the collection of waste samples. Their active participation was significant in shaping this thesis.

Further appreciation is extended to my family, friends, colleagues, and my thesis coach for their encouragement, assistance, emotional support, and valuable inputs. They include Solomon Uhunamure, Gundo Mulaudzi, Lucy Molefe, Khumo Makgalemela, Neo Sekgome, Benny Tlhoaele, Carol Matlou, Mukondi Mudau and Caroline Dale. To my husband, Kabelo Tlhoaele, and children, thank you for giving me the space to fulfil my academic desire. To my parents, Avhurengwi and Seth Ramulongo, siblings, Masindi and Thavha, helpers, Daisy and Mphephu - I thank you and love you always. To my late grandmother who strongly believed in nature conservation and the protection of the environment, THIS MASTERPIECE IS FOR YOU!!!

ABSTRACT

Ecological sanitation is a systematic approach whose aim is to safely close the loop for nutrients and organic matter. The 6th Sustainable Development Goal focuses on the need to ensure sustainable management of water and sanitation. This study was designed to develop an integrated Ecological sanitation framework for water consumption reduction and energy generation. The research was conducted to explore the implementation of Ecological sanitation framework and water consumption reduction using self-administered surveys and observations at 108 schools within the Capricorn District, Limpopo province in South Africa.

Results revealed a significant association between the duration of Ecological Ventilated Improved Pit (EVIP) toilet use and the toilets' condition with a χ^2 (df = 9, n = 107) = 19.004, p = .025. The study showed that 78.7 % of the respondents did not think that human waste can be a beneficial resource, hence 99.1 % of the schools are not reusing the waste. In addition, 66.5 % of the respondents indicated that they will never consume crops that used composted human excrement. However, a positive association (χ^2 (df=3, n = 108) = 26.243, p = .000) between the number of toilets and reuse of human waste compost suggested that the component of user sustainability in terms of the beneficial concepts will complete the sanitation system cycle. This positive association entails a successful implementation because when concepts are better known, the ideas are better accepted.

In terms of water consumption, results showed that before the implementation of EVIP, overall, the schools used an average of 1 231 litres per day. However, upon the implementation of EVIP toilets, a dry sanitation system, an average of 338 litres was used daily, translating into 893 litres of water saved per day (73 %). In addition, the biochemical methane potential (BMP) test was used to estimate the amount of energy that can be produced from human faeces collected from the EVIP. Optimal volatile solids of human faeces were recorded at 82. 7 %, total solids at 28.5 %, moisture content at 71.5 % while the pH was 6.4. After anaerobic digestion of human faeces, volatile solid reduction was found to be 48. 4 % while the pH decreased to 6.2.

Accumulated biogas production from 25 g of faeces was recorded at 0,00528 m^3 after 69 days of incubation, translating to 0.000346 m^3 maximum production per day and a methane content of 54 %. The total biogas produced by the 483 learners was 66,62 m^3. Overall, the experiment showed that the total energy produced could be used to prepare meals for the school feeding schemes and provide lighting to the school. This was based on the observation that 2 m^3 of biogas can be used to cook for approximately 1 hour while 1 m^3 of biogas can operate a 60–100 W bulb for six hours.

The conceptual framework of the study recommends imparting knowledge on perceived benefits, implementing supportive regulations, enforcing monitoring and evaluation tools for proper management and compliance, and initiating incentives can collectively contribute to effective implementation of the EVIP.

Key words: Ecological sanitation, energy, human waste, water reduction

LIST OF ACRONYMS, UNITS AND NOMENCLATURE

CES	Centre for Effective Services
DWS	Department of Water and Sanitation
EAWAG	Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz (Swiss Water Research Institute)
EESI	Environmental and Energy Study Institute
EPA	Environmental Protection Agency
ESKOM	Electricity Supply Commission
EVIP	Ecological Ventilated Improved Pit latrine
IRC	International Water and Sanitation Centre
LNW	Lepele Northern Water
MC	Moisture Content
NEET	National Eligibility-cum Entrance Test
ROSA	Resource-Oriented Sanitation concepts for peri-urban areas in Africa
SALGA	South African Local Government Association
SAPA	South African Press Association
Stats SA	Statistic South Africa
SUDEA	Society for Urban Development in East Africa
TS	Total Solids
U-ACT	Urban Affordable Clean Toilets
UDDT	Urine Diverting Dry Toilet
UN	United Nations
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
USGS	United States Geological Survey
VIDP	Ventilated Improved Double Pit Latrine
VS	Volatile Solids
WEC Project	Water and Wastewater Treatment Solutions
WEDC	Wisconsin Economic Development Corporation
WHO	World Health Organisation

°C	Degree Centigrade
C	Carbon
CO_2	Carbon dioxide
CH_4	Methane
GW	Gigawatt
kg	kilogram
Kw	Kilowatt
Kwh	Kilowatt-hour
MW	Megawatt
m^3	Cubic metre
MJ	Megajoule
ml	Millilitre

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DEFINITION OF CONCEPTS

Ecological sanitation: A model, which is resource minded and represents an inclusive concept towards ecologically and economically sound sanitation, whereby the underlying aim is to close the gap between sanitation, resource use, and agriculture (Langergraber & Muellegger, 2005).

Effective implementation: An execution or practice of a model or idea to carry out the planned and intentional activities with the aim to turn evidence and ideas into effective practice yielding positive results (CES, 2023).

Green energy: A subset of renewable energy from natural resources, such as sunlight, wind, water, or waste. Renewable energy resources and technologies provide the greatest environmental benefit and conservation (EPA, 2023).

Human waste: Refers to the waste products of the human digestive system, which includes urine and faeces. (Law insider dictionary, 2023). In this research the waste is referred to faeces.

Load shedding: A term used in South Africa to describe the planned electricity blackouts, where citizens experience power outage between two to twelve hours a day. The process is implemented to alleviate pressure on a failing power grid (Green matter, 2023).

Nutrient cycle: Refers to a cycle or pathway by which nutrients go through, to be recycled and reused. The cycle comprises of cells, organisms, community, and ecosystems (NEET, 2003).

Sustainability: A practice that has long-term viability, avoiding the depletion of natural resources to maintain an ecological balance. In addition, sustainable practices support ecological, human, economic health, and vitality (EPA, 2023).

Water reduction: A practice of using fresh water efficiently to reduce water requirements (Ihalawatta *et al.*, 2015).

1. CHAPTER 1: GENERAL INTRODUCTION

This chapter highlights the background of the study, where the essential context of the study is outlined, including the problem statement and the significance of conducting the study, which underscores the relevance of the study. The description of the area where the study was conducted is provided as well as the ethical issues that were considered during the data collection phase. In addition, the structure of the thesis, which outlines the essential elements of the research project are included. This chapter further provides an overview of Ecological Sanitation in two lenses; a sanitation model as well as the perceived benefits, which are economically and environmentally sound.

1.1. Background of the study

In any country, there is a nexus between water and energy, which plays a paramount role within the economic sector (Ololade, 2018:194). This is because in the main, the supply of water heavily depends on the availability of energy. Water supply and availability is of particular interest in South Africa because the country is regarded as a water-stressed and water-scarce nation (Molobela & Sinha, 2011:1). The National Water Resource Strategy 3 (NWRS-3) sets out the strategy to ensure that water resources must be protected, used, developed, managed and controlled sustainably and equitably.

More so, the country is faced with erratic power supply, leading to persistent load shedding due to energy constraints (du Venage, 2020). Among the various uses of water, such as domestic useGrűbel, agriculture, mining, etc., is the sanitation process. The conventional water-based sanitation facilities satisfy all sanitation requirements except the most important aspect of environmental efficiency, such as water consumption and the reuse of human faeces. According to Shah and Sajitha (2012), the current system for collecting and disposing of human waste is insufficient, unfriendly to the environment, and likely to pose health risks to the public. Faeces are usually flushed and not reused. However, Onojo *et al*. (2013:198) noted that faeces can be used as a biodegradable material, which can generate energy for cooking and heating.

Flushing is the biggest water hog in the house and flush systems consume an average of 6 litres of water even for flushing a small amount of faeces (SA Water, 2019). Ihalawatta *et al*. (2015:786) observed that individuals in Sri Lanka lack access to fresh water as a basic necessity while a significant proportion of fresh water is squandered on excreta flushing.

Notably, freshwater is a scarce resource and according to the water facts by the Bureau of Reclamation (2020), only 3 % of the total water volume on Earth is freshwater. In 2022, the UN projected that the world human population would be 8 billion in 2023, 9.7 billion in 2050 and would peak around the year 2086 at about 10.4 billion (UN, 2022). As a result, implementing Ecological sanitation offers a valuable option for human faeces generation, collection, and disposal.

O'Neill (2023) indicated that the South African population is forecast to continuously increase between 2023 and 2028 by 7.8 %, translating to a population of 66.36 million people. Moreover, despite the annual population growth, South Africa is confronted with a water crisis and according to a South African case study on water access, it is reported that the country is inefficiently using 98 % of its natural supply (Terrascope, 2018). Therefore, this study suggests that effective implementation of Ecological sanitation can assist South Africa to conserve water to meet the agreed usage of its water resources. A study by Moosicorn (2010) noted that the old low flush toilet models could use 13 to 26 litres of water per flush, whereas the new low flush toilets use 6 litres per flush. This translates to a saving of 80 000 litres of water per annum for a family of four people. Despite the saving in water usage by the modern low flush toilets, the level of consumption of fresh water is not sustainable, especially in water scarce countries such as South Africa. The use of conventional toilets still posits flushing as the biggest water hog in South African households (SA Water, 2019).

Onabanjo *et al*. (2016:364) reported that the flush toilet is a cost-resource, an energy intensive system, which requires sewer connections for transportation, treatment and disposal of excreta using energy. On the other hand, Langergraber and Muelleggera (2005:434) suggested that vacuum toilets save more than half of water used in the conventional flush system, but most vacuum toilets consume a lot of energy and are complex in their arrangements. Therefore, options such as dry sanitation can be regarded as a solution in terms of excessive use of water and energy resources.

Several studies have been conducted to assess the adoption of Ecological sanitation as a valuable alternative enabling the reuse of human waste either as manure or as input for energy generation. Onojo *et al.* (2013:201) noted that the world's seven billion population can produce about 14 million tons of faeces every day and 25 % of this has the potential to produce approximately 40 000 MW of energy.

The study further suggested that, in India, the population could contribute 6 000 MW to its slow energy creation capacity around the country. In Rwanda, 20 human waste energy-generating plants of 500 kW have been installed, of which 13 of these digesters are located within the large prisons and provide about half of the electricity requirements for cooking and heating in Rwanda prisons (Onojo *et al.,* 2013:201).

Shaver (2015) reported that biogas produced from anaerobic digestion of human faeces in sewage could be worth 9.5 billion US dollars. Similarly, in Washington DC, United States of America, plans are underway to produce biogas from sewage sludge, which will save 13 million US dollars a year, provide 23 000 permanent jobs, and reduce carbon dioxide emissions by 2.3 million metric tons a year (EESI, 2017).

Energy security must be ensured in both rural and urban areas in India due to the country's increasing population and ongoing urbanisation drive, since energy demand has expanded across all domains of life (Mukherjee & Chakraborty, 2016:1). In South Africa, this is also evident through the persistent load shedding whereby the demand for energy has exceeded the supply. In addition, the state President, Cyril Ramaphosa pronounced that the energy crisis in South Africa has been declared a state of disaster and further indicated that amongst the roles of the minister of energy is to identify alternative energy sources that can augment the existing supply (State of the Nation Address, 2023). Therefore, the development of sustainable energy systems is one of the top priorities for global development, the need to ensure energy security through the effective implementation of Ecological sanitation cannot be overly emphasised. Additionally, the increase of urbanisation and growing population in South Africa has drastically influenced the pattern of water consumption, which continues to drive the status quo of water scarcity. Notably, the effective implementation of Ecological sanitation has not been addressed sufficiently, which could be one of the possible solutions to water and energy crises.

Renewable energy studies have been done in South Africa; however, most have focused on the use of cow dung and poultry waste as a mechanism to produce energy through anaerobic digestion (Obileke 2021; Pahla *et al.,* 2017; Manyi-Loh *et al*., 2015). Thus, this study will focus on the use of human faeces, collected by the Ecological Ventilated Improved Pit latrines (EVIP) and estimate the amount of energy that can be generated for cooking and lighting, a concept of onsite re-use of waste.

The approach aims to significantly reduce the environmental impacts, while minimising the use of water and energy, which have been noted as some of the main challenges in South Africa. Ecological sanitation is aimed at closing the nutrient and water cycle while the nutrients from human faeces are returned as a beneficial resource (Drangert, 2004:1). According to Gardner and Peterson (1997:58), Ecological sanitation saves up to at least 20-40 % of the domestic water consumption. Adding water saving devices or recycling greywater to the Ecological sanitation technology makes it possible to save even more water, which alternatively can be used for irrigation and other socio-economic activities.

1.2. Problem statement

Several sustainable sanitation systems have been introduced to reduce water consumption and reuse human faeces. South Africa is a water scarce country, which receives an average rainfall of 497 mm compared to the global average of 860 mm (Winter, 2018). Consequently, the water scarcity status provides a conducive opportunity to reduce the use of flush toilets. In addition, South Africa is facing an energy crisis, which is evident with the persistent electricity load shedding. Moreover, energy production in South Africa is based on coal burning, which produces greenhouse gases emissions and leaves large quantities of fly ash, usually stored in ash ponds or landfills Edokpayi *et al*. (2019).

Leachate from the unlined ash ponds and landfills have a high concentration of heavy metals, which have consequently polluted aquifers for decades or centuries and affect human health through water quality and food production (Edokpayi *et al*., 2019). Due to the lack of water infrastructure in rural areas of South Africa, 74 % of all rural people are entirely dependent on groundwater, thus polluted aquifers endangers lives and rural livelihoods (Goldin, 2021).

Water and energy nexus remains a serious fundamental challenge in most developing countries like South Africa because it is a critical component in the environmental, social, and economic growth, which is pivotal in the country’s development. Most governments globally are developing new and strengthening existing policies to provide adequate, accessible, efficient, and stable access to energy and water as part of efforts to meet the sustainable development goals by 2030. The sourcing of energy from a renewable alternative is considered cleaner and guarantees energy security, with less to zero emissions of greenhouse gases. More so is the provision of improved, adequate, and reliable water supply to the poor.

Moreover, in South Africa, there is drastic decline in the management of sewage water treatment plants, whereby 59 wastewater treatment plants do not meet the requirements and 80 % of South Africa’s freshwater resources are polluted due to the sewage effluent discharge (AfriForum, 2018; Herbig & Meissner, 2019). Various ecosystems can negatively be affected by inappropriately treated and disposed waste. For example, receiving water discharged from wastewater treatment plants could be laden with pathogens, heavy metals as well as excessive nutrients, which could cause eutrophic conditions (Denchak, 2018). Cordova and Knuth (2005:245) noted that waterborne systems, which are centralised or decentralised, regularly leach nutrients and pathogens into water resources. WHO (2023) indicated that black water is highly hazardous as it contains harmful bacteria such as *Escherichia coli* and *Campylobacter*, which affects a person’s digestive system. Moreover, black water contributes to nutrient build-up in ecosystems that result in anoxic aquatic systems, degrading and destroying habitat (EPA, 2021).

Therefore, there is a need to meet energy demands through recycling human waste and reduce the hazardous environmental elements associated with the use of fossil fuels for energy generation. In this research, a strong association exists between energy generation, water conservation and reduced waste load from dysfunctional sewage systems. Thus, sanitation approaches must be resource minded, not waste minded, by introducing the concept of onsite recycling of human waste. Therefore, this study aimed at addressing the following questions:

1.2.1. Research questions

i. How can the EVIP best be managed within the Capricorn District?
ii. Can the effective implementation of EVIP reduce water consumption?
iii. How much energy can be produced from human waste to sustain cooking and lighting?
iv. Can an Ecological Sanitation framework be used to achieve sustainable water consumption and energy production?

1.3. Significance of the study

The study proposes the Eco-WEDS framework, which is focused on two areas: water saving option as well as an eco-friendly digestion method for energy generation. The framework further adopts the EVIP system, aimed at water consumption reduction accompanied with energy generation.

Besides utilising human faeces to produce biogas as an alternative energy source, the concept of reusing faeces will result in less waste material being disposed into the dysfunctional sewage plants, given that 80 % of South Africa's freshwater resources are extremely polluted by sewage effluent (Herbig & Meissner, 2019). The energy produced will also assist with forest preservation as it is estimated that annually, South African households consume a total of 11.2 million tons of fuelwood, representing approximately 40 % of the total energy consumed by households in South Africa (Damm & Triebel, 2008:32). The interest in renewable energy in South Africa is increasing due to the enormous energy demand in the urban and rural areas. The energy crisis being faced in the country is a realistic point to consider other alternatives such as the integration of biogas programs. South Africa is regarded as a country in which water is a scarce resource, which necessitates that it be used prudently (Coetzee *et al.,* 2016).

In 2017, 13.3 million (82 %) households in South Africa were reported to have access to improved sanitation, which included flush toilets connected to a public sewerage (Statistics South Africa, 2018). The Urinary Habitats (2016) suggested that the normal times to urinate is between six to eight times in a period of 24 hours, which translates to using 36-48 litres of fresh water a day to flush urine. Moreover, Moosicorn (2010) indicated that the old low flush toilets normally use 13 to 26 litres of water per flush, whereas the new low flush toilets use 6 litres per flush. This suggests that 80 000 litres of water are saved per annum on the new low flush toilets. Despite the saving in water usage by the modern low flush toilets, consumption of fresh water through flushing toilets can be regarded as unsustainable, especially for a country which is regarded as a water scarce country.

In addition, having cited the environmental issues, it is clear that South Africa needs to reconsider how sanitation is done, in particular, the need to consider Ecological sanitation technology as the dominant form of sanitation provision. According to Langergraber and Muelleggera (2005:433), Ecological sanitation practice is a systemic approach and is grounded on attitude. Guided by Langergraber and Muelleggera (2005:433), in this study, effective implementation is defined as the proper usage, reuse of waste material and the proper management of the EVIP. As such, this study suggests that if the sanitation technology is not well managed it can consequently result to environmental health hazards. Hence, the proposed Ecological Sanitation framework aims to address the issue of excessive water consumption associated with flush toilets and to counteract the projected 17% water deficit in South Africa by 2030, as projected from current usage trends (Makelane, 2020).

1.4. Research aim and objectives

1.4.1. Research aim

The aim of the study is to develop an Ecological sanitation framework for water consumption reduction and energy production in Capricorn District, Limpopo province.

The specific objectives are to:

i. Evaluate the effective implementation of EVIP within the Capricorn District.
ii. Assess the potential of EVIP for reduction of water consumption.

iii. Estimate capacity of human waste to generate sustainable energy for lighting and cooking.

iv. Develop a sustainable water consumption and energy production Ecological Sanitation framework.

1.5. Description of the study area

Figure 1.1 shows the map of the study area. Limpopo province is one of South Africa's nine provinces, situated in the northernmost region of the country (Figure 1A). The Limpopo province is divided into five districts namely: Vhembe, Waterberg, Sekhukhune, Capricorn, and Mopani, which are further subdivided into 22 local municipalities (Figure 1.B). The study area is Capricorn District located between latitude 22°30'0"S; 24°30'00"S and longitude 28°00'00"E; 29°25'4.56"E (Figure 1.C). The province is one of the warmest regions in South Africa with an annual precipitation of 55.48 mm and 81.64 rainy days (weather and climate, 2023). The province has a total population of 6.015 million with 1.641 million households and recorded the highest Human Development Index (HDI) in the country of 0.710 (Stats SA, 2020).

Mining contributes to over a fifth of the provincial economy and approximately 80 % of South Africa's game hunting industry is found in Limpopo (Stats SA, 2020).

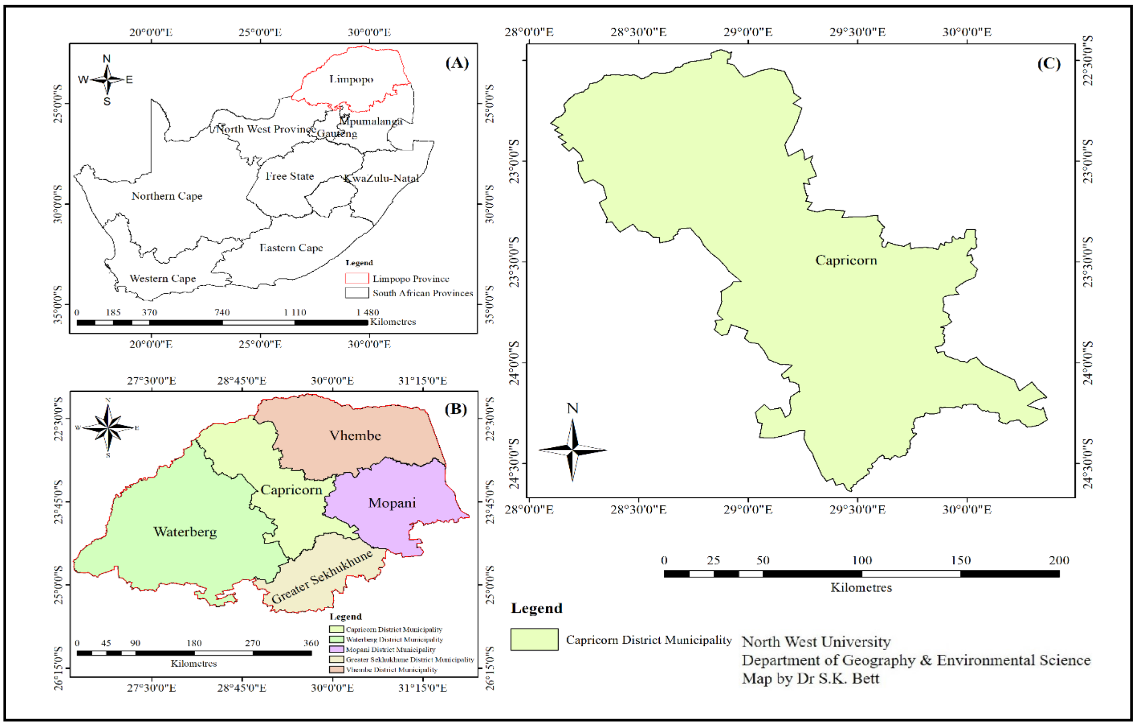

Figure 1.1: Map of the study area, Capricorn District, Limpopo province

The Limpopo province is embedded with water challenges. Reference can be drawn from the City of Polokwane, which had to implement water shedding from 12 February 2020 to cope with demand (Polokwane Local Municipality, 2020). The capacity of Ebenezer and Tzaneen Dams, which provide water for the Polokwane Municipality, have decreased by 40 % since 2019. Moreover, the Department of Water and Sanitation (DWS) issued restrictions on raw water abstraction by 15 %, which forced the Lepelle Northern Water (LNW) board to reduce potable bulk water supply to Polokwane residents (Polokwane Local Municipality, 2020).

In addition, the Limpopo province is lagging behind other provinces in South Africa in terms of access to sanitation and the hygiene practice of washing hands due to lack of water (Stats SA, 2018). As a replacement to pit latrines, the province introduced Ecological Ventilated Improved Pit-Latrines (EVIP) in 2005. The EVIP toilets do not require water or external supply of energy to dispose the waste, making it an ideal facility for a province facing water crisis. This study focused on the Capricorn District in the Limpopo province, which is one of the prioritised regions to install EVIP toilets through the government Ecological sanitation drive.

Furthermore, the study assessed the water consumption rate prior and after the introduction of Ecological sanitation and estimated the capacity of human waste to generate sustainable energy, which informed the integrated Ecological sanitation framework of the study. Thus, insights into Ecological sanitation research vis-à-vis water conservation and energy generation capability provides the much-needed water and energy solutions to most developing countries including South Africa.

1.6. Ethical consideration

The ethical guidelines of North-West University's Mafikeng Campus were followed in conducting this study. Ethical clearance was obtained from the Faculty of Natural and Agricultural Sciences Research Committee with the ethics number 01783-20-A9 (Appendix 5). Authorisation from necessary authorities, including the Department of Education, was acquired to gather data from the schools. Consent to participate in the study was sought and respondents were informed that participation was voluntary and that they could withdraw from participation at any time, without any harmful consequences. Permission to take notes was obtained from the respondents.

The study adhered to research ethics guidelines that upheld participants' rights to confidentiality, voluntariness, and refusal to participate at the individual, institutional, and national levels (Burns & Grove, 1997). The study followed information protection guidelines, and to guarantee participant anonymity, confidentiality, and privacy, numbers were substituted for names on the observation schedules. The observation schedules were kept in a secure location that was locked and only the researcher could access.

1.7. Structure of the thesis

Chapter 1: An overview of Ecological Sanitation

This chapter provides an overview of Ecological sanitation with the aim to highlight its perceived benefits beyond being a sanitation facility. The chapter further illustrates the significance of conducting the study, problem statement that informed the study, research aims and objectives including the hypotheses that guided the study.

Chapter 2: Literature review and the theoretical framework of the study

In this chapter, a review and a comprehensive analysis of existing literature was carried out on the following concepts: Ecological sanitation technologies and models used globally; understanding the ecological sanitation perceived benefits, particularly in terms of reducing water consumption and generating energy; Ecological sanitation theoretical framework and the South African perspective on sanitation.

Chapter 3: The effective implementation of Ecological VIP

This chapter provides the results and analysis obtained from the 108 schools regarding the effective implementation of Ecological VIP toilets, which includes aspects such as condition and usage of the toilet and reuse of human waste. The chapter further unpacks the research method, analysis tool, and the practical techniques applied to achieve the objective.

Chapter 4: The potential of Ecological VIP to reduce water consumption

The chapter outlines the results of the potential water consumption reduction after phasing in the Ecological VIP toilet at the schools. The methods of addressing the objective including the tools of analysis are outlined.

Chapter 5: Capacity of human waste to generate sustainable energy for cooking and lighting

The chapter provides the results on the estimated capacity of human waste collected from the EVIP toilets to generate sustainable energy for cooking and lighting. The methods and analysis used to estimate the energy generated from human waste are explored in detail in this chapter.

Chapter 6: Sustainable water consumption and energy generation Ecological sanitation conceptual framework.

This chapter aims to elaborate on a conceptual framework for sustainable water consumption and energy generation through ecological sanitation. This framework can be used to comprehensively achieve eco-friendly practices in terms of both sanitation facility and environmental and economic benefits.

Chapter 7: Conclusion, Recommendations and Contribution

The chapter provides a conclusion, which summarises the main findings of the study in relation to the research objectives, questions, and the hypotheses. The study’s contribution to the existing body of knowledge is also provided in this chapter. Furthermore, the recommendations for further studies are elaborated in this chapter.

1.8. Chapter summary

This chapter has presented the overview of Ecological sanitation through two focus areas being a sanitation model as well as the perceived benefits relating to water reduction and energy generation. The chapter provided the research problem for this study and the importance of conducting the study by emphasising the research gaps with regards to onsite re-use of human waste, alleviating water resources consumption pressure while generating energy. The chapter also outlined the research questions formulated for this study and provided the structure of the thesis. Chapter two unpacks and reviews the ecological sanitation concepts aimed at gaining a comprehensive understanding of the system as a sanitation facility and a nutrient cycle.

2. CHAPTER 2: LITERATURE REVIEW AND THE THEORETICAL FRAMEWORK OF THE STUDY

2.1. Introduction

This chapter delves into the Ecological sanitation concepts within the scope of Ecological sanitation technologies, models as well as the efficiencies aiming to reduce water consumption and enhance energy recovery. The chapter also discusses the South African perspective on sanitation, focusing on the policy and guiding principles. The concepts and principles of Ecological sanitation are understood by examining the theoretical frameworks, which shapes the notion that informs the Ecological sanitation practice.

2.2. Analysis and review of Ecological sanitation concepts

Ecological sanitation includes a range of models and technologies aimed at sustainable waste management, water conservation, and resource recovery. The global economy is moving from relying on petroleum to a bio-waste approach (Dahunsi & Oranusi, 2013:486). In this context, biological waste, typically considered as having low value, encompassing challenges associated with high-volume waste disposal, is transitioning to a useful natural resource.

The concepts that drive Ecological Sanitation are rooted on the natural processes and have been practiced for thousands of years in China (Jurga *et al.,* 2003:843). In addition, Guadagni (2012) noted that the Ecological Sanitation approach does not promote a particular sanitation technology, but rather a new philosophy in recycling resources, which renders human faeces safe, prevents pollution, and saves water. Esrey *et al*. (1998:6) reported that the flush-and-discharge system has been regarded as an ideal technology, particularly for urban areas, however, Mayo and Mubarak (2015:483) argued that flush toilets are not ideal for water scarce and stressed regions. This was further supported by Te Roopu Taurima and Otahuhu (2015:77) who reported that an individual excretes up to 400 – 500 litres of urine and 50 litres of faeces in a year, which are flushed away using 15 000 litres of fresh water, despite 2.2 billion people worldwide lacking water as a basic need (UNICEF, 2021).

Moreover, Cordova and Knuth (2005:246) suggested that Ecological sanitation is one of the environmental solutions because the disposal of sewage sludge has become a major challenge as landfill space becomes scarce and incineration generates air pollution concerns. Moreover, Werner *et al*. (2003:1) submitted that the Ecological sanitation paradigm drives the notion that human faeces and wastewater from households should be recognised as a resource, which must be made available for re-use. For instance, throughout Africa and Latin America, farmers observed that their most productive fruit trees are located on or close to old latrine sites. In China, for over five centuries, human waste also known as ‘night soil’, is gathered and used to enhance agricultural productivity (Petrik, 1954:207). An observer from suburban America also noticed that the grass is greener near the septic tank (Gabani *et al*., 2014:79). However, Cordova and Knuth (2005:249) reported that those that used the dry toilets in Mexico were not aware of the benefits and were not trained adequately in the operation and maintenance of the toilet, which resulted into the malfunctioning of the toilet, user dissatisfaction as well as inappropriate disposal of human waste.

A study by Dickin *et al*. (2018:140) investigated the use of Ecological sanitation systems in 44 rural communities of Burkina Faso, which was introduced in 2002. The emergence of the Ecological sanitation came after learning that only 7 % of the rural population had access to improved household sanitation, and 75 % practiced open defecation (WHO and UNICEF, 2015). In Burkina Faso, the most widely used Ecological sanitation technology is the double vault urine-diverting dry toilet (UDDT), which has a separate washing area next to the toilet, which allows the users to practice anal cleansing (Dickin *et al*., 2018:141). However, in this case, the focus was to improve soil productivity and reduce food insecurity through reuse of human faeces. The study in Burkina Faso concluded that only 74 % of Ecological sanitation toilets were in use and 26 % were not in use as the toilets did not meet the needs of all residents, especially women, children, and the elderly.

The unmet user needs were attributed to socio-cultural and physical barriers (Dickin *et al*., 2018:145). This suggests that a greater focus on gender equity should be considered when implementing Ecological sanitation technology. In addition, Denoon-Stevens (2016) noted that for Ecological sanitation to be accepted, it is essential that both the poor and the wealthy use it, as this will remove the stigma of dry sanitation being regarded as 'appropriate' for the poor only.

Although religious and cultural factors have been documented as barriers to the adoption of Ecological sanitation, user education and awareness programmes can be used to mitigate such hindrances (Mayo & Mubarak, 2015:491). IRC (2003) also suggested that when introducing a new technology, it is important to identify all possible limitations at the planning stage that could impede on the integration such as religion, culture, and financial constraints. Still and Louton (2012:1) also reported that within the South African context, communities perceive waterborne sewerage toilets as higher status, which creates a desire for the flush toilets. Paradoxically, the flush toilets are perceived as a symbol of political fairness and in turn result in discontentment towards dry sanitation systems.

Ecological sanitation concepts note that the sanitation technology is not a zero-risk solution, but rather an alternative practice to promote a safe and hygienic method of disposing waste, especially in areas confronted with water challenges. The Ecological sanitation also aims to alleviate poverty through nutrient reuse, which in turn contributes to environmental protection. In particular, the waterborne sanitation facilities prevalent in South Africa have led to economic and environmental challenges. However, reviewed studies suggest that Ecological sanitation may offer potential solutions to minimise these challenges and positive scenarios have been noted in the studies conducted by Esrey *et al.* (1998) and Werner *et al.* (2005).

Notably, human waste, particularly faeces collected from dry sanitation systems, have shown a potential to generate energy that can augment the existing power grid and enhance economic development. However, having cited the perceived benefits, studies have shown that culture and religion significantly influence the adoption of new technologies, hindering acceptance. In contrast, awareness programmes and imparting knowledge to the users can shape and inform their perception, ultimately leading to favourable adjustments.

2.3. Ecological sanitation technologies

Ihalawatta *et al*. (2015:786) suggested that sanitation used by humans should be hygienic, safe, easy and eco-friendly. Ecological sanitation technology is a closed system that does not need water and is ideal for regions dogged with water scarcity. The principle of recovery and recycling of nutrients from human faeces to create a valuable resource for agriculture essentially drives this technology (Gupta, 2014).

Conversely, this study supports Andriani *et al*. (2015:219) and Onabanjo *et al*. (2016:364) who suggested that human faeces can also be a valuable resource for energy generation. Over the years, many forms of Ecological sanitation technologies have been developed and tested worldwide. Some of the technologies are the urine-diversion, the ventilated improved double pit latrine, and the Forsa Alterna among others. Denoon-Stevens (2016) noted that these types of sanitation are cheaper, especially when managed at household level, substantially reducing the sanitation provision and wastewater treatment burden on the relevant departments.

2.3.1. Urine diversion technology

Urine diversion is a sanitation innovation that excretes urine and faeces separately without flushing (Rieck *et al.,* 2012). Society for Urban Development in East Africa (SUDEA) drives an integrated Ecological sanitation programme at household level, where urine is diverted, and the faeces are collected and composted with other organic household excretion that can be used as fertilizer for agricultural purposes. For example, in Uganda, the urine-diverting dehydration toilet, also known as Skyloo, has been widely promoted because it has no impact on groundwater, can be built above the ground and enables reuse of urine with minimal health implications (Jackson, 2005:6).

Urine-diverting toilets (Figure 2.1) were also built as an alternative technology of pit latrines at Kisumu region which is located along Lake Victoria. These toilets were built especially in areas where the water table was too high and where the community relied on shallow water wells for their water needs (Water and Sanitation Program, 2005:4). However, the Ecological sanitation technologies in Africa are yet to be widely adopted with the objective of enhancing agricultural production (Jackson, 2005:6).

Figure 2.1: Dry urine-diversion toilet

Source: Water and Sanitation Program (2005)

2.3.2. Ventilated Improved Double Pit latrine (VIDP)

The Ventilated Improved Double Pit latrine (VIDP) (Figure 2.2) was primarily designed to collect, store, and partially treat excreta. The VIDP is more appropriate in areas that face water scarcity and have a low groundwater table. The VIDP should be built in areas with a good breeze to facilitate proper ventilation for the dehydration of the sludge to prevent ground water contamination (Tilley *et al.*, 2008).

In comparison with other toilet systems such as UDDTs, composting toilets, Twin-pits for pour flush, Terra preta toilets, Arborloo or Fossa alterna, EAWAG/SANDEC (2008) and Tilley *et al.* (2008) noted that the treatment processes of VIDPs are limited and need no water to dispose the waste. In Tanzania, the VIDP was designed to allow the contents of one pit to decompose for a two-year period while the second pit is filling up (Jackson, 2005:7). The study further reported that at first, the villagers rejected the VIDP because handling of human faeces was regarded as a taboo (Jackson, 2005:7).

Incidentally, after a villager unwittingly dug into a disused pit latrine, and realised that the decomposed contents are harmless, there was widespread support for the initiative. A social survey concluded that all households with VIDPs use composted faeces in their agriculture activities and continues to be practiced for almost two decades (Jackson, 2005:7). A case study was conducted in Kampala, Uganda, where it was identified that there is high number of users per VIP21, and the toilets were either full or overflowing as they were not regularly emptied (Lüthi *et al.,* 2013). To overcome the challenge, VIDPs were identified as a solution and a project rolled out, supported by Urban Affordable Clean Toilets (U-ACT).

Figure 2.2: Ventilated Improved Double Pit latrine, Kampala, Uganda
Source: Lüthi *et al.* (2013)

2.3.3. Fossa Alterna

Joshi and Morgan (2007) framed the Fossa Alterna as an alternative, waterless (dry) double pit sanitation technology, and dissimilar to the VIDP which was structured to collect, store, and partially treat excreta, the Fossa Alterna is designed to make compost. The Fossa Alterna operates like the Abhor-loo sanitation technology and is used mostly in the Southern African countries. The Fossa Alterna comprises of movable upper structure and slab, which is placed on top of 70 cm pit (Figure 2.3). For the Fossa Alterna, when the first pit is three quarters full, it is covered with topsoil and short-term plants like maize and flowers are planted on the pit (Guzha, 2002:2). Notably, the Fossa Alterna and Arbor-loo toilets work best when the quantities of soil, wood ash and leaves are added periodically to produce balanced compost, whereas Skyloos require some ash to dry the faeces and increase pathogen destruction (Water and Sanitation Program, 2005:3).

The waste is normally left for six months to enable the composting process and after the six months, the rich organic manure is gathered and used for agriculture (Guzha, 2002:2). Consequently, the Fossa Alterna is not appropriate for greywater as the pit is shallow and the conditions must remain aerobic for degradation and it is extremely important that no garbage is thrown into the pit as it will reduce the quality of the material recovered, and in the worst-case scenario, may even make it unusable (Joshi & Morgan, 2007). The Fossa Alterna toilet has been well received in schools in Kisumu, along Lake Victoria (Water and Sanitation Program, 2005:4). Similarly, Shewa and Geleta (2010:1) noted that the sanitation technology was well accepted by the 117 inhabitants from Arba Minch, which is one of the fastest growing towns in Ethiopia.

Figure 2.3: The Fossa Alterna, plants planted on the filled pit

Source: Guzha (2002)

2.4. Ecological sanitation innovation

The novel dimension in sanitation must be centred on ecosystem sensitive ways and the closure of material flow cycles rather than on linear, expensive and energy intensive end-of-pipe technologies (Gupta, 2014). In addition, the new sanitation paradigm is to recognise human faeces and grey water not as waste but as a raw material that has a potential to be used for a more productive purpose (Souza *et al.*, 2020:56). The central principle of ecological sanitation is to wedge the gap between sanitation and agriculture, along with other means of closing flow cycles.

2.4.1. Ecological sanitation systems

The core principles of the Ecological sanitation system are to manage human faeces safely and sustainably and seek to close the loop between sanitation and reusing the waste material, ultimately protecting the environment. Although the recovered material from human waste is mainly used in agriculture, urine as a direct fertiliser and faeces as organic matter for soil improvement, the reuse options within Ecological sanitation are not restricted to agriculture alone, especially taking grey water into consideration (Katukiza *et al*., 2010:56). In addition, Ecological sanitation does not necessarily favour a particular technology but is rather a philosophy in recycling-oriented resource management and brings with it modern, convenient, gender friendly and desirable solutions for all (Trimmer *et al.,* 2020:10449).

2.4.2. Ecological sanitation efficiency in reducing water consumption

Lenton and Thunberg (2000) as well as Van der Ryn (1995) noted that waterless and on-site treatment of excreta systems reduces water supply needs and protect water quality from the high nutrient and pathogen-laden discharges. This is of paramount importance as water is a major limiting factor and South Africa is essentially a water scarce country (Winter, 2018). The proceeding sections discuss some examples of Ecological sanitation technologies that have been developed with the aim of reducing water consumption.

(i) The mechanical vacuum suction system

Ihalawatta *et al.* (2015:788) designed a sustainable Ecological sanitation system known as the ‘mechanical vacuum suction system’. The system is operated manually by using the user’s energy and is designed to reduce consumption of fresh water but collects grey water. Moreover, by making an energy free vacuum system, a sustainable flushing process is achieved. The percentage of water saving attained from a vacuum toilet is about 50 %. Water saving can also be achieved without consuming any electricity (Ihalawatta *et al.,* 2015:788). The system is further designed to separate solid and liquid waste and treating them separately to a state that it can be used for agriculture. The urine is separated initially by a urine diverting system and a special filtering plate, whereas the faeces are flushed using grey water and deposited on the commode walls. Figure 2.4 shows the vacuum suction toilet system.

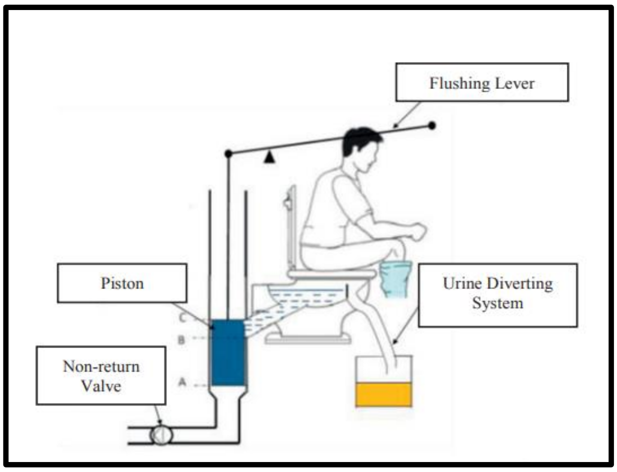

Figure 2.4: The vacuum suction toilet system

Source: Ihalawatta *et al.* (2015)

Water consumption per flush is reduced by introducing both air and grey water as the washing media (Ihalawatta *et al.,* 2015:787). The use of grey water for flushing reduces freshwater consumption as normally one person uses four litres of fresh water per flush (Ihalawatta *et al.,* 2015:790). The mechanical vacuum suction system is more economical as it uses inexpensive waste material for the digestion, grey water for flushing reduces water consumption and ultimately replaces chemical based fertilisers with homemade organic fertilisers, which promotes hygienic and social aspects (Ihalawatta *et al.,* 2015:788).

(ii) Pour and flush toilet

Still and Louton (2012:3) developed a prototype pedestal 'pour and flush' for South African users where the key design principles were based on a model used in Asia (Figure 2.5). The 'pour and flush' toilet was designed considering two critical differences namely: South African users are accustomed to using a pedestal rather than squatting and they use toilet paper or newspaper for anal cleansing, instead of water, which is a standard in Asia. The toilet was manufactured from fibreglass, Still and Louton (2012:4) tested the toilet using a standard protocol for full flush toilets while limiting the flush to 1-2 litres. The analysis further indicated that the toilet used one litre when flushing toilet paper, while using a newspaper necessitated a second flush.

Figure 2.5: Pour and flush toilet
Source: Still and Louton (2012)

The Water Research Commission (2017) supported the initiative as the toilet disposes the human waste with small quantities of water, as little as one litre, which saves more water compared to conventional flush toilets that makes use of six litres per flush. However, this study supports Mayo and Mubarak (2015:483) that such a technology will not be sustainable in regions that are water stricken or lack water supply.

(iii) Double pit pour-flush latrines

In line with the pour and flush toilet, a study by Hussain *et al.* (2017:1) indicated that within the rural area of Bangladesh, the single pour-flush pit latrine which uses one litre per flush is commonly used and the users empty the toilet themselves, posing a risk of health implications. In addition, paying an emptying service or building a new toilet was noted to be costly, hence the solution of a double pit pour-flush latrine which served as a long-term sanitation option. The double pit latrine does not only use 1-2 litres per flush as compared to conventional flush toilets that use 5-6 litres per flush, but the model addresses many of the problems inherent in the single pit latrine design. The system allows the users to divert the waste produced to the second pit and allow the contents from the first pit to decompose, which can be emptied by the user and reuse the waste material with the alternating pit system (Hussain *et al.*, 2017:2).

(iv) Ecological Ventilated Improved Pit Latrine (Enviro loo)

The Ecological Ventilated Improved Pit (EVIP) sanitation technology, also known as Enviro loo, is a waterless system which does not require water to dispose the waste. Previous studies have revealed that one EVIP toilet can save between 300 000 ℓ/y to 650 000 ℓ/y of water (Enviro loo, 2017). The EVIP is built above the ground to prevent the contamination of ground water. The most crucial parts of the EVIP sanitation technology include: toilet lid which should always be closed after use, the ventilation pipe for continuous airflow, allowing the dehydration of the waste, the drying plate which separates the liquid and solid waste, and the black inspection cover which must always face north when constructing the toilet as it allows the radiation process to take place in order to facilitate the evaporation of the urine (Figure 2.6). Notably, urine can contain excessive amounts of ammonia (Schnürer & Norberg, 2008:735). Fricke *et al*. (2007:30) noted that ammonia has shown to be an important parameter when producing biogas and has an inhibitory effect during the production of methane, even at very low concentrations.

Sheng *et al.* (2013:2005) also noted that high concentration of ammonia can act as a strong inhibitor of methanogenesis during anaerobic process. Therefore, this suggests that separating urine from the faeces enhances biogas production.

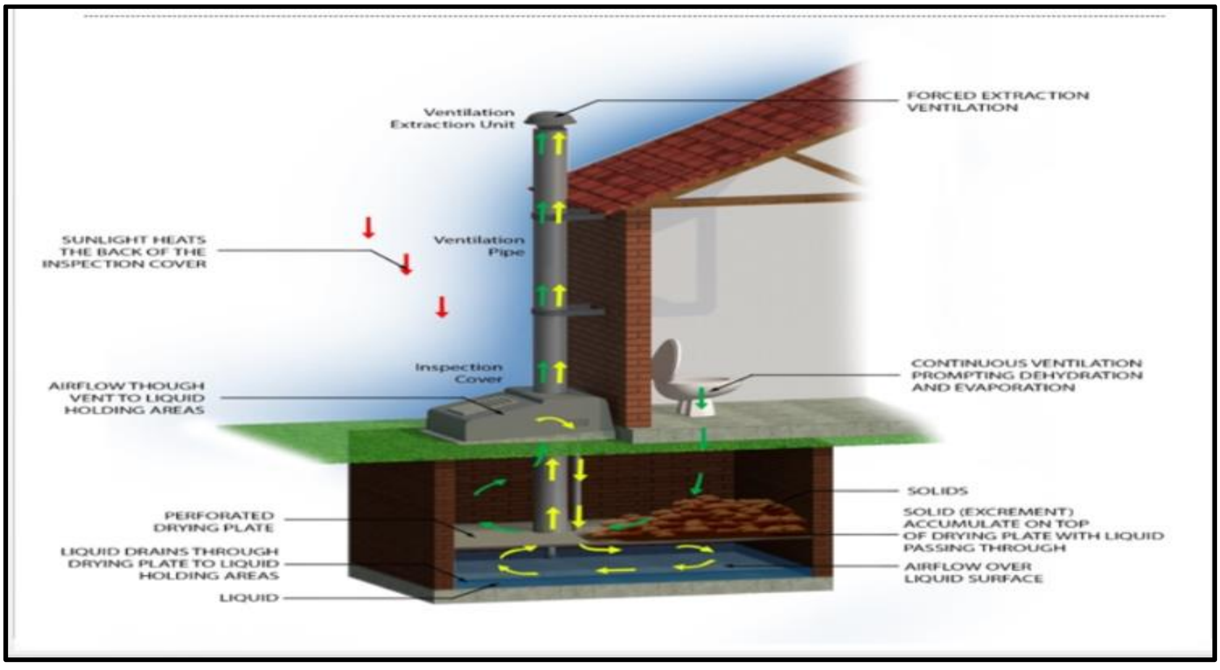

Figure 2.6: Ecological Ventilated Improved Pit (EVIP) latrine

Source: Enviro loo (2017)

When the EVIP toilet is full, the waste is raked into a collection chamber (Figure 2.7). Depending on the usage, the dry waste can be removed at intervals of between six months and three years (Enviro loo, 2017). Due to the ventilation process of oxygen-rich air, the dry faeces do not release any foul smell. In addition, less oxygen and un-interruption of the retention periods, prevents the escape of any odour through the air inlet pipes.

Figure 2.7: Waste collecting chamber, Ventilated pipe and Inspection cover (EVIP)

At the end of the process, the waste is converted to harmless and stabilised material through the stimulated bacterial and biological activity and the waste is reduced to roughly 5 % of its original volume (Enviro loo, 2017). According to Kyle (2015), the global widespread experience has shown that the EVIP is cost-effective, dignified, hygienic and eco-friendly. The EVIP sanitation technology was introduced within schools in the Limpopo Province, South Africa, in the pursuit of meeting the constitutional mandate of providing basic educational infrastructure. Studies have been conducted to understand the user acceptance of the EVIP and the key factors were found to be lack of stakeholder participation and user education, faecophobic communities and social beliefs (Scott, 1998; Tshivhase, 2023). However, little is known about the success of the implementation in terms of both sustained use of the toilet and the reusing of human waste. Therefore, this study focused its analysis on the EVIP sanitation technology as a primary unit of examination.

As depicted in Table 2.1, it was also necessary to draw reference from the Indian plumbing code (2020), which shows that Ecological sanitation reduces 39 % of the load of sewage that needs to be treated. Denoon-Stevens (2016) noted that Ecological sanitation reduces the amount of wastewater that should be treated by the municipality and the number of pipes that need to be maintained.

Table 2.1: Ecological sanitation and sewage load reduction

No. of persons	**Normal scenario**	**Scenario when using eco-sanitation**
Water treated at Sewage Treatment Plant (STP) for one (1) person.	135 Litres	30 Litres
Water treated at Sewage Treatment Plant (STP) one thousand (1 000) people.	13 500 Litres	3 000 Litres

Source: India Plumbing Code (2020)

2.5. Models of Ecological sanitation as a beneficial concept

According to Mukherjee and Chakraborty (2016:15), there are several different paradigms for handling human waste that are based on the biogas system. These models are based on the given nature of feedstock used in the biogas plant including processes such as the solid content of sewage being dried, enhanced, and used. A study by Mukherjee and Chakraborty (2016:15) proposed a model from Singapore; the Singapore Model developed by Residues and Resource Reclamation Centre (R3C) (Figure 2.8) at Nanynag Technological University (NTU). The toilet separates liquid from solid waste, and the bioreactor is used to produce biogas from the solid waste, including kitchen waste, that can be used for cooking. The disadvantage of the technology is that it requires constant refurbishment and cleaning while the collected feedstock is channelled into a safety tank.

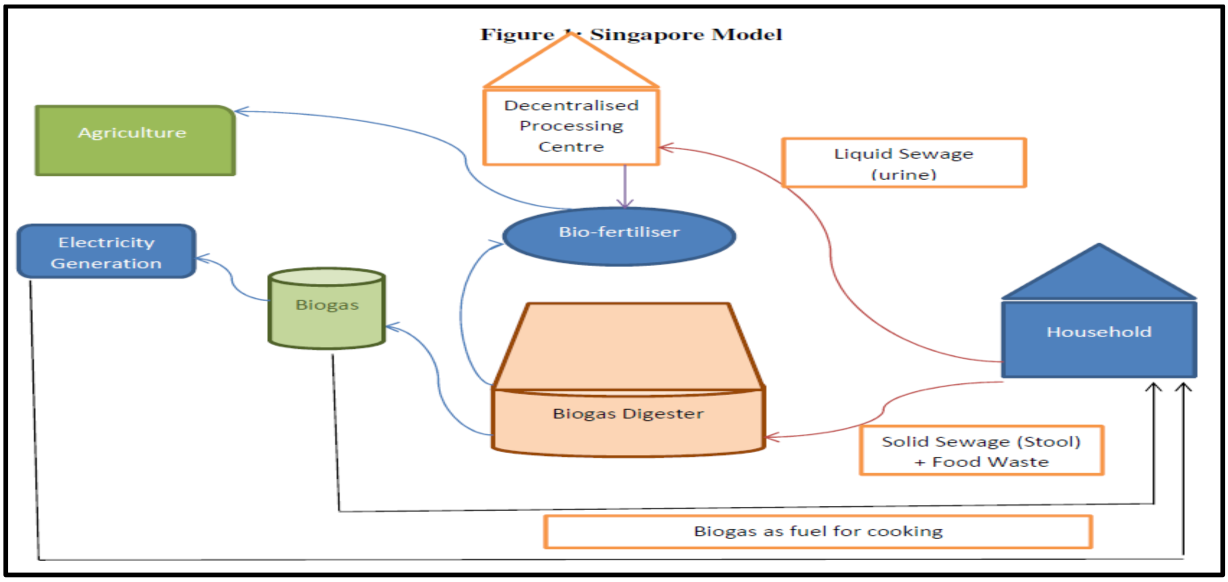

Figure 2.8: Singapore Model: Biogas (through digester)

Source: Mukherjee and Chakraborty (2016)

An alternative arrangement, prevalent in numerous Swedish cities, demonstrates how both liquid and solid waste from the toilet is gathered and directed towards Sewage Treatment Plants (STPs) for preliminary treatment (Figure 2.9). To generate biogas, the biogas digester is fed with the degradable organic waste from houses and the solid sludge produced in STPs. Electricity is produced using the biogas. Nevertheless, this model requires the STPs for initial treatment process which may not be feasible in rural areas. According to Mukherjee and Chakraborty (2016), this is because of low population density or a lack of infrastructure for sewage collection and sufficient logistical plans for getting to STPs.

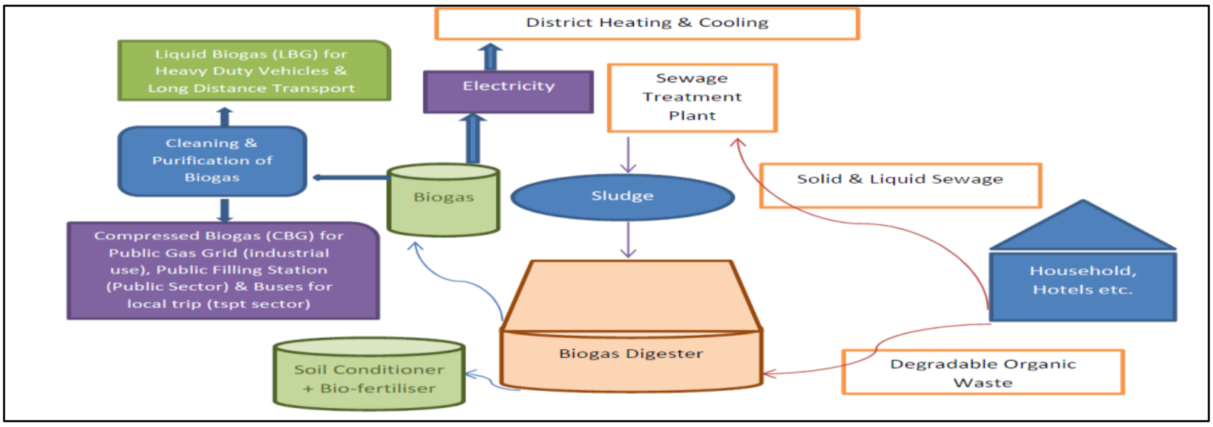

Figure 2.9: Swedish Model: Biogas (through digester)

Source: Mukherjee and Chakraborty (2016).

According to Rostmark and Oberg (2013), the Swedish model II directs the liquid and solid waste from toilets toward condensation through freezing and thawing before it is burned to provide combined heat and power. Steam is supplied for industrial usage, and the electricity produced is used for heating or cooling (Figure 2.10). This model's drawback is that sewage must be frozen and melted before it can be burned, which is an expensive procedure for areas with temperate climates and most developing nations (Rostmark & Oberg, 2013).

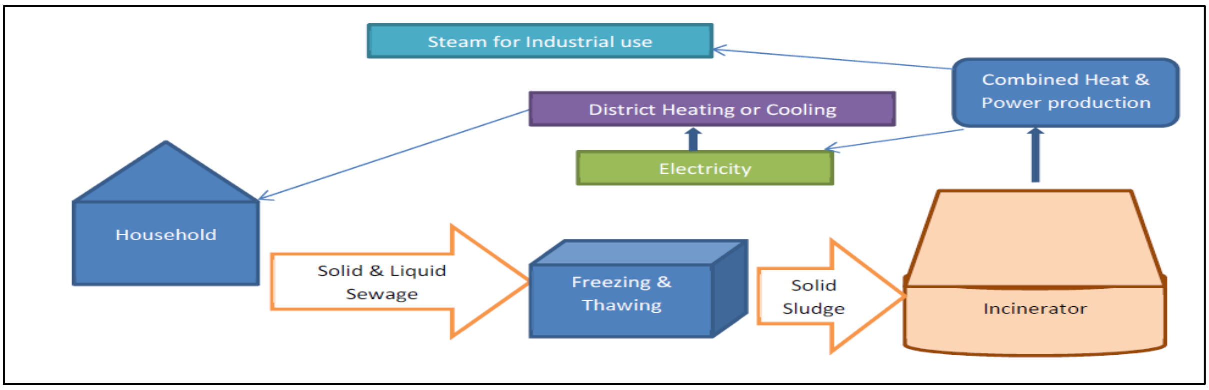

Figure 2.10: Swedish Model II - Incineration after freezing and thawing

Source: Rostmark and Oberg (2013).

According to Ganiron (2015:82), in Germany, as per Figure 2.11, greywater and black water is collected and treated separately, the vacuum toilets only use 0.7 litres of water per flush and the undiluted black water is collected and co-treated with shredded organic waste through the anaerobic digestion process after a thermal sanitisation. The generated biogas is used for heating and power generation where the digested sludge is used within the agriculture activities and further stored for the ploughing season (Ganiron, 2015:82). In addition, rainwater is harvested through small gutters on the ground surface and infiltrated by a swale system for flushing purposes.

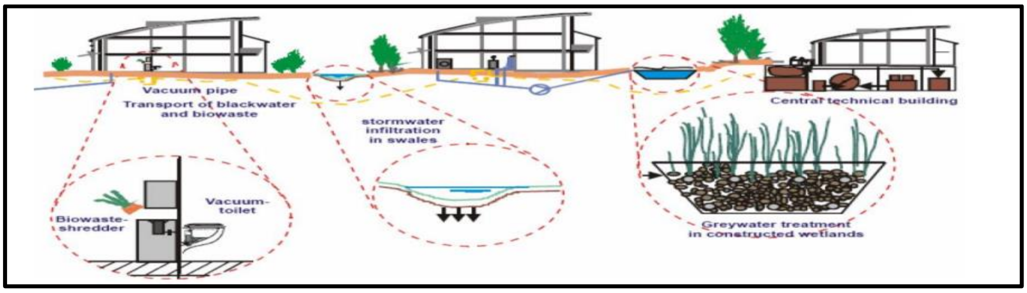

Figure 2.11: Ecological sanitation model in Germany
Source: Ganiron (2015)

In the Tlokwe Local Municipality, South Africa, sewage from the primary and secondary water treatment is collected for anaerobic digestion and before the sludge enters the digesters, the sludge is sifted and thickened to a dry solids content of up to 7 % (Figure 2.12). This process prevents high energy consumption for heating due to the extreme water content (Ferry & Giljova, 2015:2). The sludge is channelled into the anaerobic continuously stirred tank reactors where digestion takes place, and the mesophilic temperature is usually between 35 °C-39 °C. Within the retention time of around 20 days, microorganisms are broken down and the organic matter that is contained in the sludge produces biogas, which comprises of methane, carbon dioxide and trace gases (Ferry & Giljova, 2015:2). The biogas is cleaned and converted to bio methane through the combustion chamber to generate electricity and the digested sludge is further used in agriculture. This suggest that such a model may be well suited in regions where users utilise flush toilets and the wastewater treatment plants are fully functional, unlike in South Africa where AfriForum (2018), Herbig and Meissner (2019) noted that 59 wastewater treatment plants are dysfunctional, polluting almost 80 % of the country's freshwater resources.

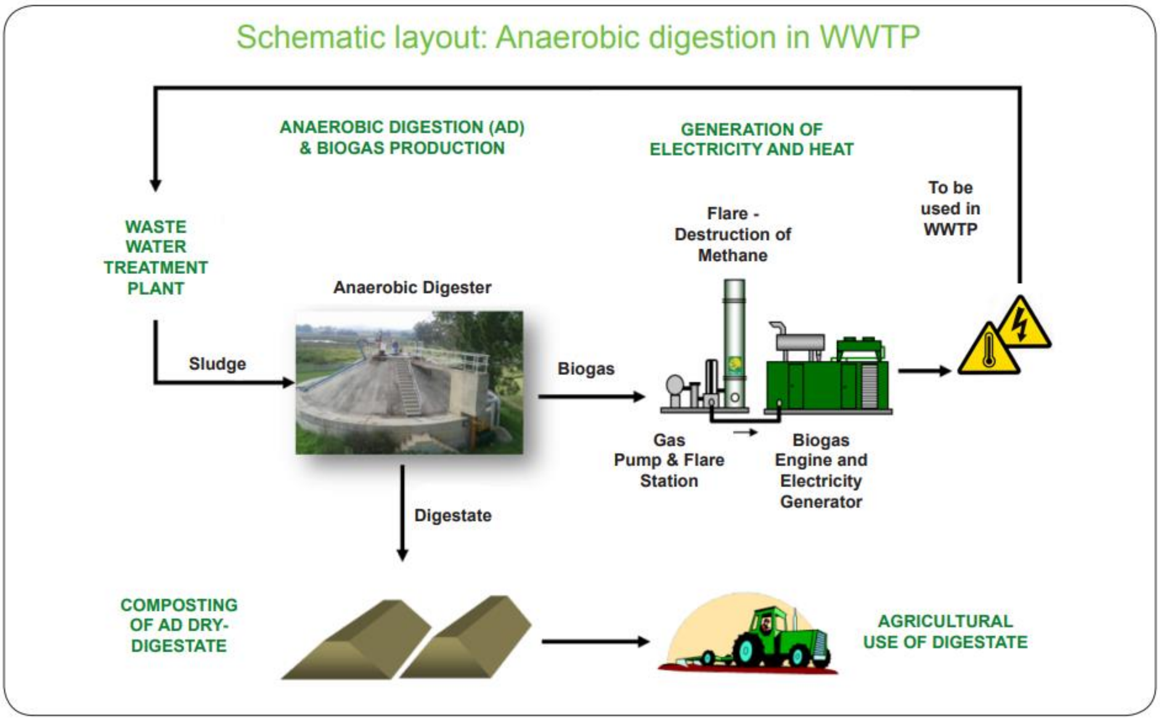

Figure 2.12: Anaerobic digester at the Tlokwe WWTW, North-West, South Africa

Source: Ferry and Giljova (2015)

2.6. Ecological sanitation and energy production

Ensuring energy security for both rural and urban areas has become a key concern due to population growth and continuous urbanisation (Mukherjee & Chakraborty, 2016:13). In 1700, Boyle and Hale noted that flammable gas was released by disturbing the residue of streams and lakes and they first reported scientific interest in the gas generation by the natural decomposition of organic matter in the 17th century (Zeb *et al*., 2006:49). In 1808, Sir Humphrey Davy determined that methane was present from cattle manure during the production of gas (Cruazon, 2007). Within this context, this study focused on the potential of energy generation from the human waste collected from the EVIP toilets.

It is an established fact that methane gas is a major product of anaerobic digestion of human waste and the combustion of this gas can also be used to generate electricity (Onojo *et al.*, 2013:199). The study conducted by Onojo *et al.* (2013:201) presents an approach of estimating the amount of electricity that can be generated from a specified amount of human waste. When microorganisms digest organic material including human faeces, animal waste, and plants in the absence of oxygen through anaerobic digestion, a gas is released consisting of 60 % methane and 40 % carbon dioxide. This gas is referred to as biogas and it may be used as a cooking and heating agent. For example, in Indonesia, huge population and unequal deployment of electricity supply became a strong reason in developing biogas from human faeces and the main use of the biogas is for cooking and generating electricity (Andriani *et al.*, 2014:220).

A study by Mudasar and Kim (2017:97) focused on human faeces to examine the potential to produce biogas. The study concluded that fresh human faeces, when 80 % of the sample is waste with a sample weight of 0.35 m^3/kg of biogas, produces 26.8 kWh of power under mesophilic temperature conditions. The study further suggested that power generation is optimal when a ratio of 8:2 faeces to water weight sample is employed and the feeding is applied every fifth day. If continuous feeding is given on every fifth day the biogas produced would be 0.7 m^3/kg, resulting in 60 kWh (Mudasar & Kim, 2017:98). Moreover, Colón *et al*. (2015:57) suggested that human faeces can produce 0.35–0.5 m^3 /kg biogas.

The analysis by Onojo *et al.* (2013:202) gathered data from a students' hostel pit toilet at the Federal University of Technology, Owerri, Nigeria. The results concluded that the available biomass waste per day was 3.66 tonnes and the biogas accruable bi-monthly was 154.76 m^3/kg, which can run a 5kW biogas generator for six days. The study further showed that people living in countries with flush-toilets and running water produce a huge quantity of wastewater daily. Waste from such countries is full of organic compounds that store usable energy in their chemical bonds and several methods can be executed to generate electricity (Onojo *et al*., 2013:202). For example, methane can be extracted through anaerobic (oxygen-free) digestion or produce electricity using microbial fuel cells (Onojo *et al.*, 2013:202).

2.6.1. Potency of biogas production from human faeces

Mukherjee and Chakraborty (2016:10) investigated the potential for recovering nutrients and energy from human faeces. Table 2.2 shows a guideline of substances needed to create biogas as well as their percentage contribution to the mix. Methane and hydrogen, two of the elements of biogas that are combustible gases, are combined with carbon dioxide and nitrogen, two inert gases (Yadav & Hesse, 1981). In addition to animal waste, human faeces are a rich resource that can be used as fertilizer and a source of energy (Schuster-Wallace et al., 2015:13). Poocheera *et al*. (2014:1105) also reported that human faeces can produce biogas.

Table 2.2: Composition of biogas

Substances	Symbol	Percentage (vol. %)
Methane	CH_4	50-70
Carbon dioxide	CO_2	30-40
Hydrogen	H_2	5-10
Nitrogen	N_2	1-2
Water Vapour	H_2O	0.3
Hydrogen Sulphide	H_2S	Traces

Source: Yadav and Hesse (1981)

Several methods have been developed to estimate the amount of biogas generated from human faeces. Equation 2.1 shows the Buswell equation (Banks, 2014):

$C_{450}H_{2050}O_{950}N_{12}S_{1}$ Equation 2.1

According to the Buswell equation, total of dry human faeces is equivalent to 30 grams of dry matter:

Dry matter (kg) = Total amount of faeces (TF) kg × 0.3

Dry matter (DM) kg × Carbon (C) kg C= Carbon of dry matter (COD) kg C

COD × Carbon biodegraded (CB) 60% = Carbon Converted Biogas (CCB) kg C

Buswell equation methane (CH4) is 53 %

Weight of methane (C CH_4-C) kg C CH_4 = CCB × C CH_4 × 16/12 (Conversion ratio between carbon and methane).

Therefore, one mole of an ideal gas will occupy a volume of 22.4 litres at STP (Standard Temperature and Pressure) and 16 g of C CH_4 is 22.4 litres.

CCB (g) × CH_4/16= C CH_4Moles

C CH_4 Moles × 22.4 = litres of C CH_4

MJ/day = litres of C CH_4 × 22 or kWh/day = MJ/day/ 3.60

Therefore, using the Buswell equation, Andriani *et al.* (2015:224) estimated that the methane produced from 2500 kg/day of human faeces is 106.85 m^3C CH_4. The calorific value of 22 MJ/m^3 and the mega joules unit of 3.60 MJ equates the energy yield of 106.85 m^3 produced from human faeces to 2,350.7 MJ/day or 652.97 kWh/day. The study concluded that the potential biogas generated from human faeces is sustainable considering the large population of Indonesia. Based on the Buswell equation, the potency of biogas from human faeces that is possible to be generated in Indonesia is depicted in Figure 2.13.

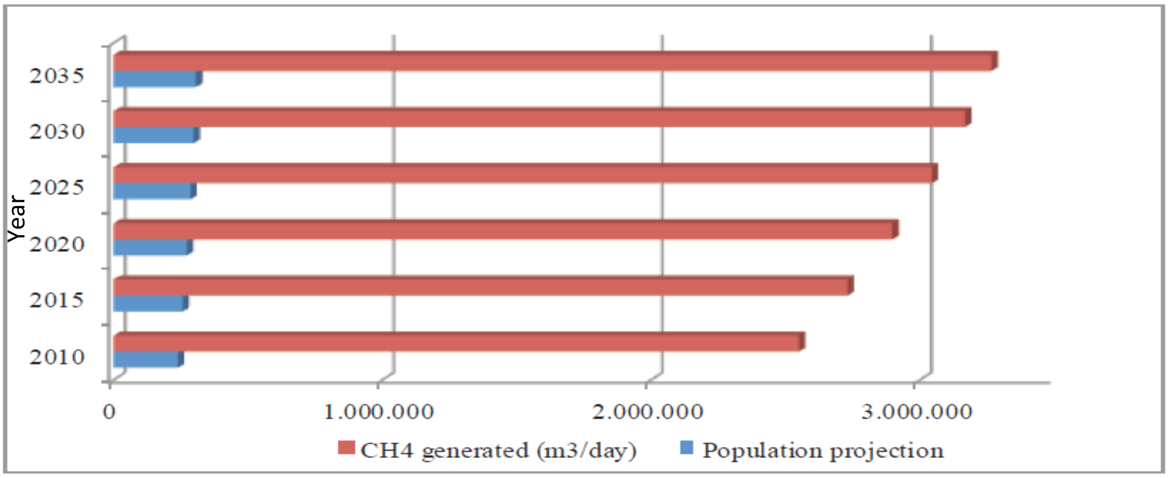

Figure 2.13: Population projection in Indonesia from year 2010-2035 and potency gas generated (m3/day)

Source: Andriani *et al*. (2015)

Onabanjo *et al*. (2016:364) investigated the suitability of human faeces as a feedstock for gasification, using a thermodynamic equilibrium model (TEM) which quantified the recoverable energy potential from human faeces and explored the optimal routes for thermal conversion (Figure 2.14). The study observed that the maximum recoverable energy from the human faeces was 15 MJ/kg when the gasifier was operated at optimum equivalence ratio of 0.57 (Onabanjo *et al*., 2016:367). Ptasinski *et al.* (2007:568) as well as Shabbar and Janajreh (2013:755) noted that the ability of the TEM to calculate the gas production at given operating conditions has enabled the estimation of the energy recovery potentials from different biomass feedstocks.

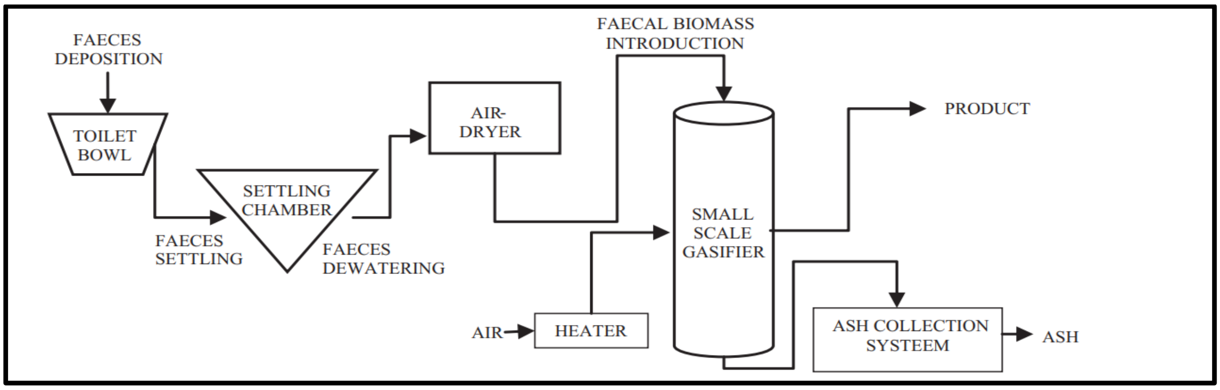

Figure 2.14: Flow process of the faecal biomass

Source: Onabanjo *et al.* (2016)

2.6.2. Biochemical Methane Potential (BMP)

Biochemical Methane Potential (BMP) is a laboratory test used to determine the potential methane production from organic materials including organic waste in the absence of oxygen. Filer *et al*. (2019:1-29) provided guidelines on performing the BMP test conducted under controlled conditions to simulate the anaerobic digestion and the organic material mixed with inoculum which acts as a catalyst. The mixture of the substrate and inoculum is stored and sealed in reactors and kept at specific temperature conditions, either mesophilic which is between 35-40°C or thermophilic which is 50-55°C, and this depends on the conditions of the actual biogas production system. The biogas and methane produced is monitored daily for a period of 30-90 days, depending on the biodegradability of the substrate.

This study adopted the BMP procedure to estimate the amount of biogas and methane that can be produced from the human waste collected from the EVIP. Remigi and Buckley (2006) also noted that the BMP test is valuable in evaluating the energy potential and efficiency of organic materials for biogas production. In addition, the BMP test is crucial when designing and optimising biogas production systems, as well as evaluating the feasibility and sustainability of utilising organic waste as a means of renewable energy.

2.7. Ecological sanitation theoretical framework

A theoretical framework provides a structure of relationships to understand the associations that exist between various concepts and ideas, including the influence or impacts (D'amour *et al.*, 2005:116). Ekane *et al.* (2016:6) reported that when developing a sanitation framework, it is crucial to acknowledge that social, cultural, economic, political, legal, and environmental conditions differ from country to country, which also results to potential variations in policy response. Based on the study conducted in Rwanda, Uganda, and Tanzania, Ekane *et al*. (2016:25) noted the differences of translating the frameworks for sanitation practices. As a result, it was recommended that there is a need to develop different sanitation frameworks due to the distinctiveness of the countries. Additionally, Ekane *et al.* (2016:6) further stated that there is no blueprint when developing sanitation frameworks.

However, Elledge *et al.* (2002) proposed specific essential factors that a comprehensive framework should arguably contain to provide an enabling framework for effective action. The factors include target groups, human and environmental implications or benefits, legal framework, vision, and ambitions supported by financial commitments roles and responsibilities of both users and implementers. These factors were also supported and explored by WEDC (2005) who evaluated the sanitation frameworks in developing countries such as Bangladesh, Cambodia, Ghana, Indonesia, and Mozambique. Some of the key findings from the WEDC (2005) evaluation include the distinctive requirements of the target groups/users such as the urban poor which were not adequately specified, and the environmental challenges were not considered, thereby hindering the effective action. The specific essential factors include:

- **Target groups**: Who is the sanitation technology being developed for and why?
- **Human and environmental implications/benefits**: What are the human and environmental implications/benefits when developing the sanitation technology?
- **Legal framework**: Does the sanitation technology acknowledge the existing legal framework for effective action?
- **Vision and ambitions supported by financial commitments:** Is the sanitation technology and programs backed by the appropriate financial budget for sustainability purposes?
- **Roles and responsibilities of both users and implementers:** Are the users and implementers inclined to their roles and responsibilities and enhanced through awareness programs?

Schübeler *et al*. (1996:17) developed a conceptual framework for solid waste management and four contexts were established. The effectiveness and sustainability of the solid waste management highly depends on the established contexts:

- **Socio-cultural context**: The efficiency of a solid waste management system is influenced by how waste is handled and underlying attitudes. These factors are shaped by peoples' social and cultural context. Nonetheless, initiatives aimed at providing programmes, knowledge and skills can improve the behaviour of people.

- **Political context:** The existing relationship between local and central governments whereby citizens engage in the public processes of policy formulation.

- **Economic context:** The level of economic development plays a significant role as it informs the willingness and ability to pay for a particular level of service.

- **Environmental context:** Environmental health conditions can be exacerbated by the pollution of ground and surface water by leachates from unlawful waste disposal. Uncontrolled disposal of waste is a breeding ground for vector diseases.

From the works by Ekane *et al*. (2016), WEDC (2005) and Schübeler *et al.* (1996:17), it is emphasised that the Ecological sanitation framework cannot be universally applied, and it is not readily available as a pre-packaged solution. When considering the implementation of such a framework, it is important to consider the prevailing social, cultural, economic, political, legal, and environmental conditions. These factors are crucial in developing and implementing a successful Ecological sanitation framework.

In this context of Ecological sanitation, a structured approach is adopted to comprehend and evaluate the diverse variables and concepts involved in achieving a sustainable Ecological sanitation practice. The basis of Ecological sanitation is to holistically address wastewater management in a manner which is cost effective and integrate ecological factors into a system which encourages resource conservation and recycling. To conceptualise the sanitation framework, the following aspects are of significance as proposed by Langergraber and Muellegger (2005:435) and modified by Shonde (2016:16) (Figure 2.15):

Technological aspect: The sanitation technology should be appropriate for the users such that it is user friendly and meet the needs of the users, especially in terms of hygiene.

Nutrient cycle: Human excreta and grey water collected by the sanitation technology is recognised as a resource, which must be made available for reuse.

Waste management: The system is an alternative method of managing waste, with the aim to reduce environmental risks and enhance economic development.

Economic development: One of the main principals is the resource recovery which can be either used for agricultural practice or energy generation for economic development.

Community acceptability: Providing the users with information about the sanitation technology enables them to make informed choices and encourages them to accept the new technology.

Water conservation: The idea which informs the sanitation technology is the minimal or no water usage when disposing the waste.

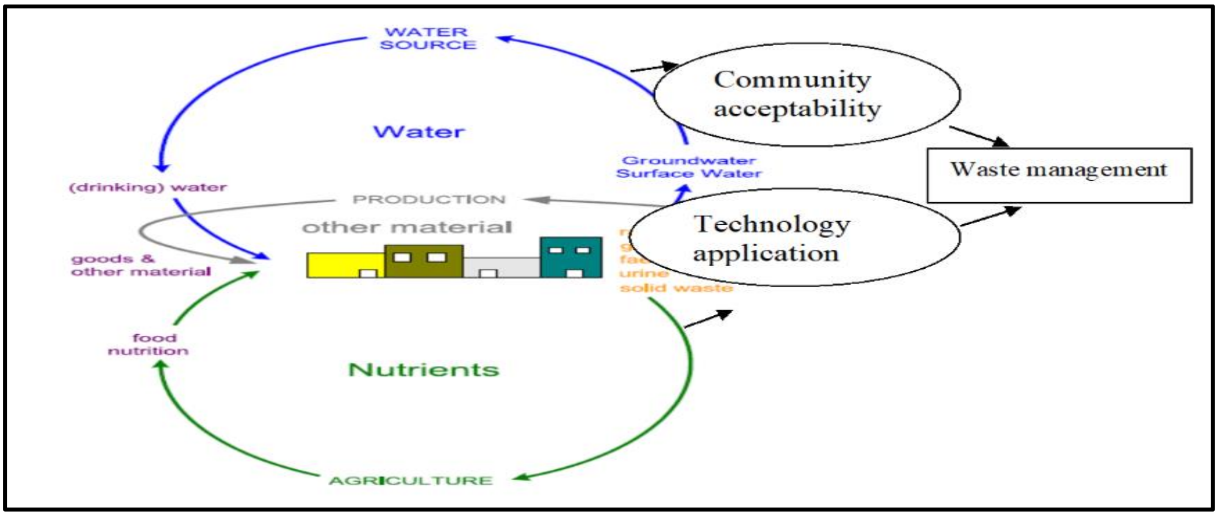

Figure 2.15: Ecological sanitation conceptual framework

Source: Shonde (2016)

According to Langergraber and Muellegger (2005), Ecological sanitation paradigm is resource minded and represents an inclusive concept towards ecologically and economically sound sanitation, whereby the underlying aim is to close the gap between sanitation, resource use, and agriculture. Langergraber and Muellegger (2005) further indicated that the Ecological sanitation concept regards human faeces as a resource and is usually processed on-site and then reused for agricultural purposes, whereas conventional sanitation systems treat human faeces as waste material. For an Ecological sanitation system to work, all the components such as the natural environment, society, occurring processes, and the device for defecation must be considered together (Werner *et al.*, 2003:963).

On the other hand, Werner *et al.* (2003) suggested that Ecological sanitation is an alternative approach to avoid the disadvantages of conventional wastewater systems, whereby the nutrients are removed from the human faeces. Moreover, human faeces and water from households should be recognised as a resource not as waste, which should be made available for re-use. Werner *et al.* (2003) reiterated the importance of the following concepts of Ecological sanitation:

- Reduces the health risks related to sanitation, contaminated water, and waste,
- Reduces pollution of surface and groundwater,
- Prevents the degradation of soil fertility and
- Optimises the management of nutrients and water resources.

Within the sanitation concept, the Ecological sanitation paradigm is based on ecosystem approaches and the closure of material flow cycles as depicted in Figure 2.16. Andersson and Minoia (2016), Esrey (2001) as well as Shonde (2016) also stated that Ecological sanitation systems are designed to recover nutrients and the organic matter found in human faeces for safe agricultural reuse. Moreover, according to Langergraber and Muellegger (2005:435-441), the concept of Ecological sanitation offers an alternative to flush and discharge systems and can further be a solution to the poor sanitation infrastructure in many areas worldwide, more especially in developing countries. Langergraber and Muellegger (2005:435-441) support Werner *et al.* (2003) that human faeces and grey water from households should be seen as a resource and not as waste material.

Therefore, the Ecological sanitation concept is a holistic approach towards sanitation, and it is focused on the idea of reusing the nutrients (Langergraber & Muellegger, 2005:435). Furthermore, Ecological sanitation aims at minimising hygienic risks and protects the environment by preventing human faeces from contaminating water sources, food, and the environment (Huuhtanen & Laukkanen, 2006:7). Jewitt (2011:613) added that one of the main concepts of Ecological sanitation is the saving of water, which enables more water to be diverted to agriculture activities.

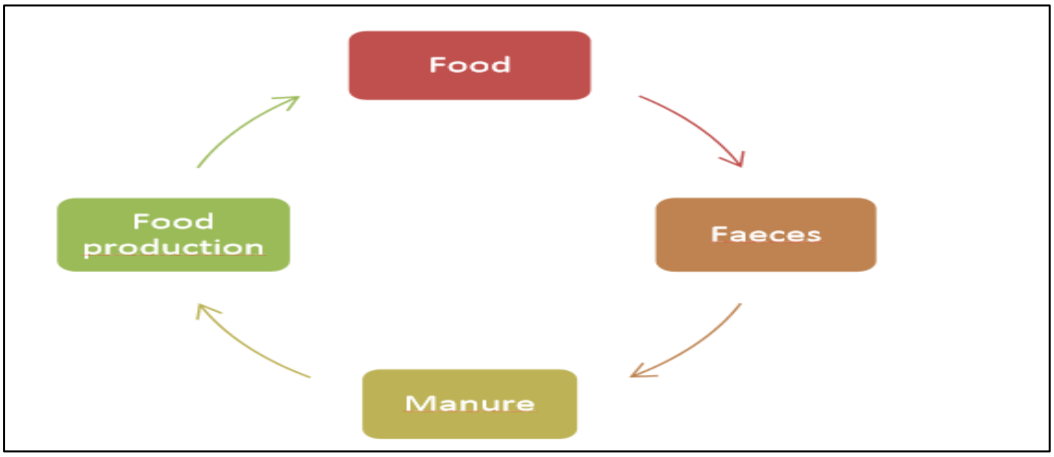

Figure 2.16: Principle of nutrient cycle, based on the Global Dry Toilet Association of Finland

Source: Huuhtanen and Laukkanen (2009)

2.8. South African perspective on sanitation

According to the Green Paper (1996), environmental policy has a crucial role in meeting the development needs of people in the new democratic South Africa. Sustainable development requires the sustainable use of natural resources and protection of the environment in which people live in. A review on sanitation related policies from nine countries noted that only South Africa, Mozambique and Ghana consider VIP as their minimum sanitation standard (Nakagiri *et al*., 2015:6). Given the critical environmental issues in South Africa, there is a need to reconsider the practice of sanitation in the country to satisfy the environmental policy.

The right of access to basic sanitation services is enshrined in the Constitution of South Africa (1996), Section 24(a), which stipulates that everyone has the right to an environment that is not harmful to their health or well-being. According to the Constitution, municipalities have the role to ensure the realisation of this right (Constitution of South Africa, 1996). According to the Water Research Commission (2010), well-constructed VIP toilet has led to the promotion of this technology as a solution for meeting the basic sanitation service needs of households that are without basic sanitation infrastructure. According to the National Sanitation Policy (1996), the minimum acceptable level of basic sanitation includes the safe removal of human waste, sustainable operation of the facility, and removal of wastewater from the premises if necessary.

Moreover, the National Sanitation Policy drafted in 1996 did not promote sanitation technology innovation, as the focus was on VIP technology and waterborne sanitation systems. In contrast, the 2016 National Sanitation Policy noted that the economic value of sanitation by-products should be recognised, and the reuse of the organic material should be encouraged. The sanitation policy additionally stresses out that sanitation extends beyond the provision of toilets, but rather entails a comprehensive approach that encompasses institutional and organisational frameworks, along with financially, technical, environmental, social and educational considerations. In addition, the 2001 White Paper on Basic Household Sanitation suggests great emphasis on the need to adapt to integrated environmental management approach with special reference to solid waste disposal.

In the Eastern Cape, the Urine Diversion Sanitation (UDS) Technology was piloted by the CSIR in 2006 (Duncker *et al*., 2006). The toilets provided were well received by most of the users. The primary reasons cited was the absence of odours, waterless disposal of the waste and the potential utilisation of faeces for compost (Duncker *et al*., 2006:86). Therefore, the implementation of dry sanitation can be one of the notable solutions in South Africa as the sanitation technology will satisfy the National Sanitation Policy and the White Paper.

2.9. Chapter summary

This chapter has provided a comprehensive analysis and reviewed relevant literature to enhance the understanding of the Ecological sanitation concepts, particularly in relation to technologies and perceived benefits. The understanding has been shaped by the theoretical framework and the South African perception of sanitation. Having reviewed the concept of Ecological sanitation, the next chapter explores the effective implementation of EVIP within the 108 sampled schools with the objective of gaining insight of whether the sanitation technology is viewed beyond a sanitation facility.

3. CHAPTER 3: EFFECTIVE IMPLEMENTATION OF EVIP

The opening section of this chapter offers insights into sanitation standards and provides an overview of their influence on sanitation practices. The method used to answer the research question is outlined, focusing on the following key concepts: reuse and benefits of human waste, condition of the toilet, induction, and the assertiveness of proper usage. The chapter concludes by discussing results on the effective implementation of the Ecological VIP toilets in schools. In addition, this chapter explores whether the Ecological VIP toilets introduced at the schools satisfy the inclusive concept of Ecological sanitation.

3.1. Introduction

Within the South African sanitation sector, there is a growing emphasis on reduction, re-use, recycling, and recovery of waste. However, these concepts have not yet been fully adopted within the sector. The National Sanitation Policy Draft of 2016 advocates that economically viable and sustainable waste materials should be recycled for further use and for environmental benefits (National Sanitation Policy, 2016). In addition, Tissington (2011:6) alluded that there is a need to clarify the roles and responsibilities within the hygiene and user education sector when it comes to waste management, because the discrepancy leads to the lack of awareness by the locals. Hygiene and user education are often carried out with little planning or focus. The implementation of new sanitation technologies is reportedly hindered by the lack of insight into the public's willingness to utilise them (Poortvliet *et al*., 2018:90; Nkusi & Wang, 2018: 758). This indicates that the absence of public involvement during the introduction of new sanitation systems can impede their acceptance, rendering the sanitation technology ineffective and frustrating.

According to Water Wheel (2005:24), users perceive Ecological Sanitation as a temporary and alternative form of sanitation primarily meant for the poorest individuals, as they are accustomed to relying solely on waterborne sanitation facilities. There is little public sensitisation about the environmental benefits of Ecological sanitation, as such the system continues to be recognised as a structure rather than a beneficial nutrient cycle.

Evidently, schools in the Capricorn District in Limpopo regard the technology as a sanitation structure instead of viewing it as an economic and ecological resource. To ensure effective implementation, comprehensive communication and engagement enable the end user to feel a sense of ownership, thereby promoting the necessary change and technology adoption.

According to De Groot and Steg (2009:61), sanitation campaigns often do not promote sustainable behaviour because they fail to include environmental benefits while focusing on egoistic considerations. Jonah (2007:20) stated that cultural barriers are some of the factors reduce the acceptability of Ecological sanitation approach. Many end users are faecophobic and usually react with disgust when informed about the reuse of human faeces in agriculture (Rwabigene, 2002:7). Therefore, adequate support and advice to end users will enable a cultural environment that is favourable for effective implementation of Ecological sanitation technology. For instance, in Mulanay Municipality, Philippines, an Ecological Sanitation system was introduced to the community, along with the associated roles and responsibilities, through a consultation meeting with relevant stakeholders. This engagement produced favourable outcomes. (Ignacio *et al*., 2018:3).

According to the study conducted in Kabale, Western Uganda, for a new system to be successful, it is crucial that at least 80% of the intended users possess the necessary knowledge (Tumwebaze *et al*., 2011:299). Such findings provide valuable insights for policy makers in achieving the sixth Sustainable Development Goal (SDG) (clean water and sanitation for all) and promoting the sustainable development of Ecological sanitation. Several studies highlighted that the significance of end users' acceptance of new technology, their perceptions of risks and benefits, as these factors play a pivotal role in determining the effectiveness of the technology. (Hurlimann, 2007:85; Van Dijk *et al*., 2017:277).

In addition, when discussing the topic of sanitation, considerations of hygiene and health implications are crucial factors, especially for decision-makers, to ensure the success of the new technology. Bolderdijk *et al*. (2013:83) stated that communication about environmental benefits of new sanitation technology is motivational for individuals who have a strong biospheric background.

The lack of water and sanitation in Limpopo province schools has been making headlines since 2012 constituting a significant barrier to high quality teaching and learning (Section 27 Spotlight on school sanitation, 2012). In the 2012-2013 financial year, a budget of R997 million was allocated to eliminate bucket and pit toilets in schools in Limpopo, replacing them with ecological VIP sanitation systems (Department of Education, 2012). However, some schools had been using the new sanitation technology. In total, 148 schools in the Capricorn District are using the ecological VIP sanitation system. The introduction of ecological VIP toilets in schools aligns with the Ecological Sanitation approach, which emphasises resource sustainability and promotes inclusive, ecologically, and economically sound sanitation. The primary goal is to bridge the gap between sanitation, resource utilisation, and agriculture.

3.2. Materials and methods

3.2.1. Research design

Implementation of Ecological VIP toilets in Capricorn District was evaluated using the quantitative method approach. Quantitative data were collected using a closed-ended questionnaire and the elicited information included the description and condition of the toilet, usage of the waste material, proper usage of the toilet, and the perceptions of re-using human waste (Appendix 1). Cross cutting information related to factors influencing the use of human waste as a beneficial resource was solicited.

3.2.2. Sampling procedure

Inclusion and exclusion criteria

A random sampling method was used to obtain a representative respondent sample of schools from the Eco-schools list. The school setting was used as a case study as the EVIP toilets are already set and operational. For key informants, purposive sampling was used to identify the officials responsible for the water and sanitation programme in the schools. The main goal of purposive sampling is to focus on characteristics of a population that is of interest to answer the research question.

Sample size

The sample size was derived using RAOsoft statistical software (2004). Accordingly, from the 148 schools in the Capricorn District using the EVIP system, data were collected from 108 schools (5 % margin of error and response distribution of 50 %). Equation 3.1 shows the formula used to calculate the sample size (n), given the population size (N), and a margin of error (e):

The formula is $n = N/(1 + Ne^2)$ Equation 3.1

Where:

n = sample size

N = population

e = margin of error

Since the confidence coefficient is 95 %, the margin of error is 5 %.

n = 148 / (1 + 148 (0.05) ^{2}

n = 148 / 1.37

n = 108 schools

3.2.3. Data sources

Survey interviews

To determine the effectiveness of Ecological VIP in Capricorn District in Limpopo, a structured and closed ended questionnaire was administered to the 108 schools. The questionnaire (Appendix 1) was administered to the schoolmaster or individuals who are responsible for the school sanitation. According to Busayo (2023), self-administered surveys reduce the chances of bias, producing socially desirable responses. In addition, self-administered surveys allow the researcher to gather data from many respondents spread over a wider geographical area. Self-administered surveys were a good choice for this objective.

Questions 1-13 of the questionnaire were based on the school's point of view (SPV), which included the description and condition of the toilet, reuse of waste, proper usage of the toilet, and the human benefits of the toilet. Questions 14 and 15 were formulated to gauge the respondent's personal opinion (POR) regarding the consumption of crops fertilized with human excrement, as well as their belief in the potential harm to crops when utilising human waste as a fertilizer. Where the response is based on personal opinion, the POR abbreviation was used. Only one (1) respondent answering questions 14 and 15 in the negative, stating that "*I will never consume crops that used composted human excrement and crops can be killed when fertilised with human waste*".

Generally, the key issues raised in the questionnaire included duration and condition of the toilet, perception of the use of human waste including its benefits, induction and assertiveness of proper usage and source of energy. To ensure proper understanding, the researcher administered the questionnaire. The condition of the toilets was verified using the observation guide (Appendix 1). The observations included the basic parts of the EVIP toilet such as the lid, inspector cover, ventilation pipe, drying plates, and toilet roof.

In addition, three key theories that underpin sanitation management were also used as a guide to fully understand the key factors that affect sanitation practice. The combination of the three theories were advocated by Mensah (2020), who suggested that they provide a solid understanding for effective sanitation management.

The theories include behavioural change, participation, and systems of change. The key variables of the behavioural change are that attitude influences behaviour, thinking and belief shapes attitude and behaviour, informed knowledge increases awareness which influences behaviour and attitude. Participation theory focuses on empowering stakeholders and the involvement of the ultimate beneficiaries such that they take ownership of the intervention, making it sustainable. On the other hand, the systems theory discourages compartmentalisation, and the key principle is to ensure that all components of a system (including stakeholders) are in sync to attain the intended objective.

The Knowledge-Attitude-Behaviour change theory, which explains how knowledge, attitudes, and behaviours are interrelated and how they impact on an individual's action was used to also understand the sanitation practice within the schools.

3.2.4. Data analysis

Collected data were captured by using Microsoft Excel for preliminary analysis. Thereafter, the data were imported into Statistical Package for Social Scientists (SPSS) software for further analysis. The statistical procedures used included descriptive statistics (frequencies, means and standard deviations). A Chi-square test was used to measure the correlation between variables. According to McMillan (2008), Chi-square determines relationships between two independent variables that report frequencies of responses or cases. Chi-square inquires whether what the investigator observed is significantly different from what the investigator would have expected to get by chance alone (Nardi, 2006). In this study, Chi-square test was used to calculate significant differences of the perception of respondents.

The following variables were tested: the relationship between the condition of the toilet and the duration of the toilet, the induction, and the number of toilets.

Factors associated with the number of toilets were also tested to determine relationships between the; number of toilets and the reusing of waste, induction and the method of waste disposal used when the toilet is full. Lastly, the factors associated with the duration of the toilet were also tested, which include relationships between; duration and reuse of human waste, induction, and the method of waste disposal when toilet is full, and perception on the reuse of human waste.

3.3. Results and discussion

3.3.1. Duration and number of EVIP toilets usage

Findings of the survey in Table 3.1 show that, out of the 108 schools, 59.3 % of the schools have 6-10 EVIP toilets, while 28.7 % have 11-15, 8.3 % have 0-5 and 3.7 % have more than 15 EVIP toilets. Most of the schools (43.5 %) have been utilising the toilets for 3-6 years, followed by 42.6 % who have been using the EVIP's for 7-9 years. In addition, only 8.3 % and 5.6 % have been using the EVIPs for 1-2 years and over 10 years respectively.

Table 3.1: Number and duration of usage of EVIP toilets

	Frequency	Percent
Number of EVIP toilets		
0-5	9	8.3
6-10	64	59.3
11-15	31	28.7
>15	4	3.7
Total	108	100
Duration of EVIP toilet/s use		
1-2 years	9	8.3
3-6 years	47	43.5
7-9 years	46	42.6
≥10 years	6	5.6
Total	108	100

3.3.2. Conditions of the EVIP toilet

Upon inspecting the toilets, damaged/missing items were noted (Figure 3.1). From the sampled schools, results show that the most frequently damaged/missing item on the toilets was the drying plate (23 %) and the least damaged/missing item was the roof of the toilets (9 %) (Figure 3.2). All the 108 schools involved had at least one toilet with a damaged/missing item. Jonah (2002:31) noted that the users' attitudes towards Ecological sanitation system are also attributed to the responsibilities that come with the operation and maintenance of the system.

A similar study was done in the Makhado Local Municipality in South Africa, 35 schools were assessed and, in each school, at least one item of the EVIP toilet was vandalised and the act of vandalism was attributed to the unruly behaviour of the learners (Tshivhase, 2016:37). Enforcing a monitoring and evaluation system, such as regular checks by the relevant organisations, is necessary to prevent partial or complete collapse of the systems. Awareness and incentive programs that aim to change people's perceptions and therefore alter their behaviour should also be launched.

In support of the knowledge-attitude-behaviour change theory as argued by Matthews and Riley (1995), when a person is more informed about environmental sanitation, it influences their attitude and behaviour towards upholding acceptable sanitation practices. Tshivhase (2016: 23) observed that the dilapidated condition of the toilet could potentially lead to the toilet being abandoned, resulting to users resorting to historically inadequate poor methods, posing health risks and environmental pollution. Therefore, the reported state of the toilets undermines the fundamental concept of Ecological sanitation, which aims to minimise pollution and health hazards.

Figure 3.1: Damaged drying plate, inspection cover, and ventilated pipe and broken toilet lid

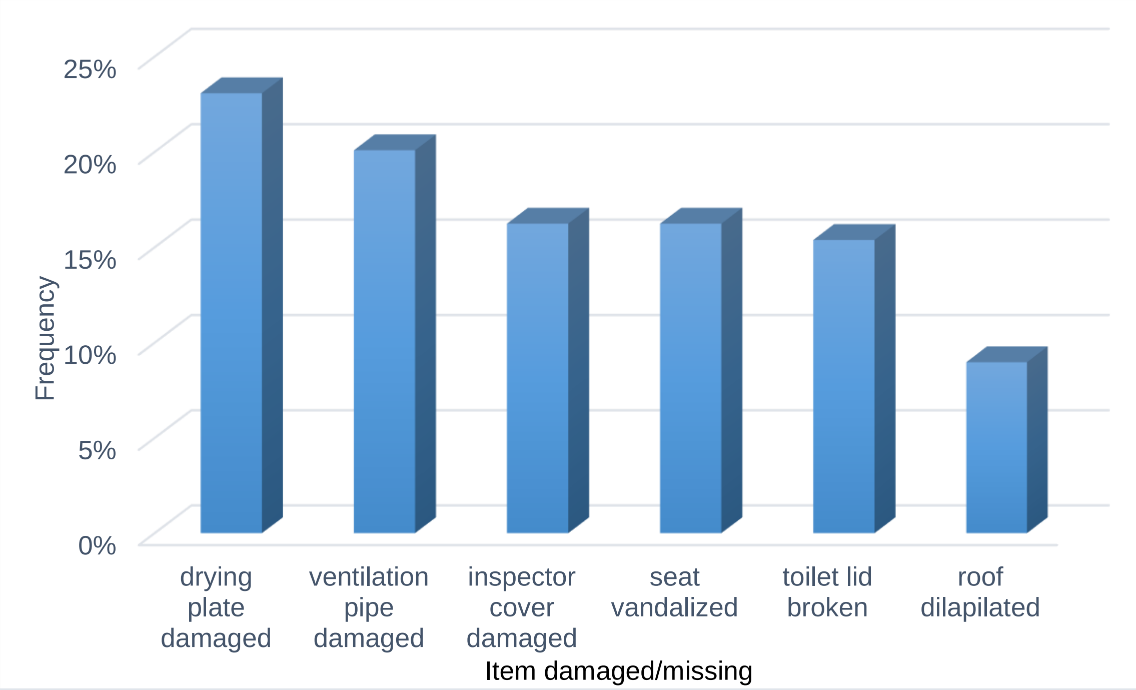

Figure 3.2: Condition of the EVIP toilets

3.3.3. Availability of school garden and source of energy for cooking

Table 3.2 shows that most of the schools have a garden (75 %) while 25 % indicated that they don't have a school garden. When asked what source of energy the school uses, 48.1 % indicated that they make use of gas stoves, 31.1 % use wood and 20.8 % use electricity for cooking as all the schools have a feeding scheme. These results mask some significant gaps, particularly given the green economy concept which the country has put in place. South African households continue to consume 40 % of fuelwood annually (Damm & Triebel, 2008). Moreover, with the persistent electricity crisis, such energy cannot be relied on, hence the need for alternative means.

Table 3.2: Availability of vegetable gardens and source of energy for cooking at schools

	Frequency	**Percent**
Vegetable garden		
Yes	81	75
No	27	25
Total	108	100
Source of energy for cooking		
Electricity	22	20.8

	Frequency	Percent
Gas stove	51	48.1
Wood	33	31.1
Total	106	100

3.3.4. Induction and asserting proper use of EVIP toilet

In terms of receiving induction prior to using the sanitation technology, 58.3 % of the schools indicated that they were inducted while 41.7 % were not. In addition, of the 45 schools that were not inducted, 53.3 % further indicated that they use common sense for operation of the toilet, 28.8 % contacted a knowledgeable person, and 17.7 % ignored proper usage (Table 3.3).

Table 3.3: Assertiveness of proper usage

	Frequency	Percent
Common sense	24	53.3
Contact those with knowledge	13	28.8
Ignore proper usage	8	17.7
Total	45	100

Results depict that the purpose to provide sanitation was achieved but there is a user education gap, which could impact proper use of the dry sanitation within the schools. Wilkinson *et al.* (2014) reported that the main obstacle to effective implementation is the lack of clarity on the roles and responsibilities of various stakeholders in terms of management and monitoring, which has affected the sanitation services in South Africa.

The findings of this study confirm the White Paper on Basic Household Sanitation (2001) in pointing out that there is a lack of public understanding of the critical connections between user education, sanitation, and health. The National Sanitation Policy (2016) also pointed out a gap in the policy, assuming that end-user education is a component of hygiene education rather than explicitly addressing it. Nkusi and Wang (2018:758) noted that the community development officers in Rwanda did not participate in the planning and implementation of the Ecological sanitation project, which eventually resulted into the poor utilisation of the new sanitation system.

However, continued information dissemination and education resulted into an increase in the number of households that embraced the project. On the other hand, according to Cordova and Knuth (2005:252), users in Mexico were not actively engaged in selecting the sanitation technology that could have been easily tailored to their individual lifestyles. Moreover, they were not informed about the potential for incorporating dry toilets into their homes, which acted as a significant barrier to user acceptance. User-hygiene education and awareness programmes must be developed together when introducing new sanitation technologies and servicing the projects. This is because end-users are likely to accept responsibility and ownership for a sanitation programme if they are involved. Evidently, a positive progress of attitude was picked up by Heikkilä *et al.* (2012:9) at Msunduza in Swaziland and at Embangweni, which is a rural area in Malawi, after an awareness programme of dry sanitation. Citizens in Malawi showed an unprecedented interest in Ecological sanitation technology as the benefits were thoroughly communicated and farmers became enthusiastic advocates for Ecological sanitation, which is now self-promoting within the area (Water and Sanitation Programme, 2005:9).

With regards to emptying the toilet when it is full, 46.3 % of the schools indicated that they contact the Department of Basic Education (DBE) to come and empty the toilets, which indicates an unwillingness to empty the toilets. However, 31.5 % of the schools mentioned that they remove the waste themselves, 14.8 % pour acid whilst 6.5 % indicated that they pour water and 0.9 % do nothing when the toilet is full (Table 3.4).

Table 3.4: Actions taken by schools when toilet is full

	Frequency	**Percent**
Contact DBE[1]	50	46.3%
School removes	34	31.5%
Pour acid	16	14.8%
Pour water	7	6.5%
Do nothing	1	0.9%
Total	108	100.0%

[1]DBE = Department of Basic Education

According to Matsebe and Duncker's study (2005:1), 86% of those who used urine-diversion toilets refused to empty their toilet containers. Similarly, research by Jonah (2002:31) revealed that the end users were irritated by the need to remove and empty the toilet's full containers on a regular basis. Therefore, most of the end-users found that Ecological sanitation toilets require more attention than flush toilet.

3.3.5. School perception on the reuse of human waste

In terms of reusing the human waste material, 99.1 % of the schools indicated that they do not reuse the waste whilst 0.9 % reuse the waste (Table 3.5). As noted in this study, 41.7 % of the schools were inducted, however, the low reuse rate suggests that they were not fully informed and integrated in terms of the environmental and nutrient recovery benefits of the sanitation technology. It is, therefore, not surprising that 99.1 % of the schools do not reuse the waste.

Table 3.5: Reusing waste material from EVIP

	Frequency	**Percent**
Reuse of waste from EVIP		
Yes	1	0.9
No	107	99.1
Total	108	100
Reason for not reusing		
Not hygienic	51	47.6
Not aware	48	44.8
Religion	5	5.4
Cultural	3	3.2
Total	107	100

With regards to reasons for not reusing the waste, 47.6 % of the schools indicated hygiene reasons while 44.8 % are not aware that the waste can be used as a beneficial resource. Religious and cultural reasons for not reusing waste were cited by 5.4 % and 3.2 % of the schools, respectively (Table 3.5). These findings are consistent with those of Duncker *et al*. (2006:20), who concluded that Ecological sanitation technology was accepted as a toilet but not as a technology where the waste material could be recycled as a beneficial resource.

The findings are also aligned to Nkusi and Wang (2018:765), who observed culture and religion as the major hindrances to the adoption of Ecological sanitation toilets and the reuse of human waste. Therefore, in the context of sanitation, choices and behaviour are usually deeply rooted in cultural knowledge and religious beliefs (Tshivhashe, 2016:18).

Generally, the handling and reuse of faeces is considered a taboo, while eating food fertilised with human waste is considered a major challenge. In Northern Cape, South Africa, end-users indicated that the disposal of human faeces should be the responsibility of the local municipality and households should not be handling or reusing human waste (Duncker *et al.*, 2006:20). In the case of Indonesia, the use of human waste material for biogas generation was noted as a potential of reducing environmental problems and electricity supply (Andriani *et al*., 2014:220).

Whereas in Mulanay, Philippines, Ignacio *et al. (*2018:18) indicated that the community members will adopt the sanitation technology if the water conservation benefit is guaranteed and the collection of human faeces and nutrient reuse for food production are the least priorities.

Heikkilä *et al. (*2012:7) indicated that locals of Msunduza in Swaziland had difficulties in understanding the concept of dry sanitation. However, results of a study conducted with the local leaders revealed that the participants seemed to be knowledgeable of the sanitation technology, including the reuse of the waste material within the agricultural sector and many advocated that natural fertilisers could be even better than commercial ones (Heikkilä *et al.*, 2012:5).

In this study, 47.6 % of the schools perceive that handling and reusing human waste is unhygienic, which presents a huge barrier for the reuse of human faeces as a complimenting resource. As such, more education and practical training on composting, handling of the waste material and its beneficial use is needed.

3.3.6. Perception of re-using human waste

Ecological sanitation is being investigated by numerous African governments and agencies, however, the most important consideration when evaluating the possibility of more sanitation technologies is the level of acceptance, as indicated by the willingness to invest in or adopt the technology (Water and Sanitation Programme, 2005:1).Early social- psychologists emphasised that sanitation technology acceptance and management is attributed to an individual's perception of excreta and social structure (Mensah, 2020).

In this study, the personal perception of the respondent (POR) of reusing human waste was explored and 78.7 % disagreed that human waste has benefits for humans while 20.4 % agreed and 0.9 % indicated that they don't know. Table 3.6 shows that 22.2 % agreed that human waste can be used to fertilise soil in a vegetable garden, whereas 75.9 % disagreed and 1.9 % indicated they don't know. In addition, the results show that 41.1 % of the respondents are of the view that crops can be killed when fertilised with human waste, 21.5 % disagreed and 37.7 % indicated they don't know (Table 3.6). A study conducted in Dzivarasekwa, Zimbabwe, revealed that while community members prefer to buy vegetables, they will not eat vegetables that have been fertilized by human faeces (Guzha, 2002:6). Additionally, results of this study further indicated that 87 % disagree that human waste should be used for energy generation, while 12 % agree, and 0.9% were not aware.

Table 3.6: Personal perceptions of using human faeces

	Agree		Disagree		Don't know		Total	
	Count	%	Count	%	Count	%	Count	%
Human waste has benefits for humans	22	20.4	85	78.7	1	0.9	108	100
Human waste should be used for energy generation	13	12	94	87	1	0.9	108	100
Human waste can be used to fertilize soil in vegetable garden	24	22.2	82	75.9	2	1.9	108	100
I will never consume crops that used composted human excrement	71	66.4	4	3.7	32	29.9	107	100
Crops can be killed when fertilized with human waste	44	41.1	23	21.5	40	37.4	107	100

The negative perception about the reuse of human faeces for agriculture could be attributed to lack of knowledge. For example, a study by Guzha (2002:7) noted that households did not use urine as a fertiliser because they were of the view that it would burn crops. Duncker *et al*. (2006:23) noted that the households disposed of the urine in a soak pit as they were not aware that it had benefits.

However, previous studies have documented that urine contains macronutrients such as nitrogen, phosphorus, and potassium, hence a plausible alternative fertiliser for crops (Jönsson, 2001:1; Winker *et al*., 2009:4090). Similarly, the Swedish Environmental Protection Agency (2002) also noted that human urine contains adequate nutrients to satisfy crop needs and can replace mineral fertilisers. An empirical study by Filling (2018:25) revealed that non-diluted human urine is as good a fertilizer as chlorophyll fluorescence, the leaf area and weight results were noted compared to the other treatments.

Besides knowledge, this study has revealed that hygiene (65.9 %), cultural (16.8 %) and personal (18.9 %) reasons are the drivers of non-use of human faeces (Table 3.7). This could be attributed to households' fear of bad odour and infectious diseases (Balamurugan *et al*., 2013:1). However, recycling human waste offers a variety of benefits, such as the production of alternative energy and nutritional advantages, making it a more practical choice than purchasing pricey inorganic fertilizers.

Although the results in this study do not indicate the significance of religious attributes in terms of reuse, other studies have highlighted the existence of barriers to reuse human waste are related to religious and socio-cultural factors (Andersson & Minoia, 2017:184; Mariwah & Drangert, 2011:817; Nawab *et al*., 2006:238; Uddin *et al*., 2014:885).

Table 3.7: Reasons for not using human waste as fertilizer or energy source

	Hygiene		**Cultural**		**Personal**		**Total**	
	Count	%	Count	%	Count	%	Count	%
Fertilizer	51	60.7	16	19	18	21.1	85	100
Energy generation	62	65.9	16	16.8	18	18.9	94	100

3.4. Chi-Square correlation analysis

3.4.1. Factors correlating with EVIP toilet conditions

Based on the optimal EVIPs, the study sought to identify the condition of EVIP toilets in the schools which participated in this study. Six elements of the EVIP were observed using an observation guide (Appendix 1). The elements included: drying plate, ventilation pipe, inspector cover, toilet seat, toilet lid, and toilet roof. A perfect toilet with no item missing was assigned a score of 1 and the least perfect with all five items missing a score of 5. The study used Chi-Square analysis to determine the relationship between the variables. For example, cross-tabulations were done for the condition of the toilets and the school's duration of using the EVIP toilets, the condition of the EVIP toilet and the school being inducted on how to use the EVIP toilet, and the condition of the toilet and the number of EVIP toilets at the school (Table 3.8). Chi-Square ($\chi 2$) and p-values of the correlations are shown to explain the relationships between the variables. For this study, the p-values were considered statistically significant at 0.05 level of significance.

The hypotheses tested were: (1) the condition of EVIP toilets is affected by the duration the toilets have been in use, (2) schools which have been inducted maintain the toilet better and (3) the condition of the EVIP toilets is dependent on the number of toilets at the school. It is expected that schools with more toilets struggle with maintaining the toilets and where induction took place, the conditions of the toilets should be better. Results are presented in Table 3.8.

Table 3.8: Factors correlating with EVIP toilet conditions.

	Chi-square	Df	p-value
Duration of use	19.004	9	.025*
Was the school inducted	5.727	3	.126
No. of EVIP toilets	11.315	9	.255

df=degrees of freedom, *statistically significant

Table 3.8 shows a significant association between duration of EVIP toilet use and the toilets condition $\chi 2$ (df=9, n = 107) = 19.004, p = .025, thus the null hypotheses that the condition of EVIP is not dependent on the duration that the toilets have been in use is rejected. The older toilets were likely to be in a better condition than new ones (Table 3.9). The 7-9 years category has the lowest mean score (M=3.09 SD=±0.55) which suggests that the toilets within this duration range are in a better condition. Drangert (2004:8) noted that users are cautious and adapt to technology overtime while in use so that the usability and maintenance is well understood. Therefore, this study adopts the concept of "experience overtime induces adaptation, proper usage and maintenance". The longer a user is inclined to a sanitation technology, coupled with attaining experience on the usability, the technology is well maintained.

Table 3.9: Duration and conditions of the EVIP toilets

Duration of EVIP use	Condition of toilet (average score ± standard deviation)
1-2 years	3.22 ± 0.44
3-6 years	3.23 ± 0.48
7-9 years	3.09 ± 0.55
<10 years	3.17 ± 1.17

On the other hand, no association was found between the schools receiving induction on toilet use and the condition of the toilets χ^2 (df=3, n= 107) =5.727, p = .126 and also there was no significant association between number of toilets at the schools and the conditions of the toilets χ^2 (df=9, n =107) = 11.315, p = .255 (Table 3.8). In that case the null hypotheses that the condition of EVIP toilets is determined by whether the school was inducted or not and the number of EVIP toilets at a particular school were accepted (Table 3.8). Generally, it is expected that schools that have been inducted on how to use the EVIP toilet should be in a better if not the best condition. This is supported by Heikkilä *et al.* (2012:4) where the study reported that thorough user education yields positive results as the concepts are understood better and the adoption and maintenance of the technology is easier.

Mayo and Mubarak (2015:490) argued that user education should not be relegated to implementation, rather, users should be involved from the initial planning stage so that the technology is not only imposed to the user. Involvement of the end-users at the planning stage introduces the ownership of the technology and such an approach will result in better maintenance of the technology. Ecological sanitation is still a relatively new, approach, therefore, this study supports Mayo and Mubarak (2015:490) that the adoption and effective maintenance of the technology should not solely depend on induction but also other aspects such as involvement of the users during the planning and implementation stages. Similarly, Nkusi and Wang (2018:758) noted that users from Huye and Musanze District in Rwanda were excluded in the planning and implementation of the project and there was poor utilisation and maintenance of the new sanitation system.

3.4.2. Factors correlating with number of EVIP toilets on the school

It was anticipated that schools with more toilets will reuse the waste as more raw material is collected and the practice could be sustainable. Therefore, a Chi-square ($\chi 2$) analysis was used to test if there is any significant association. The tested hypotheses were (1) The more toilets a school has, the higher the likelihood that the school reuses the waste from the toilets, (2) the number of toilets within the schools determines the methods used to deal with the waste when the toilets are full.

Table 3.10 shows a significant association between number of EVIP toilets within the schools and the reuse of waste material $\chi 2$ (df=3, n = 108) = 26.243, p = .000 and also the method used when the toilet is full $\chi 2$ (df=15, n = 108) = 51.768, p = .000. The results of the study revealed that the disposal method used when the toilet is full and the reuse of waste material is not dependent on the number of EVIP toilets within the schools.

Table 3.10: Number of EVIP toilets and reuse, induction, and waste disposal methods

	Chi-square	df	p-value
Reuse of waste from EVIP	26.243a	3	.000*
Induction on use of toilets	1.176a	3	.759
Dealing with a full toilet	51.768a	15	.000*

df=degree of freedom, *statistically significant

Similarly, in southern Tanzania, there was a large project where over 17 000 Ecological sanitation facilities were constructed and human faeces use in agriculture was highly practiced (Water and Sanitation Programme, 2005:7). Given interest in the reusing of human waste, this study suggests that the more toilets in use, the more quantity of the waste material could be collected, hence the findings indicated that the school with more toilets reused their waste as the practice can be considered sustainable.

On the other hand, an Ecological sanitation program was implemented in several regions in Burkina Faso as a way of simultaneously addressing sanitation challenges and the need for agricultural inputs (Dagerskog *et al.*, 2015). The study further suggested that citizens that received training on the Ecological sanitation subject with a greater emphasis on agricultural reuse were more strongly associated to using the toilet and emptying than those whose training focused more on sanitation access and health benefits (Dagerskog *et al.*, 2015). This study's findings indicate that the school with more toilets reused their waste. Concurrently, the schools with more toilets (>15) also removed their own waste (Figure 3.3). The findings suggest that such schools become more prone to reusing human waste as it is viewed as a beneficial resource.

Dickin *et al.* (2018:144) reported that over 135 million Ecological sanitation toilets were constructed and 62 % of the users in Burkina Faso indicated that the emptying of the toilet was very easy.

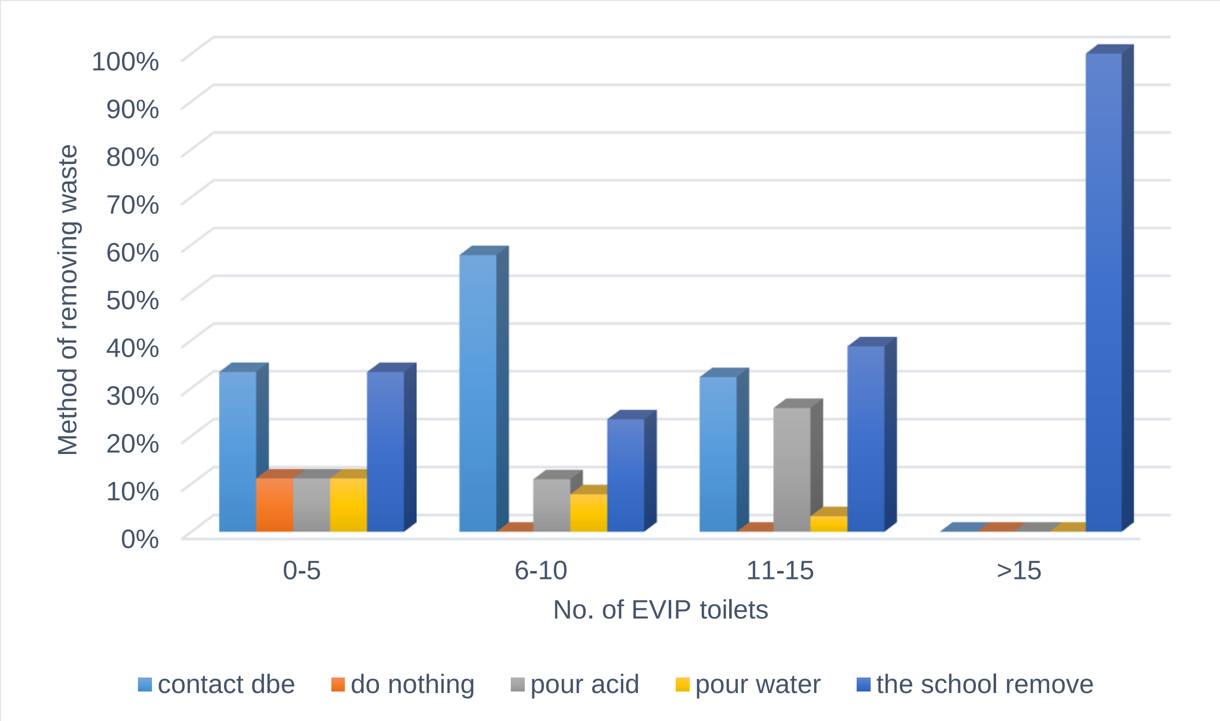

Figure 3.3: Comparison of number of toilets on the schools and method of removing waste

Chi-Square (χ2) analyses further revealed that there is no significant association between the number of EVIP toilets within the schools and the school being inducted. χ^2 (df=3, n = 108) = 1.176, p = .759. However, a study by Heikkilä (2013:103) indicated that in Zambia, a dry sanitation project unfolded in phases from 2006 to 2013 within 14 communities. As the number of the toilets increased, a central committee was formed to oversee the operations of the toilets and to provide user education.

3.4.3 Factors correlating with duration of EVIP toilets use

Furthermore, the study sought to determine the correlation between the schools' duration of using the EVIP toilet and (1) the reuse of waste material from the EVIP toilets; (2) the perception of reusing human waste and (3) the method of waste disposal used when the toilet is full. It is expected that schools that have been using the toilet longer will reuse the waste based on the adopted concept "experience overtime induces adaptation, proper usage and maintenance" as exposure overtime is a breeding ground of tangible results which a user can easily adopt to.

Table 3.11: Duration of EVIP toilets and reuse, induction and dealing with toilet when full and perception on the reuse of human waste

	χ^2	df	p-value
Reuse of waste from EVIP	17.159	3	.001*
Induction on use of toilets	1.793	3	.616
Dealing with a full toilet	23.464	15	.075
Perception on reuse of human waste	2.210	6	.899

df=degree of freedom, *statistically significant

The findings indicate that there is a significant correlation between schools' duration of using the EVIP toilets and reusing waste from the toilet (Table 3.11). The Chi-square result yielded χ^2 (df=3, n = 108) = 17.159, p = .001 and thus the null hypothesis that the reuse of the waste from the EVIP toilets is not dependent on the duration of using the EVIP toilets is rejected. The study noted that the longer the toilet is in use the users are likely to reuse the waste. The schools where the EVIP toilets have been used for more than 10 years, indicated a 17 % probability of reusing the waste (Figure 3.4).

It can be assumed that the longer a user is exposed to a sanitation technology, they will be willing to adapt to the sanitation technology and not only as a toilet but a beneficial resource. In Hatcliffe extension, which is in Zimbabwe, it was reported that when the dry toilets were still a new concept to the community members, they did not exploit the re- using of the human faeces (Guzha, 2002:6). Similarly, the Water and Sanitation Programme (2005:9) noted that in Malawi, the resistance and doubt of reusing waste decreased overtime while using the technology and farmers became advocates of reusing human waste.

Also, the citizens of Msunduza in Swaziland noted overtime that the toilet is of beneficial use with regards to collecting the waste and using it as fertilizer and a means of earning extra money by selling the fertilizer (Heikkilä *et al.*, 2012:6). These findings suggest that when users are exposed to a system which is both economically and environmentally sustainable, the likelihood of conforming to the system is high. This was also reported by Fischhoff *et a*l. (2000:80) that perceived benefits influences the acceptability.

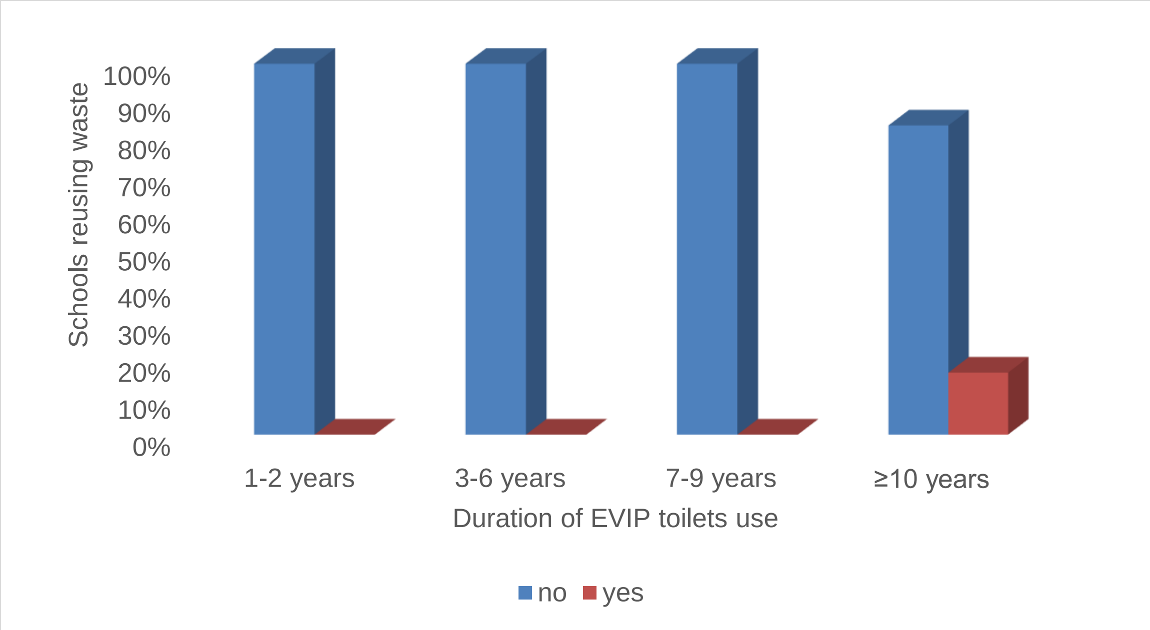

Figure 3.4: Duration of EVIP toilet use and reusing waste from the toilets.

The findings of this study revealed that there was no association between the duration of using an EVIP and the perception on reuse of human waste (POR) (χ^2 (df=6, n = 108) = 2.210, p = .899). No significance associations were also noted between duration of using EVIP toilet and the method of dealing with the waste when the toilet is full χ^2 (df=15, n = 108) = 23.464, p = .075 and induction being conducted χ^2 (df=3, n = 108) = 1.793, p = .616 (Table 3.11). Ordinarily, it is expected that the schools that have been using the EVIP toilet longer would advocate for the reuse of human waste. However, a study by Mayo and Mubarak (2015:490) indicated that regardless of the prolonged duration of using Ecological sanitation in Tanzania, Mkuranga District, which is mostly dominated by Muslims, religion played a vital role in shaping the perceptions of the individuals whereby they rejected the reuse of urine and faeces as it is regarded unholy despite the benefits.

Jonah (2007:20) noted that culture is a factor that informs an individual's perceptions when approaching the Ecological sanitation subject. The findings of this study also reported that the duration of using the toilet does not inform the perception of an individual on reusing the waste. The main factor being hygiene (60.7 %), followed by personal reasons (21.1 %) and culture being the least (19 %).

3.5. Chapter summary

This chapter has discussed the results of the effective implementation of Ecological VIP. The research findings reported that 78.7 % of the respondents indicated that human waste cannot be a beneficial resource, hence 99.1 % of the schools are not reusing the waste collected from the EVIP toilets. This was further attributed to hygiene (47.6 %), lack of knowledge (44.8 %), and religious (5.4 %) reasons.

Based on the findings, it is suggested that user education, especially in terms of the beneficial concepts, should be prioritised for successful implementation because when these concepts are understood, the ideas will be better accepted. When introducing a sanitation technology, user education should also be proactive, practical, and involve all stakeholders. The study revealed that it is also important to find ways to integrate information in existing structures before and during implementation so that Ecological sanitation is not perceived as a temporary concept or structure. Furthermore, it's important to note that achieving positive results also depends on exposure, practice, and the gradual increase of awareness and user education over time. It is envisaged that when introducing new sanitation technology, exposure overtime allows users not only to understand but also develop management strategies of the sanitation technology. Experience provides noticeable results, which could motivate the users to be the gatekeepers of the sanitation technology.

For the reuse of human waste to be regarded as a beneficial practice, sustainability should be guaranteed, and this is mainly dependent on the quantity which is collected from the EVIP toilets. Results of this study have shown that the users were not exposed to the sanitation technology as a beneficial mechanism, but rather as a sanitation structure. Nonetheless, several factors such as sustainability in terms of the waste collected should be assured such that the sanitation approach is viewed as a beneficial resource, not as waste. The next chapter discusses the potential of Ecological VIP to reduce water consumption.

4. CHAPTER 4: THE POTENTIAL OF EVIP TO REDUCE WATER CONSUMPTION

This chapter provides the results and analysis obtained from the schools regarding the potential of Ecological VIP to reduce water consumption. The chapter commences with an exploration of water consumption within the realm of sanitation practices. It then delves into an attempt to understand the claim that Ecological VIP toilets have the potential to conserve water, promoting the establishment of a common practice aimed at bridging the divide between water scarcity and water consumption. The research method employed to gather the information was guided by the following key concepts: nature of water supply, main use of water, and water consumption before and after the implementation of Ecological VIP toilets.

4.1. Introduction

South Africa is regarded as a water scarce country. It has 13.3 million households with access to improved sanitation, which includes flush toilets (Stats SA, 2018). The water and sanitation report by South African Human Rights Commission in 2021 noted that 33 % of the schools in South Africa use flush toilets. This situation is predicted to exacerbate the water deficit by 2030 given that the flush system consumes an average of six litres of fresh water per flush, which equates to 48 litres per day per person (Urinary Habitats, 2016). Furthermore, the use of fresh water in flushing toilets can be deemed unsustainable, particularly given the current state of excessive water consumption in ablution facilities.

Decreasing quality and quantity of freshwater is increasingly becoming a major concern worldwide. Ecological sanitation is an integrated approach of water and natural resource management, and the approach is more holistic, which provides possible solutions to the ongoing depletion of water resources and continuous water pollution through dysfunctional sewage systems. Esrey *et al*. (2001:10) noted that the flush and discharge systems, which are waterborne only assist with the disposal of human faeces. However, these systems have not been able to solve environmental concerns because excessive amounts of fresh water is consumed while human faeces is disposed into the natural environment.

Schneider *et al.* (2019) indicated that to achieve water security, water should be available in terms of quantity, quality, and access. The South African Constitution Section 27(1b) guarantees everyone the right to access sufficient water and every person is entitled to 25 litres of water per day (RSA, 1996). Although energy and other resources are invested in producing domestic water supply, over 3 million people do not have access to this basic requirement, including 113 Limpopo schools (SAHRC, 2021). A cause of concern is the use of about 48 litres of fresh water per day to dispose waste (SA Water, 2019), a practice which is not sustainable in regions that are regarded as water scarce. It has been predicted that the gap between water supply and demand will increase by 17 % by 2030 if the consumption and water usage practices continue (Makelane, 2020). Therefore, the emphasis on the effective implementation of economically and environmentally sustainable Ecological sanitation systems could narrow the gap and encourage the fundamental aspects of the Sustainable Development Goal 6, which aims to ensure water security through sustainable approaches.

According to Johan (2007:16), almost 90 % of the sewage produced in developing nations is dumped into water bodies. In South Africa, Mema (2010:60) noted that large amounts of sewage are from towns and cities. The waste does not reach the wastewater treatment plants, but rather flows raw into rivers, creating nuisance and health hazard environments. Sometimes inadequate procedures result in the waste being partially processed and released into rivers (Mema, 2010:61). According to Cosgrove and Rijsberman (2000), about $30 billion is invested yearly on contemporary water and sewage systems. However, this amount is expected to rise to $75 billion by 2025. However, for poor developing countries, the waterborne sanitation systems are not sustainable and remain very difficult to maintain. Esrey *et al*. (2001:10) reported that due to the large dependency of water, these systems are not suitable for water-stressed countries as using 15 000 litres of safe drinking water per person per year to flush away a yearly production of 500 litres of urine and 35 kg of faeces is not optimal.

Still and Louton (2012) conveyed that there is a requirement for an on-site flush sanitation facility that can fulfil the aspirations of many South Africans. This can be achieved through the use of a pour flush toilet, which consumes just one litre of water per flush. Gardner (1997:58) reported that ecological sanitation systems save up to 20-40% of the domestic water use.

Langergraber and Muelleggera (2005) suggested that vacuum toilets save more than half of water used in the traditional flush system. Nonetheless, even though there are water savings, the significant consumption of fresh water remains unsustainable, especially when considering that by the year 2030, more than half of the world's population is anticipated to face water scarcity (UN, 2016). In addition, such systems will not be feasible in areas where water supply is not reliable. Hence, it is imperative to channel our efforts towards enduring practices that encourage water conservation and the preservation of water resources. This includes implementing the Ecological Sanitation approach.

Cordova and Knuth (2005:245) noted that waterborne sanitation facilities have been conventionally accepted as adequate sanitation, yet over four billion people are confronted with water scarcity for at least one month in a year. This suggests that the waterborne system approach will not be achievable as a universal solution, nor can it be sustainable.

4.2. Materials and methods

4.2.1. Research design

A qualitative approach was used to assess the potential of the Ecological VIP to reduce water consumption. Qualitative data were collected using open-ended questions through interviews with key informants. The gathered information encompassed details about the water supply and usage, as well as the water consumption rates both prior to and following the adoption of the Ecological VIP system.

4.2.2. Sampling procedure and size

Sampling procedure and sample size determination were as reported in Chapter 3, Section 3.2.2. Furthermore, the study assessed the potential of EVIP toilets to reduce water consumption at the same schools where the effective implementation of these systems was evaluated.

4.2.3. Data sources

To assess the potential of the Ecological VIP to reduce water consumption, key informant interviews were conducted at the 108 schools within the Capricorn District. The interviews involved an open discussion with individuals who are very knowledgeable about the nature of water supply and water consumption rate at the schools and are able to provide context on the supply and consumption of water (Appendix 2).

According to Brown (2020), key informant interviews are a good choice when dealing with key expert subject matters. In this case, the informants were able to provide in-depth information on the relationship between water consumption before and after the Ecological sanitation implementation. A situational analysis was employed where the respondents referred to past experiences to draw up a water consumption rate picture.

4.2.4. Data analysis

Content analysis was used to study the empirical data on the potential of Ecological sanitation in relation to the rate of water consumption. The data were grouped and discussed in themes and the categorisation assisted in understanding the rate of water consumption relationships before and after implementation of Ecological sanitation between (i) schools that continued to use both flush toilets and dry sanitation, (ii) schools that refrained from using flush toilets after the phasing in of dry sanitation (complete adoption of ecological sanitation), (iii) schools that reopened flush toilets due to the COVID-19 pandemic, and (iv) schools where only teachers continued to use flush toilets after introducing dry sanitation. The data on the consumption rates were also analysed using descriptive statistics and has been presented graphically.

4.3. Results and discussion

4.3.1. The nature and the main source of water at the schools.

The 2030 Agenda has established a global goal to achieve water supply for all by the year 2030: not only at household level but also within schools (UNICEF, 2018). A baseline report by UNICEF (2018) indicated that 19 % of schools worldwide have no access to water or rely on unprotected dug wells. This figure translates to 570 million children worldwide that lack basic water supply within their schools. In South African schools, a similar situation exists in the Limpopo province, where 113 schools do not have access to water while 78 % of the schools rely on boreholes as their primary source of clean water (South African Human Rights Commission, 2021).

Findings of this study revealed that out of the 108 sampled schools, 66 (61 %) depend on boreholes while 42 (39 %) depend on the water tankering system for water supply. However, reliability is a major challenge especially for those schools that rely on the water tank system. The supply of water is often delayed due to the lack of water trucks in the province. Ripunda (2019:2) also observed that water supply is often unreliable in 4 773 South African schools.

This unreliability is primarily attributed to the inadequate maintenance of water systems, including logistical arrangements within schools that do not rely on boreholes as their source of water supply.

4.3.1.1 The main use of water at schools

UNICEF (2012) has set out standards for water, sanitation, and hygiene in schools, which recommend that sufficient water must always be available for drinking, personal hygiene, food preparation, and cleaning. This study noted that 54 % of the water in the sampled schools is used for cooking, 19 % for drinking, 16 % for gardening, and 9 % for flushing toilets (Figure 4.1).

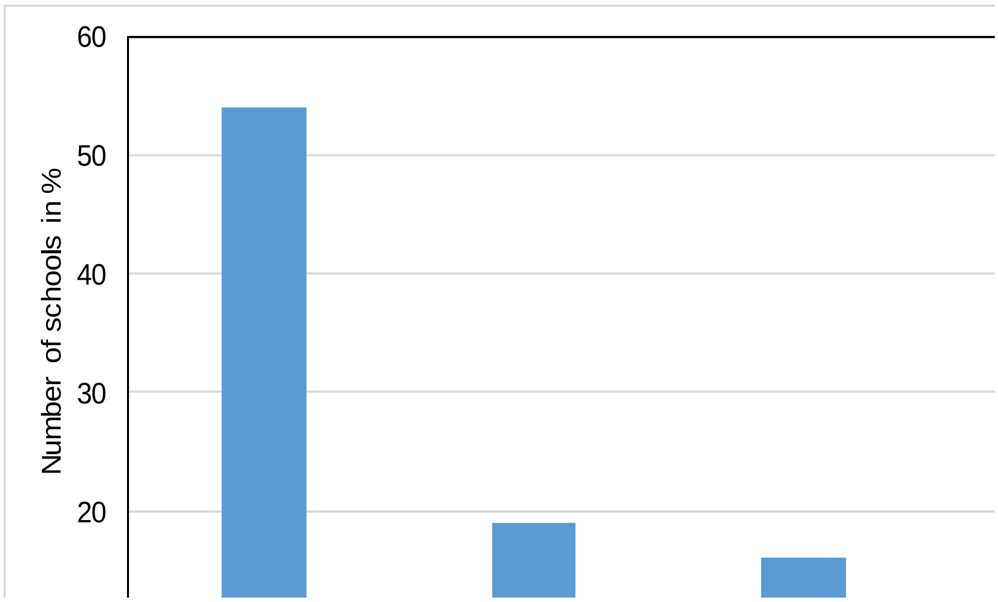

Figure 4.1: Main use of water at the schools

According to the Limpopo Department of Education (2021), more than 3 800 public schools benefit from the feeding programme. Unsurprisingly, this study's findings indicated a high percentage (54 %) of water usage for cooking. The school feeding scheme is a tool which enables millions of underprivileged children worldwide to attend school (Drake *et al.*, 2020:1). Only 9 % of water is used for flushing toilets because most of the sampled schools use EVIPs or pit toilets. These findings present a contrast with the assessment conducted by Gibberd (2021:6), who indicated that water consumption rates in schools located in Pretoria differ significantly.

According to Gibberd (2021:6) approximately 71 % of the water usage is attributed to flushing toilets, while 18 % is allocated for irrigation purposes, and 5% is designated for handwashing. Farina *et al.* (2011:929) noted that in Brazil, school nurseries use more water every day for laundry and kitchens while in elementary school, students mainly use water for flushing toilets.

4.3.2. Water consumption before and after the implementation of Ecological VIP

Costner *et al*. (1990), Otterpohl *et al*. (1997:212), and Van der Ryn (1995), reported that Ecological sanitation does not only encourage water conservation but economic savings as well. This is due to the reduction in the volume of water that need to be supplied, distributed, collected, and treated. Gibberd (2021:7) suggested that replacing conventional toilets with dual flush toilets reduces water consumption by 44 %. Holistically, the results of this study revealed that before the implementation of EVIP, the sampled schools consumed an average of 1 231 litres of water per day. Following the implementation of dry sanitation, the daily average water consumption dropped to 338 litres, resulting in a saving of 893 litres daily, equating to a 73 % reduction in water usage (Figure 4.2).

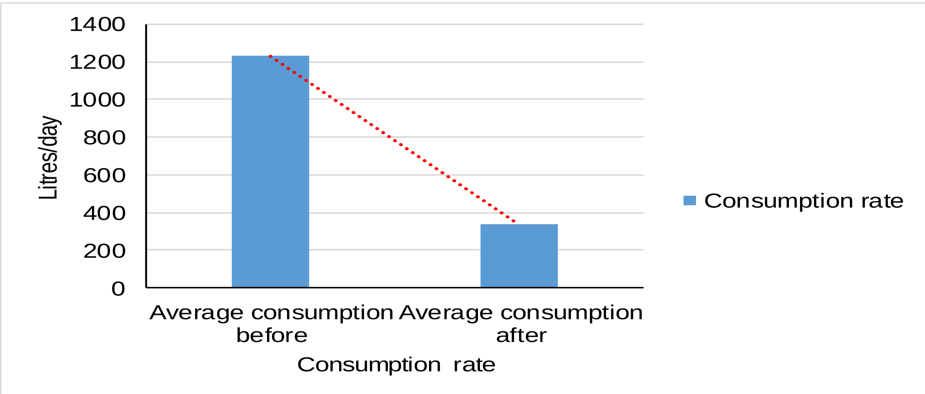

Figure 4.2: The overall average water consumption before and after implementation of Ecological VIP

The relationship between water consumption and EVIP will further be discussed in five categories: (i) 28 % of the schools that fully implemented and adopted EVIP, (ii) 6 % of the schools where only learners used EVIP while teachers continued to use flush toilets , (iii) 9 % of the schools that continued to use flush toilets despite the introduction of EVIPs , (iv) 6 % of the schools which re-opened flush toilets and hand washing due to the impact of COVID-19 pandemic, and (v) 0.9 % of the schools which re-opened flush toilets due to gastroenteritis conditions (Table 4.1 and Table 4.2).

Table 4.1: Water consumption categories at the schools

Category	Schools represented (%)	Consumption before (l)	Consumption after (l)*	Water saving (%)
1. Schools implemented EVIP	28 %	1 029	297	71
2. Continued to use flush toilets	9 %	690	690	0
3. Teachers only using flush toilets	6 %	1 214	340	72
4. Reopening of flush toilets due to gastroenteritis	0.9	1 666	1 000	40

**The refilling of the tank is dependent on the number of learners in relation to the size of the tank*

Table 4.2: Water consumption categories at the schools

Category	Schools represented (%)	Consumption before reopening (l)	Consumption after reopening (l)*	Consumption increase (%)
5. Reopening due to Pandemic	6 %	108	1 038	90

**The refilling of the tank is dependent on the number of learners in relation to the size of the tank*

Category 1: Schools which have exclusively implemented Ecological VIP

This study noted that the use of EVIP, which is a waterless system, can save up to 71 % of water. This was evident after 28 % of the schools that replaced flush toilets with EVIP reduced their water consumption from 1 029 litres to 297 litres. However, Ihalawatta *et al*. (2015:788) noted that a vacuum toilet where a greywater system is installed saves 50 % of water and reduces the consumption of fresh water. One of the respondents commented that "*after being introduced to these toilets that don't flush, we did stop using flushing toilets as the borehole sometimes gives us problems as it is old*." Apparently, the use of dry sanitation has not only saved water consumption, but also alleviated the problem of water supply due to old boreholes.

The water reduction relationship was evident in 28 % of the schools which refrained from using flush toilets after the implementation of dry sanitation. In addition, the results revealed that prior to the implementation of EVIP, schools using a 2 500-litre tank refilled water on a weekly basis but after implementation, the water tank is filled every 3rd week. For other schools, a 1 000-litre tank which was filled every 2nd day, is now refilled every 3rd week when the schools introduced EVIPs. On average the schools are using 297 litres per day instead of 1 029 litres per day before replacing the flush toilets with EVIP (Figure 4.3). This practice saves an average of 732 litres per day (71 %) and as indicated that water supply is not reliable and the province is water stricken, such a saving practice will bridge the gap between excessive water consumption and water scarcity.

The anecdote quote from one of the respondents support this result:

"*When the EVIP's were built, we decided to not to use the flush toilets anymore because the school was already facing a problem of water supply because the water truck did not come on time. When using the flush toilet, the 2500 litre tank would last for 3 days but now we can go for almost 2 weeks. Things are much better now because the school can stay longer with water"*.

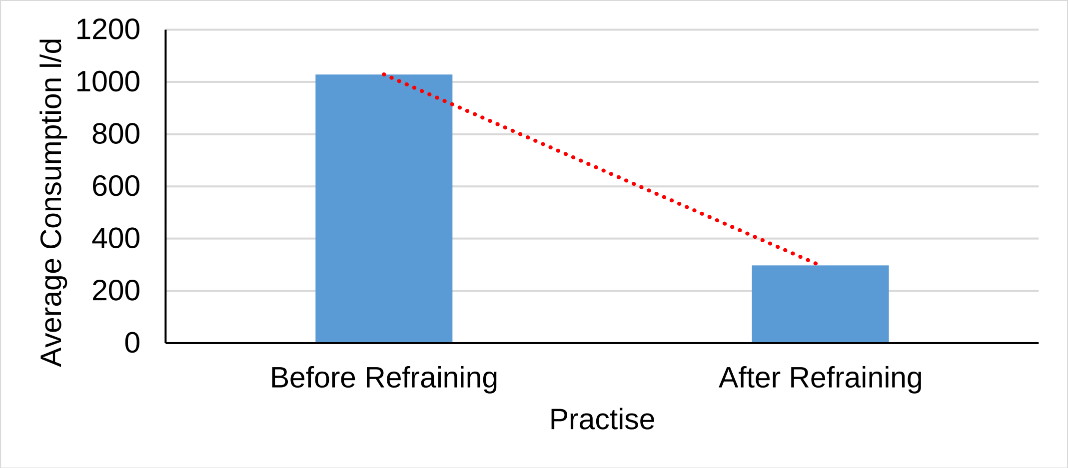

Figure 4.3: Average water consumption before and after refraining from using flush toilets

Category 2: Schools that continued to use flush toilets

Research findings indicate that 9 % of the schools that continued using flush toilets use an average of 690 litres per day compared to 297 litres per day for schools that have exclusively implemented EVIPs. As reported in section 3.6.4, 41.7 % of the sampled schools indicated that they were not inducted when EVIPs were introduced in the schools. Out of the 10 schools that still use the flush toilets, six schools of the 10 (60 %) are those that were not inducted. Nkusi and Wang (2018: 758) reported that the implementation of sanitation technology is hindered by the lack of awareness into the public's willingness to utilise the new sanitation technologies.

One respondent exclaimed that:

"*The people who put up the toilets did not teach us anything and it is very frustrating and sometimes the toilet smells with worms, that is why we still use all the flush toilets.*

Again, a local with a honey sucker told us that per toilet it is R500.00 but the school does not have this budget". Another respondent explained that:

"*After building this toilet there was not much change because we still pour water in the 1 500 litre tank every day because we still use all the eleven flush toilets. These four toilets that are not flushing are not enough that is why we still flush, maybe when they are enough we will close the other ones, we don't know*".

The management from the schools, which are still using flush toilets indicated that; "*we are planning to request for induction and an awareness programme to inform the learners and teachers on the importance of using the EVIP with the hope that the practice will show positive results including the benefits of the EVIP*".

The sentiments reported by the respondents in this study agree with the study by Ashebir *et al*. (2013:629), which reported that in Tigray, Ethiopia, 54.5 % of the respondents having urine-diversion dry toilets did not use them at all as they had little knowledge, and this did not yield outcomes such as water reduction. Mayo and Mubarak (2015:488) also noted that 92.8 % of the respondents using flush toilets in the Mkuranga District, Tanzania, were not willing to convert to the urine-diversion dry toilets. The findings draw to the attention that if the use of flush toilets is continued despite the implementation of EVIPs, the notion behind water saving will not be achieved. The Environmental Protection Agency (2022) also noted that flush toilets are the main water hogs in a household, accounting for an average of 30 % of the total household water consumption. UNICEF (2012) indicated that a learner requires 10–20 L/person/day for flushing, which cannot be feasible in water stressed regions. It is evident that flush toilets consume excessive amount of water and to adapt to water shortages and scarcity, alternative approaches for sanitation practice should be emphasised.

Category 3: Only teachers using flush toilets, while learners use EVIP

Introducing Ecological VIP did not result to the total shut down of the flush toilets in 6 % of the schools. Results from the study revealed that; within these schools, only the learners resorted to using EVIP's while the teachers continued to use flush toilets. One of the r*espondents reported that: The tankering system is very frustrating because they can skip a day without coming, we then insisted that the learners use the new toilets while only the teachers continue to use flush toilets"* The partial adoption of dry sanitation practice resulted in water consumption reduction.

For instance, a school that used 16 flush toilets for both the learners and teachers, a 1 500-litre tank was refilled daily, whereas after phasing in the EVIP, the tank is refilled once a week. In other words, the school would use 1 500 litres per day but when the learners shifted from flush toilets to dry sanitation system, the daily water demand is 300 litres, resulting to 80% water saving (1 200 litres per day).

Overall, the 6 % schools which adopted the practice of only teachers using flush toilets experienced a 72 % saving in water consumption as the daily average water consumption is 340 litres instead of an average of 1 214 litres per day. In addition, there were instances where teachers would voluntarily refrain from using the flush toilets, saving up to 90 %. Gibberd (2021:7) also noted that installing composting toilets and waterless urinals reduces 71% of water consumption associated with flush toilets.

Category 4: Reopening of flush toilets due to the pandemic

According to the World Health Organisation (WHO, 2019), good hygiene practice was one of the key factors to combat and reduce the risk of being infected with COVID-19. The prevalent hygiene and sanitation practices included regular washing of hands and the use of clean, well maintained sanitation facilities. Due to the pandemic, 6 % of the schools reopened all the flush toilets and the demand for water increased. The 6% schools that adopted this approach experienced a 90 % increase of water consumption as the daily average consumption rose from 108 litres per day to 1 038 litres per day and as reported, a person uses a daily average of 36-48 litres a day for flushing (The Urinary Habitats, 2016). The findings from the results evidently indicate that flush toilets use a greater amount of water as compared to dry sanitation methods.

Category 5: Reopening of flush toilets due to gastroenteritis conditions

Findings of the study reported that in 0.9 % of the schools, there were circumstances where learners would resort to using the flush toilets due to gastroenteritis conditions as the EVIP were not enough in number. One of the respondents mentioned that *“After been given the EVIP toilets, we would open five of the ten flush toilets when learners have running tummy especially in summer”.*

The tank is refilled every 2nd week instead of every 3rd day when using all ten flush *toilets.* In this case, this arrangement still reduced the water consumption as there was 50 % use of flush toilets (i.e., five flush toilets) instead of 10 flush toilets. This practice resulted into filling a 5 000-litre tank every 2nd week instead of every 3rd day. The water demand when using 10 flush toilets translates to 1 666 litres per day whereas when using both EVIP and five toilets, the water consumption was at 1 000 litres per day. As such, the partial implementation of EVIP coupled with using five flush toilets resulted in water savings of 666 litres (40 %).

Notably, 42 % of the schools which were already using dry sanitation technology known as pit toilets before the implementation of EVIPs, consumed a daily average of 277 litres as compared to an average of 690 litres per day. The water consumption comparison between the schools that used pit toilets and flush toilets depicts that the use of dry sanitation saves an average of 413 litres per day (60 %).

Langergraber and Muelleggera (2004:433) noted that vacuum toilets save more than half of the water used in the conventional flush system, though the toilet consumes a lot of energy associated with complexity in the arrangements. However, the research findings suggest that the use of dry sanitation saves more than 60 % of water consumption as compared to using a vacuum flush toilet (Figure 4.4).

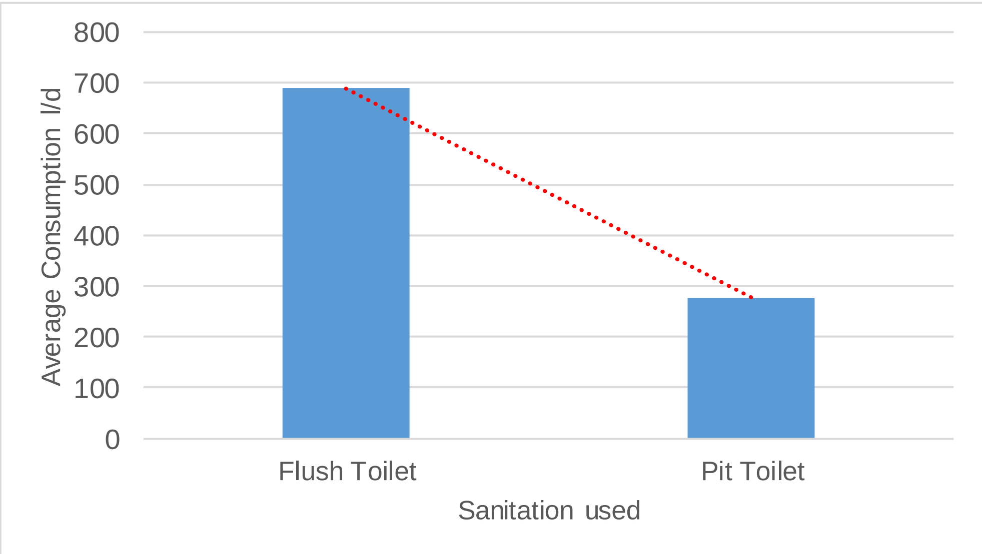

Figure 4.4: Average water consumption when using flush or pit toilets

4.4. Chapter summary

The results indicate that prior to the adoption of EVIP, the schools collectively consumed an average of 1 231 liters per day. However, after the introduction of dry sanitation, the daily average water usage significantly decreased to 338 liters. This reduction amounts to a daily water savings of 893 liters, representing a 73 % decrease in consumption. The research findings suggest that the management of water should be done on-site by consumers through approaches such as Ecological Sanitation.

The findings also indicate that there was a 72 % saving of water consumption at the schools where only the learners resorted to using EVIPs while the teachers continued to use flush toilets. The schools that reopened 50 % of the flush toilets due to gastroenteritis conditions experienced a 40 % saving in water consumption while those that reopened due to the Covid-19 pandemic, experienced 90 % increase in water consumption. The schools that still use flush toilets continue to use an average of 690 litres per day compared to 297 litres per day for schools that have exclusively implemented EVIPs.

The research findings have highlighted the potential of the dry sanitation system to contribute to achieving water security by promoting conservation through sustainable practices. Results of this study revealed that EVIP toilets could bridge the water consumption gap. In the next chapter, the concept of onsite reuse of human waste is discussed in the light of addressing the municipal concern raised by Still and Louton (2012:3) regarding the disposal of waste when VIP toilets are full and alternative means of reusing the waste. Fundamentally, the primary objective was to determine the capacity of human waste to generate sustainable energy for cooking and lighting. This integrated approach aims to not only address environmental concerns but also tackle the energy crisis, as evidenced by the ongoing electricity load shedding.

5. CHAPTER 5: HUMAN FAECES NEEDED TO GENERATE SUSTAINABLE ENERGY FOR LIGHTING AND COOKING

This chapter reports on an experiment that was conducted to estimate the amount of energy that could be generated from human waste collected from EVIP toilets. The first section provides a background to renewable energy and environmental benefits of clean energy. This is followed by a descriptive explanation of the Biochemical Methane Potential test which determines the volume of biogas and methane produced from human faeces substrate. The chapter ends with a discussion of the utilisation of the energy generated for lighting and cooking within the schools using EVIP toilets.

5.1. Introduction

With the on-going electricity crisis in South Africa, which is evident through the persistent load shedding, there is a need to investigate other sources of energy. In addition to various initiatives aimed at advancing renewable energy development in South Africa, strategies are being devised to expand the recovery of energy from waste. This is being done with the goal of reaching the 2030 target of 17.8 GW to bolster the existing energy supply (Ferry & Giljova, 2015:1). The use of human faeces to generate energy can be considered as an environmentally friendly process that can reduce deforestation. Damm and Triebel (2008:32) noted that South African households consume a total of 11.2 million tons of fuelwood annually. In addition, the approach of on-site renewal of waste ensures that the water bodies are protected. Studies by AfriForum (2018) and Herbig and Meissner (2019) revealed that 80 % of South Africa's freshwater resources are polluted by effluent from wastewater treatment plants. The increase in demand of clean and affordable energy and the urge to mitigate the release of unsafe elements into the environment has led to the constant search for sustainable and renewable energy generation possibilities.

Amigun (2012) reported that Africa is a net energy exporter, but most of its population lacks access to clean energy. South Africa depends largely on coal as the main source of energy. Edokpayi *et al*. (2019) reported that the use of coal to produce energy results into greenhouse gases emissions and leaves large quantities of fly ash, usually stored in ash ponds or landfills, which have a high concentration of heavy metals.

This consequently pollutes water sources and impacts on human health through water pollution and water borne diseases. Biogas is regarded as a clean and renewable form of energy available through anaerobic digestion of organic waste. Though numerous studies have focused on the use animal waste, food waste, and municipal wastes for biogas generation with the aim to address the state of energy security, human waste is rarely considered (Kell, 2019; Pahla *et al.*, 2017; Manyi-Loh *et al.*; Thenabadu, 2014; Yi *et al.*, 2014).

Several studies have been done to evaluate the potency of human faeces as a source of energy generation. XI *et al*. (2022:1) evaluated the plasma electrolytic faeces liquefaction and concluded that the method offers a sustainable approach for recovering resources from human waste. This study noted that the highest liquefaction yield was 85.67 % with a heating value of 28.10 MJ/kg. Emetere and Pindar (2019:6) also studied enhancing biogas generation by optimising human waste and recommended that to improve biogas production, the fluid in toilet system should be changed from water to pressurised air. Under pressurised air, methane production increased from 180-230 ppm. Andriani *et al*. (2015:223) investigated the current human waste collection system in Indonesia to investigate the potential recovery of energy and nutrients from human faeces. The study reported that the biogas produced was 106.85 m^3, which can be used at household level to augment the country's existing supply. Onojo *et al*. (2013) also conducted a similar study at the Federal University of Technology, Owerri, Nigeria, to augment the energy supply at the university and the biogas produced could run a 5 KW biogas generator for a period of six days.

Over and above human waste being a beneficial resource for energy generation, other studies have revealed environmental and health benefits. For example, Ihalawatta *et al*. (2016:791) noted that Ecological sanitation systems utilise less water as compared to the conventional systems and the reuse of human waste plays a vital role of protecting the environment by promoting a sustainable and responsible waste management practice.

Werner *et al*. (2003) also cited prevention of soil degradation and reducing health risks and water contamination. Schönning (2003:397) suggested that the application of the Ecological sanitation concept when treating human waste reduces the spreading of pathogens. This was also reinforced by Gabani (2014:79) who argued in favour of on-site treatment of human waste due to the increase of health risks associated with waterborne sewage when untreated sewage is discharged into water sources. A similar scenario of the South African wastewater treatment systems as reported by Herbig and Meissner (2019) as well as Zama (2021:1), which threatens the integrity of effluent receiving water sources. Boot (2007:2) also reported that 90 % of developing countries do not properly treat sewage waste before discharging it to the environment and advocates for Ecological sanitation practice as it eliminates a large scale of health risks and water pollution. Therefore, reusing human waste promotes minimisation of environmental impacts while maximising resource recovery.

To achieve the 2030 target, South Africa has considered to generate renewable energy from sewage sludge and agricultural wastes (Ferry & Giljova, 2015: 2). Burton *et al.* (2009:5) conducted a feasibility study in South Africa, to assess the potential energy that could be produced from wastewater. The study observed that 10 000 MW could be recovered from all wastewater plants in South Africa which represents 7 % of the existing electricity supply from ESKOM. A similar study was conducted by Ferry and Giljova (2015:17) in South Africa, where the potential of biogas production was assessed in nine municipalities. The assessment recorded that the wastewater treatment plants in the Western Cape, specifically Outeniqua and Gwaing, with a capacity of 5 ML/d and 12 ML/d respectively, have a potential to produce 0.3 MW of electricity.

On the other hand, Potgieter (2011:1) investigated the use of agricultural residue to generate energy and found that the Greater Gariep agricultural area is estimated to have 311 000 ton/yr of maize and wheat straw and the quantity is equivalent to 196 000 tons of coal annually and should be used as a sustainable source of renewable energy. In 2022, the South African Breweries (SAB) signed a power purchase agreement (PPA) with Bio2Watt where livestock waste is used to generate energy from a biogas plant with a capacity of 4.8 MW which is converted to electrical power (Bio2Watt, 2022).

Within the Limpopo province, pit latrines have been replaced by ecological ventilated improved pit (EVIP) toilets. Therefore, this research notes that the effective implementation of Ecological VIP will assist in scaling up the recovery of energy from human waste. This eco practice within the schools will ultimately assist South Africa to move closer to its 2030 target of reaching 17.8 GW energy generation, by simultaneously reducing the electricity consumption of 3.5 TWh a year by South African schools (Booysen *et al.* 2021:1). As such, human waste collected from the EVIP toilets offers alternative renewable energy source to supplement the energy produced by ESKOM.

5.2. Materials and methods

5.2.1. Research design

In this study, an empirical approach was carried out to estimate the capacity of human waste collected from the Ecological VIP to generate sustainable energy for cooking and lighting. The results on estimated amount of biogas produced from human faeces were compared with Kristoferson and Bokalders (2013) biogas usability and its equivalent. In addition, the sustainability of biogas produced for cooking purposes was measured against the Limpopo school nutritional programme.

5.2.2. Data sources

5.2.2.1 Experiment

Sample collection and preparation

The samples (human waste from the EVIP) were collected while they were still moist using a lab beaker clip. The samples were stored in six specimen jars (250 g) with leak-proof screw lids designed to preserve the samples (Figure 5.1). The jars were placed in resealable plastic grips to avoid external contamination. The collected samples (human waste) from the EVIP were stored at 4 °C and -20 °C refrigerator for shorter and longer periods, respectively. According to Holliger (2016:2515), the substrate composition changes due to water loss and the changes in volatile solids content are minimal at 4 °C for shorter storage periods (less than 7 days) and at -20 °C for longer periods (greater than one month).

Figure 5.1: Samples in specimen jars (250g) with screw lids.

5.2.2.2 Characterisation of substrate - human waste

Determination of moisture content, total solids, and volatile solids in human waste

Total solids and volatile solids content of human waste has a significant impact on methane production (Wang *et al*., 2020:96). To determine total solids (TS) content and volatile solids (VS), the pH of the substrate was tested. This was done because the anaerobic process is sensitive to pH. The ideal pH range for anaerobic digestion is 6.5 - 7.5 (Himel *et al*., 2018:53).

After testing the pH using a laboratory pH meter, three sets of human waste (10 g each) were weighed into pre-dried (105°C) crucibles using a weighing balance scale (Figure 5.2). The three sets were placed in a laboratory oven (ProLab Oven: manufactured by: FMH instruments, Cape Town, South Africa) at 105 °C for a 24 h period (15h30-15h30). The crucibles were labelled using a pencil.

Figure 5.2: Preparing and weighing the substrate and crucibles

The dried samples were removed from the oven after a 24 h and placed in a desiccator container for 20 minutes to cool down (Figure 5.3). The dried samples were weighed using a precision balance scale and incinerated in a muffle furnace (CNW Model SXL, Manufactured in China) at a temperature of 550 °C for 240 minutes. After the specified time, the crucibles were removed from the furnace and cooled for 120 minutes. Equations 5.1, 5.2, and 5.3 were used to determine moisture content (MC), total solids (TS) and the volatile solid content, respectively.

Figure 5.3: Desiccator container, for the cooling off the crucibles

$$\mathrm{MC} = \frac{(M3-M1)}{M3-M2} \times 100 \qquad \text{Equation 5.1}$$

$$TS = \frac{(M1-M2)}{M3-M2} \times 100 \qquad \text{Equation 5.2}$$

$$VS = \frac{(M1-M4)}{M1-M2} \times 100 \qquad \text{Equation 5.3}$$

where:

M1 = mass (g) of the dried sample + crucible

M2 = mass (g) of the crucible

M3 = mass (g) of the wet sample + crucible and

M4 = mass (g) of the residue + crucible after ignition

5.2.2.3 Degassing of the inoculum "Cow dung slurry"

In this study, cow dung slurry was used as an inoculum. Filer (2019:6) highlighted that inoculum is a significant factor for BMP test as it supplies microorganism during the anaerobic digestion process. The inoculum acts as a catalyst and does not influence the biogas produced by the substrate during the anaerobic digestion process. For the degassing process, the water bath (manufactured by: FMH instruments, Cape Town, South Africa) was prepared at 37 °C (mesophilic temperature) and filled with water.

The digested cow dung was collected from a local biogas plant. On a flat surface, 400 mL of the cow dung slurry was filled into a 500 mL Duran glass vessel reactor, and the mouth of the reactor bottle was lubricated using a vacuum grease to prevent air entering and leaving the reactor bottle. The reactor bottle was sealed using a 500 mL eudiometer and the oxygen in the reactor bottle was flushed out for 2-3 minutes using nitrogen gas tube connected to the opening of the eudiometer (Figure 5.4). The valve of the eudiometer was always opened when flushing out the oxygen and the nitrogen gas tube was slowly removed from the eudiometer while preventing air to enter and swiftly closed the valve.

The 400 mL glass vessel compassion tank was filled with water and swiftly connected the tube from the compassion tank to the eudiometer opening. The reactor tank was placed into the water bath and the valve of the eudiometer was opened until the water reached 500 mL while the water in the compassion tank was kept at 400 mL. After 60 minutes, the remaining oxygen was flushed out for 5 seconds by opening the eudiometer valve.

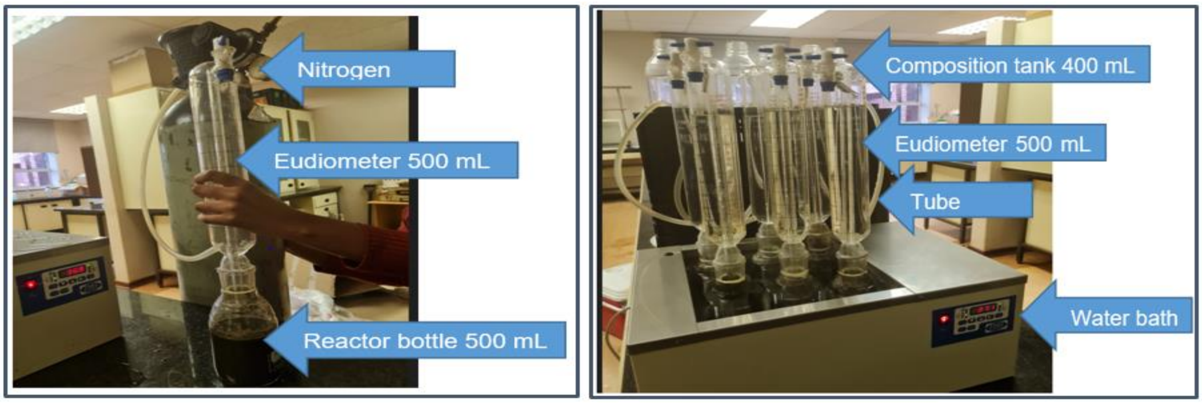

Figure 5.4: Flushing out of oxygen using nitrogen gas and degassing of inoculum

The water in the water bath was monitored, including the pre-incubated inoculum for 12 days at 37 °C (mesophilic temperature) for degassing purposes to reduce the impact of its methane production during the anaerobic digestion process. The anaerobic “cow dung” slurry was degassed at test temperature until insignificant biogas was produced. The volume of water in the eudiometer was monitored daily and the biogas produced was monitored until no biogas was produced. Anaerobic sludge “cow dung” was stored at ambient temperature for a shorter period at 25 °C as suggested by Elbeshbishy *et al.* (2012:18).

5.2.2.4 Anaerobic digestion

After degassing the cow dung slurry, the process of anaerobic digestion was carried out using the water bath which was prepared at 37 °C (mesophilic temperature) and filled with water. The experiment was carried out in triplicate. 500 mL Duran glass vessels (reactor) were filled with 268. 85 (g) degassed inoculum and 25 (g) of substrate “human waste” which was weighed using a scale (Figure 5.5).

The mass of the inoculum was calculated using Equation 5.4. Water was used to fill up the reactor bottle to 500 mL. The 500 mL eudiometer was used to seal the reactor bottle and the oxygen was flushed out using nitrogen gas. The volume of biogas was monitored daily for 69 days and measured at 15h00 using a gas analyser (Manufactured by: Envirotech, UK: Biogas 5000 series) (Figure 5.6). The reactor bottles were shaken daily to prevent sedimentation and also to influence the distribution of the substrate, microorganism, nutrients, alkalinity. The daily shaking of the reactor bottles allowed the release of any trapped gas bubbles. The substrate was further characterised for pH, volatile solids reduction and total solids after the 69 days of the anaerobic digestion.

Mass of the inoculum was calculated according to Equation 5.4.

$$M_{ino} = \frac{M_{sub} * VS_{sub} \times 2}{VS_{ino}} \qquad \text{Equation 5.4}$$

where:

M_{ino} = mass (g) of the inoculum,

M_{sub} = mass (g) of the substrate,

VS_{ino} = the volatile solids content (%) in the inoculum

VS_{sub} = volatile solids content (%) in the substrate.

Substrate calculations

$$\text{Mass TS (Substrate)} = \text{Mass Substrate} \times \text{TS (\%)}$$

$$\text{Mass TS (Substrate)} = \frac{25\ (g) \times 28.48037}{100} = 7{,}1200$$

$$\text{Mass VS (Substrate)} = \text{VS/TS (\%)} \times \text{Mass TS}$$

$$\text{Mass VS (Substrate)} \quad \frac{82.6891}{100} \times 7{,}1200$$

$$\text{Mass VS (Substrate)} = \frac{5{,}8875}{25} = 0{,}2355$$

Inoculum calculations

$$\text{Mass TS (Inoculum)} = \text{Mass Substrate} \times \text{TS (\%)}$$

$$\text{Mass TS (Inoculum)} \quad \frac{25\ (g) \times 7{,}7268}{100} = 1{,}9317$$

$$\text{Mass VS (Inoculum)} = \text{VS/TS (\%)} \times \text{Mass TS}$$

$$\text{Mass VS (Inoculum)} \quad \frac{56{,}7829}{100} \times 1{,}9317$$

$$\text{Mass VS (Inoculum)} = \frac{1{,}0968}{25} = 0{,}0438$$

Therefore,

$$\text{Mass (Inoculum)} \quad \frac{25g \times 0{,}2355 \times 2}{0{,}0438} = 268{,}83\ (g)$$

Figure 5.5: The inoculum (268,85 g) for the anaerobic digestion process

Figure 5.6: Day 1 of the anaerobic digestion process and the collection of biogas produced

Having outlined the data sources, Figure 5.7 shows the BMP test process employed to estimate the capacity of human waste to generate sustainable energy. Results of the BMP test are discussed in section 5.3 of this chapter.

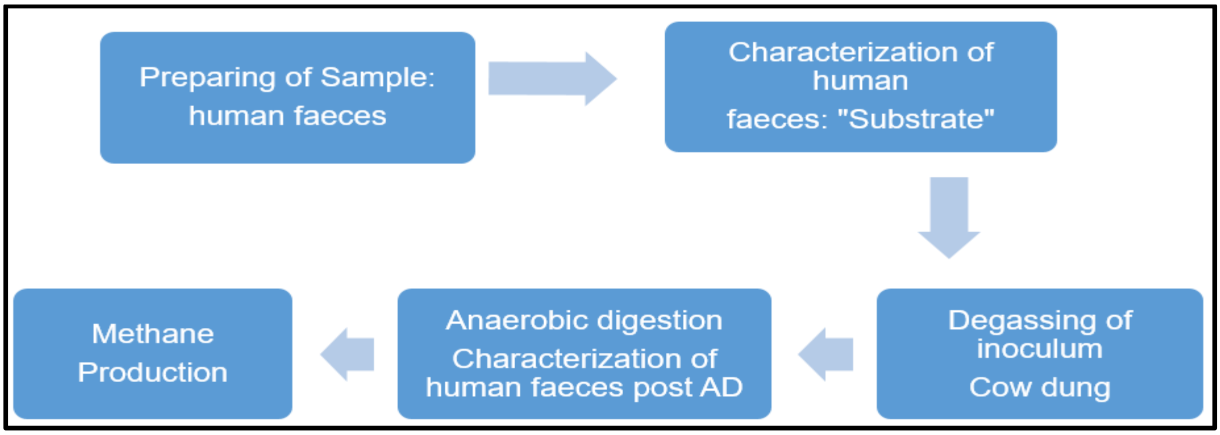

Figure 5.7: BMP test steps for estimating energy produced from human faeces

5.2.3. Data analysis

The results obtained from estimating the biogas production from human waste were compared with the biogas usability criteria and its equivalent outlined by Kristoferson and Bokalders (2013) as presented in Table 5.1. In addition, the study assumed that a 2 kW gas burner consumes 2 kWh per hour when operating at its maximum output (Electric Ireland, 2023).

The comparison was designed to determine whether the biogas produced from a specific quantity of human faeces will sustain energy requirements for cooking and lighting. To estimate the biogas produced, the study adopted the daily average of 400 g of faeces, which a human produce in a day (Weisberger, 2018). As indicated in Chapter four of this thesis, all the 108 schools have a feeding scheme, which entails cooking meals for the learners (Appendix 4). Experiments were conducted to deduce whether the biogas generated is sustainable for the schools to prepare the meals.

Table 5.1: Biogas usability and its equivalent

Application	1 m^3 biogas equivalent
Lighting	Equal to 60-100 watt bulb for 6 hours
Cooking	Can cook 3 meals for a family of 5-6
Fuel Replacement	0.7 kg of petroleum
Shaft Power	Can run a one horsepower motor for 2 hours
Electricity generation	Can generate 1.25 Kilowatt hours of electricity

Source: Kristoferson and Bokalders, 2013

5.3. Results and discussion

5.3.1. Characterisation of substrate

Implementation of biogas generation from human waste can only be feasible when the variables of the substrate are ideal and known. Any combustible waste can be used for energy generation but only those with the ideal pH, optimum total solids, moisture content, and volatile solids in adequate quantities would be suitable in efficient biogas generation process. Wang (2015: 240) reported that a substrate for biogas production should be analysed for total and volatile solids, alkalinity, and moisture content to mitigate any potential inhibition problems.

(i) *pH*

In this study, results of the BMP test revealed that the average pH value of human faeces was 6.4, which is within the limits of biogas production as proposed by other researchers. Singh *et al*. (2021:4) indicated that human faeces with a pH value of 7 provides the highest biogas yield. Appels *et al*. (2008:755) as well as Chen *et al*. (2014:1523) also noted that the accumulation of inhibitory compounds such as ammonia and hydrogen affects the pH of the substrate, which prevents biogas production and indicated that the optimal pH range for biogas production is between 6.0 and 8.5. However, Parkin and Owen (1986:867) recommends a range from 6.5-7.6 while Singh *et al*. (2021: 4) suggests 6.8 to 7.2; yet the process can withstand a range of 6.5 up to 8.0. Nevertheless, when the pH level increases beyond 9, toxic ammonia (NH_3) is formed, preventing methanogenesis during anaerobic digestion Appels *et al*. (2008:755).

(ii) *Moisture content*

Results of the characterisation of the substrate revealed that the moisture content ranged from 70-72 % with an average of 71.5 %. Singh *et al*. (2021:4) reported that moisture content of human faeces was 84 %, which is higher than cow dung (66 %) and poultry litter (29 %).

Thenabadu (2014: 9) conducted a study in Sri Lanka using municipal waste and found the moisture content value to be between 70 % and 80 %. Adjama *et al*. (2022:2) found the moisture content of human faeces sampled in Sunyani-Ghana to be 79.5% and Woolley *et al*. (2014:276) reported 78.3 % from the samples collected in Durban, South Africa. It should be noted that previous researchers indicated that age and diet have an impact on moisture content of human faeces. Adjama *et al*. (2022:3) noted that human faeces collected from adults contain more moisture than younger people as they drink more water, while Forsum *et al*. (1990) cited diet as an indicator impacting the moisture content composition of human faeces. This study did not look at the diet of certain age groups, however, it is worth noting that the age of the learners at the sampled schools falls in the range of 6 to 13 years old. Thus, the lower moisture content of the faeces obtained in this study in comparison to other studies (average 71.5 %) could be attributed to the younger age group. Sandra *et al*. (2016:47) stated that high moisture content is a supportive agent of biodegradation and is essential for bacteria to survive.

In addition, biological reactions can be slowed down if moisture content is recorded below 40 % and the reactions will entirely stop when moisture content is recorded below 20 % (Sandra *et al*. 2016:47). Sayara and Sanchez (2019:4655) also noted that a substrate that mostly comprises of solids and little moisture content slows down the overall biodegradation process. Therefore, the average of the moisture content (71.5 %) recorded in this study suggests a positive indicator of biodegradation for biogas production.

(iii) *Volatile solids*

Wilkie (2019) reported that total solids (TS) and volatile solids (VS) content are the most significant parameters for characterising a substrate. Volatile solids content is an indicator of potential methane production whereby increased gas generation is directly proportional to the amount of volatile solids found in the raw substrate, which is highly biodegradable (Mattocks *et al*.1984: 8). Schievano *et al*. (2011: 8814) reported that volatile solid content is valuable for determining the organic content of the feedstock.

Onojo (2013:199) cited that faecal matter is highly biodegradable. Similarly, Singh *et al*. (2021:4) recorded that cow dung had the highest volatile solid value of 88 % while human faeces recorded 81% and poultry litter recorded the lowest value of 78 %. Rose *et al.* (2015) reported that human faeces comprise 92 % volatile solids while Penn *et al.* (2018: 222) reported 88.5 %. This study reported that the substrate has an average volatile solid value of 82.7 %. Notably, as supported by Mattocks (1984:8), this study recorded a higher volatile solid (82.7 %) which suggests increased gas generation.

(iv) *Total solids*

The total solids content of feedstocks has a significant impact on anaerobic digestion because the higher the total solids content, the more difficult it is to breakdown the organic matter resulting to less production of biogas (Yi, 2014:2). The total solid content of the substrate characterised in this study was 28.5 %. These results are within the range of total solids found in human faeces as reported in the studies by Adjama *et al*. (2022:3) in Sunyani-Ghana (20.5 %), Forsum *et al*. (1990:177) reported 32.2 % and Rose *et al*. (2015) reported 25–54 %.

A study in India noted that total solids of poultry litter is 66 %, cow dung (20 %) while human faeces recorded the lowest (18 %). Ahmadi-Pirlou and Gundoshmian (2021:1938) observed that lower total solid content of municipal waste (5–10%) produced more methane of 230.3 mL/g unlike 25 % which produced 83.3 mL/g. A study by Andriani *et al*. (2015:223) suggests that for biogas production, organic matter in faeces that could be degraded was 50 % of total solids. This study's total solid average of 28. 5 % is within the range as suggested by Rose, (2015), optimum value for increased breakdown of organic matter and biogas production.

5.3.2. Degassing of inoculum "Cow dung slurry"

Although Elbeshbishy *et al*. (2012:18) studied the impact of inoculum pre-incubation and reported no significant difference in methane generation or biodegradability compared to non-incubated inoculum, other researchers have noted the significance of incubated inoculum. Incubation of the inoculum is broadly recommended in literature, since it is a significant variable that impacts on the production of methane (Li *et al*. 2013:127; Raposo, 2012:861; Qamaruz-Zaman & Milke, 2008:1).

As such, this study used cow dung slurry as an inoculum during the anaerobic digestion process. Filer *et al*. (2019:4) recommended the incubation of inoculum for one to five days at mesophilic temperature to degas and decrease the impact of its methane production as outlined in the German guideline for fermentation tests (VDI-Handbuch, 2006). Raposo *et al*. (2012:1444) supported that degassing should be prolonged until there is no significant methane production, with an incubation period of 2-5 days. However, Li *et al*. (117:2013) reported that pre-incubation of the inoculum can go up to 21 days depending on the inoculum source, especially if the reactor is fed with high content of fats or oils. Angelidaki *et al*. (2009:927) also noted that incubation periods can be prolonged, to reduce all the residual substrate. This was the case in this study as the experiment was concluded after 12 days where the biogas generation plateau was achieved (Figure 5.8). Therefore, cow dung slurry was used as inoculum during the anaerobic digestion process. The readings of the biogas produced from the six reactor bottles was collected at a 24hr interval at 15:00hrs.

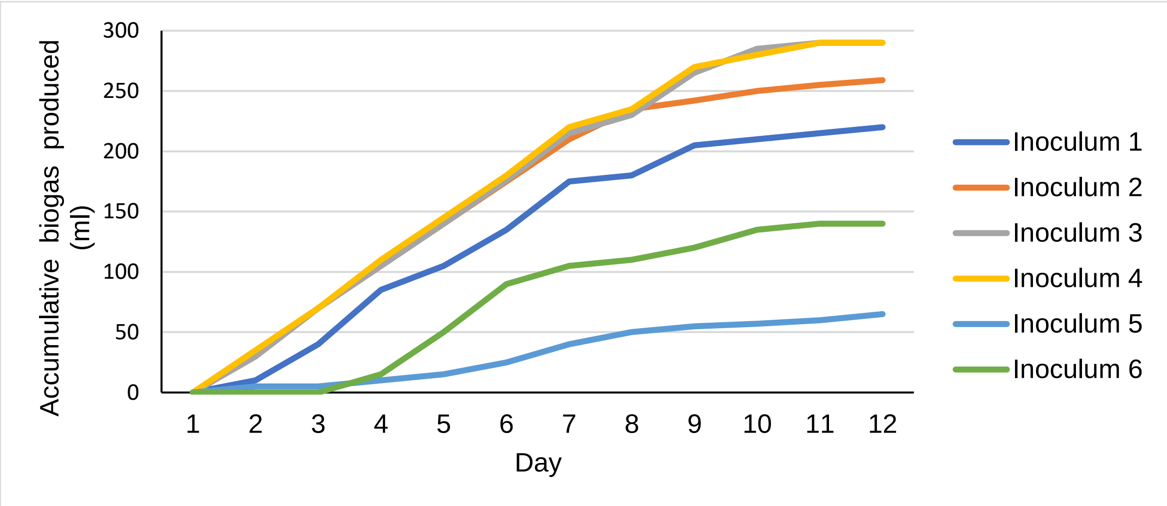

Figure 5.8: Cumulative biogas production from inoculum “cow dug” slurry

In addition, Holliger *et al*. (2016:2515) and Abudi *et al.* (2020:887) stated that the recommended optimal inoculum range for pH should be between 7.0- 8.5. Chandra *et al*. (2012:1462) studied the impacts of pH value during anaerobic digestion and found that pH value higher than 8.5 has toxicity effects on the anaerobic digestion. This study found an average pH value of 7.9 and is within the recommended conditions, which suggests that the inoculum can be used during the anaerobic digestion as a catalyst.

5.3.3. Anaerobic digestion

5.3.3.1 Daily biogas production

Dahunsi and Oranusi (2013: 489:492) noted that the anaerobic digestion of human faeces lasted for 60 days, and generated biogas composition containing 58 % methane (CH_4). Poocheera *et al.* (2014: 1105) reported that the methane produced from human faeces was 67.6 % within a 40-day cycle experiment. Singh *et al*. (2021: 101551) carried out a similar experiment for 52 days, citing that the composition of human faeces varies from one human being to another, which impacts on biogas generation. Raposo *et al.* (2012: 861) argued that the incubation time ranges from 30 to over 100 days, which is highly dependent on the biodegradability of the material.

Therefore, in this study, the experiment ran for 69 days, and the significant amount of biogas (1720 mL) was produced between the 3rd and the 10th day. However, there was a gradual decrease of methane produced from the 11th day to the 17th day (i.e., from 1780 mL to 946 mL). A steady decrease was noted from day 20 while minimal and no biogas was produced from the 62nd day to the 69th day (Figure 5.9). These results are similar to the findings by Adjama *et al.* (2022:3) which reported an increase in biogas production from day one to five (2296 ml) and a decrease from day six to ten with methane production from 2 296 mL to 1 749 mL. From day 11 to 20 a slight similarity of methane production was reported (1 500 mL) and a gradual decrease up to day 30.

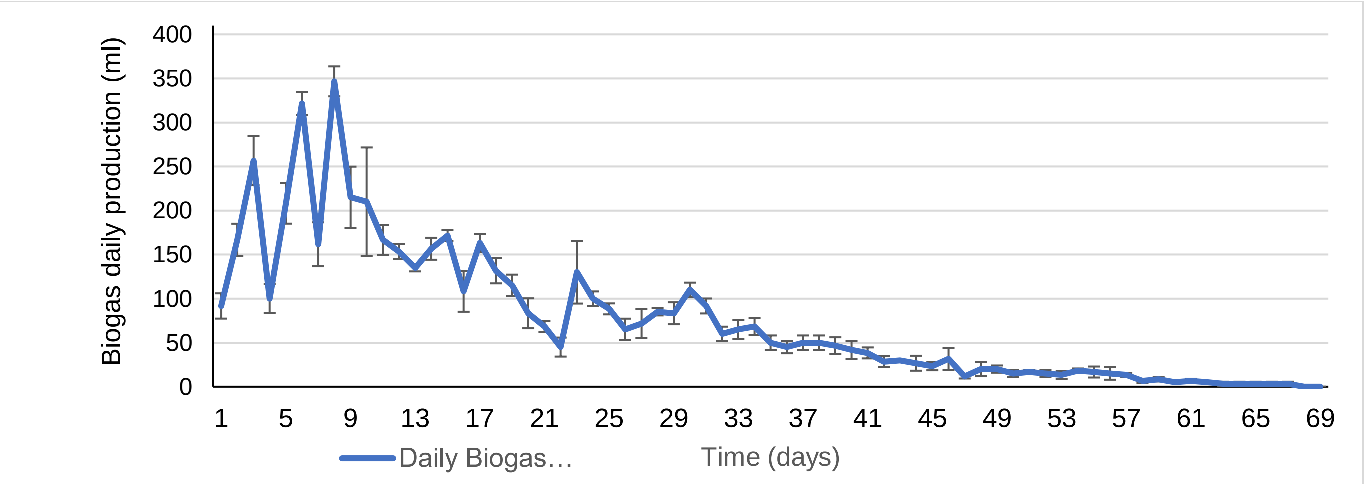

Figure 5.9: Daily biogas production from the "human faeces" substrate

The continuous decrease of biogas from the 20th day could be explained by the decrease in volatile solids (48.4 %) and the decrease of nutrients contained in the faecal matter over time. This situation results in the reduction in methanogenic bacteria population resulting in low methane production (Andriani *et al*., 2015:219; Azman *et al.,* 2015:2523; Nopharatana *et al*., 2007:595). Notably, the volatile solids of the human faeces in this study were recorded at 82.7 % before anaerobic digestion (AD) and had reduced to 48. 4 % after the process (Figure 5.10), which is within the acceptable range as suggested in other studies. For example, Novak *et al.* (2011:618) reported 50 % of volatile solids reduction while Grűbel *et al.* (2013:349) reported 44 % of volatile solids reduction. The acceptable range of volatile solid reduction after the AD process is between 45-50 %, which is a metric used to assess the effectiveness of the process.

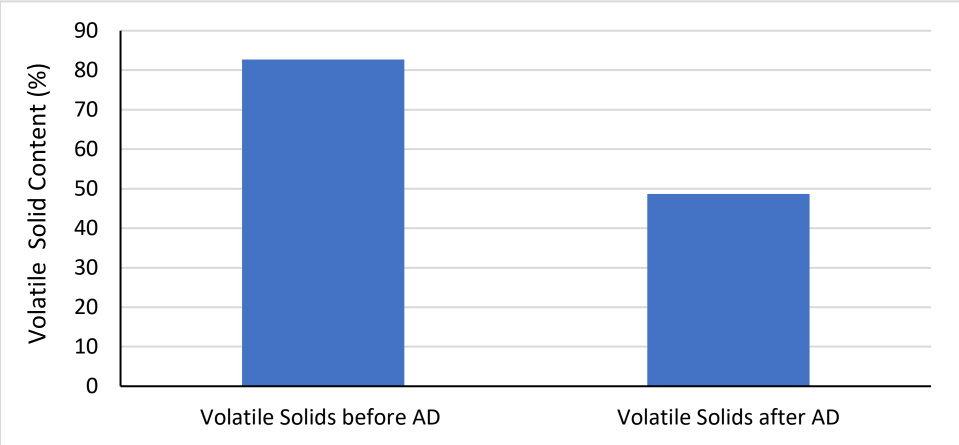

Figure 5.10: Volatile Solid content before and after AD process

The findings are further supported by Kouzi *et al.* (2020: 28155) who cited that biogas generation slows down towards the end of the process due to inhibitory factors such as non-digestible biomaterials found in human faeces such as fats and carbohydrates. In this study, the recorded results suggest that the AD process of the substrate was fully incubated rather than being interrupted by inhibitory factors. The biogas generated was monitored and collected up to its minimal point (Figure 5.9). Therefore, the observation from this study agrees with other researchers who reported that a fraction of the organic material in the final phase of biogas production is not microbiologically degradable resulting to no biogas generation (Tyagi & Lo, 2011:215*;* Weiland, 2010:846; Chen *et al.,* 2007:683), hence the gradual decrease in biogas production from day 62*.*

5.3.3.2 Cumulative biogas

The daily biogas production was monitored and recorded to calculate the corresponding cumulative biogas volume (mL). Comparatively, this study observed cumulative biogas of 5280 ml during the 69-day cycle, while the study by Singh *et al (*2021:5) observed 6720 mLl for a period of 52 days and Poocheera *et al.* (2014:1103) reported 1865 ml over a period of 40 days. Figure 5.11 demonstrates that the purpose of pre-incubation to minimise the gas production from inoculum which was used as a catalyst, was achieved and this is further supported by the degassing results where the biogas generation plateau was achieved (Figure 5.8). Therefore, the inoculum had no influence on the daily biogas produced.

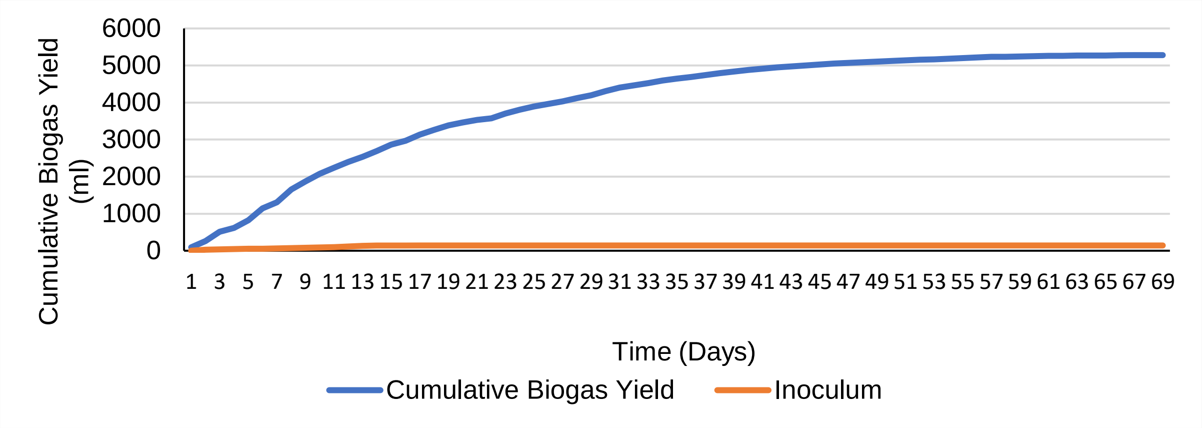

Figure 5.11: Cumulative biogas production from substrate "human faeces"

5.3.3.3 Methane content

As noted in literature, the composition of methane in biogas ranges between 50-70 %, (Li *et al*., 2019: 11567; Yadav & Hesse1981) while Ezekoye *et al.* (2011:53) suggest 40-70%. Several empirical studies have reported different methane content produced from human faeces. Cook (2010) studied the generation of biogas from human faeces and reported 60 %, Jha (2005) reported 60 %, Duan *et al*. (2020:1) observed 50 % and Khanto and Banjerdkij (2013: 236) recorded 48 % of methane (CH_4) composition. In this study, from the three sets of substrates, an average methane count of 54 % was recorded (Figures 5.12 and 5.13).

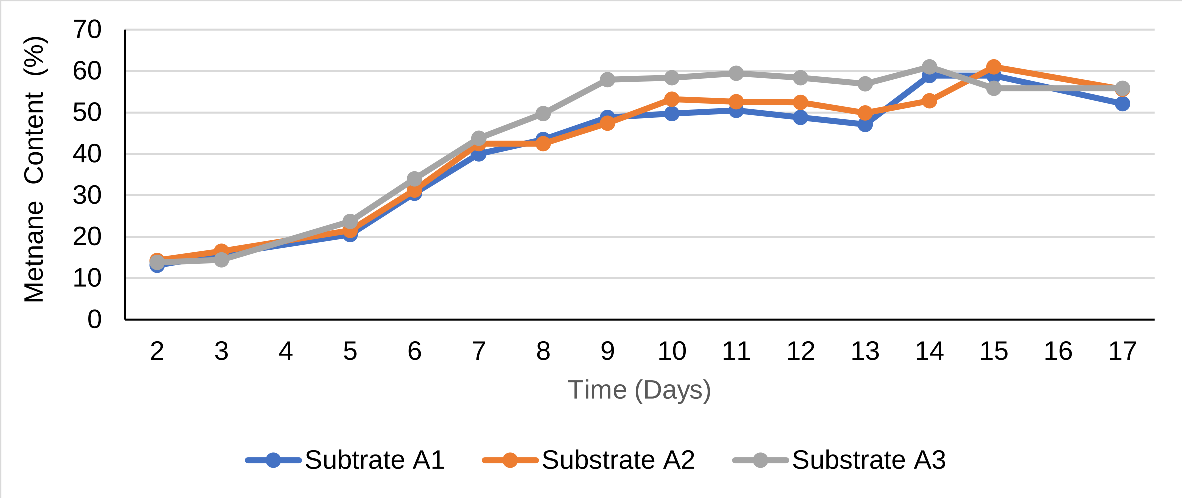

Figure 5.12: Methane gas production from substrate "human faeces"

Several factors have been attributed to the variations in methane composition. The study by Duan *et al*. (2020:1) reported that the 50 % of methane content was due to the high concentration of ammonia from the high pH levels, which inhibited the reactor performance. Khanto and Banjerdkij (2013: 236) and Rose *et al.* (2015:1827) cited non-biodegradable material contained in the human faeces such as carbohydrates, fibre, protein, and fat, which is highly dependent on an individual's diet, inhibited the reactor performance. In this study, the pH level after the AD process was found to be 6.2, therefore the 54 % content of methane is not attributed to the pH level but rather the methanogenesis in human faeces dependent on the diet.

To explain the variation in methane content, Emetere *et al.* (2022: 4) reported that microbes, which are responsible for methanogenesis in human faeces are dependent on the diet of the individual. Vanderhaeghen *et al*. (2015:1) examined faecal samples and found that out of eight, people only five produce methanogen and 65 % of children carry methanobacteriales while 89 % is carried by adults. Notably, this study collected faecal samples at a school with learners between the ages of 6-13 years. As reported by Vanderhaeghen *et al.* (2015:1), only a fraction of children (i.e., 65 %) carry methanobacteriales in their faeces which is responsible for methane generation, and this explains the 54 % methane content reported in this study.

5.3.3.4 Potential biogas produced from human faeces

From the study experiment, the cumulated biogas produced from 25 g of faeces was 0,00528 m^3 in 69 days and the maximum production rate per day was 0,000346 m^3. To calculate the sustainability usage of the cumulated biogas produced from the human faeces substrate collected from the school, the following assumptions were adopted:

(i) Previous studies have reported individual faeces production to be an average of 400 g (Weisberger, 2018), 520 g (Torondel, 2010), and 796 g which includes adults above 18 years of age (Rose *et al*. 2015:1833). This study adopted the daily average of 400 g of faeces reported by Weisberger (2018).

(ii) Based on the study population, one learner is likely to produce 0,129 m^3 of gas per day and the total learners (483) from the sampled school are likely to produce 62,66 m^3.

(iii) Considering the calorific value of 22 MJ/m^3 and the mega joules unit of 3.60 MJ, the energy yield of 62,66 m^3 gas produced from human faeces is 1,378.52 MJ/day or 382,92 kWh/day. Therefore, a biogas generator using 382.92 kWh can run for approximately three days.

According to the Limpopo primary schools' nutritional plan, the menu for the learners is as follows: Monday (rice with fish and butternut), Tuesday (samp with beans and cabbage), Wednesday (thick maize porridge with milk) Thursday (thick maize porridge with beans and cabbage), and Friday (thick maize porridge with fish and butternut) (Appendix 4). For cooking, a normal gas burner uses 2 kWh in one hour when operating at maximum output (Electric Ireland: 2023). For lighting, Kristofferson and Bokalders (2013) noted that 1 m^3 can operate a 60–100 W bulb for six hours and generate 1.25 Kilowatt hours of electricity.

Therefore, the above-mentioned nutritional meals can be prepared by the daily amount of biogas produced by the learners (62.66 m^3) as 2 m^3 can burn for approximately 1 hour. Tables 5.2 and 5.3 indicates the amount of biogas required to prepare the nutritional meals and the energy which could be used for lighting. From the daily production of 62, 66 m^3 the maximum energy needed for cooking is 9 m^3 on Tuesday and the minimum being 2 m^3 on Wednesday.

The school has 40 (32W) fluorescent tube lights which require 40 m^3 and are selectively used, primarily on overcast days or when required. The school does not illuminate the school during the night because it relies on the community Apollo lights for lighting. After cooking and lighting, the daily minimum surplus is approximately 13.66 m^3 and maximum is 20.66 m^3, which can be diverted to other energy needs within the school or sell the biogas to the locals to generate revenue for the schools. Notably, for a continuous biogas generation process, it is crucial that the human waste feedstock is introduced to the anaerobic digestion process daily as reported in this study that the significant amount of biogas is produced between the 3rd and the 10th day.

Table 5.2: Biogas usability and its equivalent within the school

Menu prepared	Duration for preparing	Biogas needed (m^3)	Duration of combustion
beans	2 hours	4	2 hours
Fish	30 minutes	1	30 minutes
Samp	2 hours	4	2 hours
Butter nut	30 minutes	1	30 minutes
cabbage	30 minutes	1	30 minutes
Thick maize porridge	1 hour	2	1 hour
Rice	1 hour	2	1 hour
Soya mince	30 minutes	1	30 minutes

Table 5.3: Biogas required (m^3) for preparing the nutritional meals and lighting

Day	Biogas for cooking	Biogas for lighting	Total	Daily energy surplus
Monday	4	40	44	18.66
Tuesday	9	40	49	13.66
Wednesday	2	40	42	20.66
Thursday	4	40	44	18.66
Friday	4	40	44	18.66

Based on the research findings in Chapter four, the schools view the EVIP as a toilet rather than a sanitation technology, which has both environmental and economic benefits. Notably, the school buys gas to prepare the daily meals and this practice was also reported by 41 % of the schools. However, the practice of biogas generation from human faeces collected from the EVIP toilets can be regarded as sustainable based on the biogas produced per day (66.62 m^3).

The utilisation of human faeces for biogas generation serves a dual purpose by producing energy while simultaneously addressing the pressing environmental challenges in the country caused by unmanaged human faeces disposal due to dysfunctional sewage plants which are responsible for polluting 80 % of South Africa's freshwater resources. In addition, the proposed sustainable energy generation from human waste can be regarded as a solution to the energy crisis in South Africa as well as a move away from fuelwood. This study reported that 31 % of the schools rely on wood as a source of energy while 20 % rely on electricity supplied by ESKOM. Therefore, with the persistent load shedding the proposed sustainable energy generation system can be regarded as a solution which reduces deforestation.

This study did not perform further analysis of the bio slurry/residue after the AD process as reported by Mata-Alvarez *et al.* (2000:9), who noted that the safety use of the bio slurry is measured by the present pathogen concentration such as *Salmonella* spp., *Escherichia coli*, *Shigella* spp.

This study reported that 75.9 % of the respondents disagree that human faeces can be used as fertilizer while 66 % will not consume the crops fertilized by human waste citing health reasons. However, the remaining bio slurry can be used for agricultural purposes as suggested by Hammes *et al.* (1999:197); Schuster-Wallace *et al.* (2015:13), which can be further treated through a process known as incineration for the safety of the end users.

5.4. Chapter summary

There is a growing demand for energy supply, and this can be supported by the persistent load shedding schedules in South Africa. However, based on the research findings, it is evident that human waste has the potential to serve as a viable source of biogas, which can be converted into a significant amount of energy for cooking and lighting through the biodegradation of organic material under anaerobic conditions by methanogenic bacteria. It is reported that methanogenesis is particularly sensitive to both high and low pH and occurs optimally within a pH range of 6.0 to 8.5. The results of this study note that the methanogenesis process was not affected by the pH level (6.2) but the reduction in volatile solids (48.42 %) and the non-gradable material in human faeces.

The biogas produced was monitored to its minimal production where the cumulative gas from day 68-69 was recorded at 0 mL. The accumulated biogas production from 25 g of faeces was recorded at 0, 00528 m^3 within a period of 69 days with a maximum production of 0.000346 m^3. The schools have a feeding scheme and from the biogas produced by the learners (66.62 m^3), can prepare the meals based on the assumption that 2 m^3 can burn for approximately 1 hour. In the next chapter (Chapter 6), a sustainable water consumption and energy Ecological sanitation framework has been developed as the study findings suggested a positive correlation between water consumption reduction and EVIP, including energy generation from human faeces. Analysing the impacts of the adoption of EVIP as a sanitation technology with the aim of reducing ***W****ater consumption*, generating ***E****nergy*, reducing ***D****eforestation* and decreasing ***S****ewage* waste, this research developed an inclusive conceptual framework called Eco-WEDS.

6. CHAPTER 6: SUSTAINABLE WATER CONSUMPTION AND ENERGY ECOLOGICAL SANITATION CONCEPTUAL FRAMEWORK.

This chapter seeks to detail the sustainable water consumption and energy generation Ecological sanitation framework. The results discussed in chapters 3, 4 and 5 of this thesis were used as basic input elements for developing the conceptual framework, which will outline the fundamental relationships that exist between EVIP sanitation technology, water reduction, and energy generation.

6.1. Introduction

Maher and Lustig (2003:47) highlighted that a significant amount of energy is expended in the production of drinking water. However, this drinking water is often used for flushing waste, which is an unsustainable practice. Maher and Lustig (2003:47) noted that lot of energy is invested to produce drinking water, yet the drinking water is used for flushing waste, which is not a sustainable activity. To optimise water usage and thus promote sustainability, it is crucial to adopt water management strategies such as waterless sanitation technology. This practice can also be applicable to South Africa as all the 970 water treatment plants are energy powered, treating an average of 7 589 000 kilolitres of water daily for drinking. However, the use of treated water for flushing waste at a rate of 6 litters per flush is unsustainable, especially with the energy crisis and water shortages where the conservation of energy and water should be a prioritised practice.

In developing countries, flush toilet systems are regarded superior compared to the drop and store methods (Water Wheel, 2005:24). In addition, developing countries have redefined the reduction of poverty in terms of improved sanitation to a standard of flush toilets (Töykkälä, 2013:5). However, it can be argued that such a practice is not sustainable in energy and water-stressed regions, regardless of the intention to reduce poverty especially bearing in mind that dysfunctional water-based systems can be far worse due to environmental and health risks than waterless sanitation systems.

Ecological sanitation such as EVIP offers an alternative to water-based systems, with the aim of achieving ecological and economical sustainable sanitation. This can also be a solution to poverty alleviation, if properly used and maintained as the main idea of system is also rooted on the concept of a nutrient cycle, where waste is regarded as a resource to produce energy and fertilizer for crop production. However, the EVIP toilets introduced within the Capricorn District, Limpopo, requires a conceptual framework aimed at achieving ecological and economical sustainable sanitation.

The statistical tool Chi-square was used to assess the correlation between variables and to calculate the statistical significance which guided the hypothesis of the study. In this context, the tested variables included the relationship between the condition of the toilet and the duration of the toilet, the induction and the number of toilets; relationship between the number of toilets and the reusing of waste, induction and the method of waste disposal used when the toilet is full and relationship between duration and reuse of human waste, induction and the method of waste disposal when toilet is full, and perception on the reuse of human waste. The above-mentioned factors indicated the degree of the effective implementation of EVIP. Besides, a BMP test was carried out to estimate the potential quantity of biogas that can be produced from human faeces to integrate the energy benefit into the already existing initiative focused on providing safe and dignified sanitation facilities.

6.2. Conceptual framework

The conceptual framework was informed and developed based on the parameters of the empirical evidence gathered from the outcomes of the study. The relationships of the framework are sourced in Chapter three which assessed the effective implementation of EVIP; Chapter four, which evaluated the potential of the EVIP in reducing water consumption while Chapter five examined the capacity of human waste to generate sustainable energy. The research developed an inclusive conceptual framework called Eco-WEDS (Figure 6.1). The developed framework consists of two dependent variables (Effective use of EVIP and Feedstock) as well as four independent variables (Water consumption reduction, Energy generation, reduction of Deforestation, and less Sewage waste). The essential factors are denoted by the dependent variables that can critically reduce water consumption, deforestation, and sewage waste and increase energy generation.

6.2.1. Theoretical base of Ecological sanitation and management

In the field of sanitation, Mensah (2020) developed a theory-anchored framework for Environmental Sanitation Management (ESM), primarily emphasising three theories: participation, behavioural change, and systems theory. The notion of participation encourages stakeholders to actively participate, and the theory of systems supports this by stating that successful methods to ESM should capitalise on the advantages and complementary abilities of the engaged parties. Conversely, the behavioural change approach contends that as attitudes and behaviours are what ultimately guide practice, controlling them is essential to accomplishing ESM. This theoretical base guided the development of the conceptual framework.

Ecological sanitation systems have been in use since the 1970s and the noted key factors underpinning the sanitation systems as noted by Langergraber and Muellegger (2005), Shonde (2016), Werner *et al.* (2003), is the waterless nature, which requires less or no energy, and has the potential to close the gap between sanitation and agriculture. Moreover, the Ecological sanitation system is regarded as a sustainable sanitation approach that lessens the burden on infrastructure, protect the environment such as water bodies by reducing water pollution from dysfunctional sewage systems and the provision of sanitation in waterless and water stressed regions.

Notably, this study does not only support the waterless nature of the sanitation technology (EVIP) but also promotes water consumption reduction. EVIPs could sustainably generate energy from the human waste collected from the sanitation technology which also promotes protection of the environment and reduce deforestation. The critique of the EVIP within the Capricorn District is that the Department of Education concentrated more on the provision of sanitation and less on the Ecological sanitation practice. Meanwhile, the practice being very crucial due to the electricity crisis and the pollution of water bodies due to untreated waste.

6.2.2. Rationale of the proposed conceptual framework

The rationale for the proposed conceptual framework is to provide the Department of Education and other stakeholders within the Ecological sanitation space with an integrated framework which mirrors factors for effective implementation of the EVIP toilets. In this study, effective implementation is defined as the proper usage of EVIPs, reuse of waste material and the proper management of the EVIP. Therefore, it can be posited that the three theories from the ESM were used as guiding principles for developing the EVIP conceptual framework. From the existing literature review, it can be argued that studies on EVIP captures relevant issues such as socio-economic operations, benefits of compositing, health and hygiene.

Nonetheless, a prevalent criticism is that the conceptualisations lack adequate practice-based rather than framework-based foundation. Mensah and Graham (2019) also reported that sanitation management studies are more focused on practice then being grounded on frameworks. Akintunde, (2017) and Tidwell *et al.* (2018); and Weber *et al.* (2019:384) further indicated that practices that are informed by frameworks achieve better results. Hence, the crafting of Eco-WEDS for the Capricorn District as the framework has the potential to promote effective Ecological sanitation practice. This study further argues for a more comprehensive Ecological sanitation framework that captures informed management systems, water consumption reduction and energy generation as the provision of the toilet alone impacts on achieving the idea behind Ecological sanitation.

6.2.3. Assumptions for the proposed framework

The assumption of the proposed framework is guided by the background knowledge of achieving effective implementation of EVIP as highlighted in Chapters three to five. The following assumptions are put forward for the proposed framework:

(i) The schools that have been inducted manage the toilets better and the toilets are in a better condition. This assumption focuses on the induction or awareness campaigns, which informs proper management and the state of the toilet. Conditions of the toilet play a vital role because each element of the toilet plays an important role in ensuring the effectiveness of the ecological sanitation process.

For instance, the ventilation pipe allows the waste to be exposed to continuous airflow, which helps prevent the breeding of pathogens and foul smell.

(ii) Perception and attitudes inform the adoption and practice. In this regard, the assumption entails that culture, religion, personal and hygiene related reasons influence the adoption and practice of Ecological sanitation technologies i.e., thinking and belief system shapes the attitudes and behaviour towards sanitation management and practice.

(iii) The schools that have more toilets, improved knowledge and have used the toilets for a longer period are likely to reuse the waste from the toilet. It is assumed that the school with improved knowledge such as the perceived benefits and have more toilets as the practice is sustainable in terms of feedstock are likely to use the waste from the toilets.

This assumption is based on the attainment of more experience in using the toilet and possible adaptation to the Ecological sanitation practice.

(iv) The effective implementation of Ecological sanitation can generate energy that will sustain the school's feeding scheme. Ultimately, using biogas generated from human waste could reduce deforestation and sewage waste including the dependency on energy generated by ESKOM.

(v) Adoption of Ecological sanitation will reduce the daily water consumption rate and assist with water conservation as the sanitation technology does not require water to dispose the waste.

(vi) The study assumes that effective implementation of EVIP requires a collaborative stakeholder effort, which includes the end-users, the community at large and the private and public sector.

6.2.4. Proposed conceptual framework: The Eco-WEDS

Based on the research findings, there is a compelling need for a conceptual framework to guide the stakeholders on the effective implementation of the EVIP toilets within the schools in the Capricorn District. The relevant question is; what concepts are important for Eco-WEDS and how do they relate to offer an effective solution to the sanitation practice challenge?

The relationships between the variables of the Eco-WEDS framework have been represented in three ways: the dashed arrows indicate the fundamental aspects of an efficient Ecological sanitation process, hallow arrows signify the direct relationship between variables for achieving effective Ecological sanitation, while the solid arrow lines represent the perceived environmental benefits of a successful Ecological sanitation practice. Within the framework concept, direct relationship for example means perception and perceived benefits which could influence the effective implementation and the usage of the Ecological sanitation technology (EVIP). In addition, indirect relationships might not be directly seen, however, the impact of the variable is likely to have an influence, for example, the feedstock impacts on energy generation which can influence the effective implementation in terms of energy recovery.

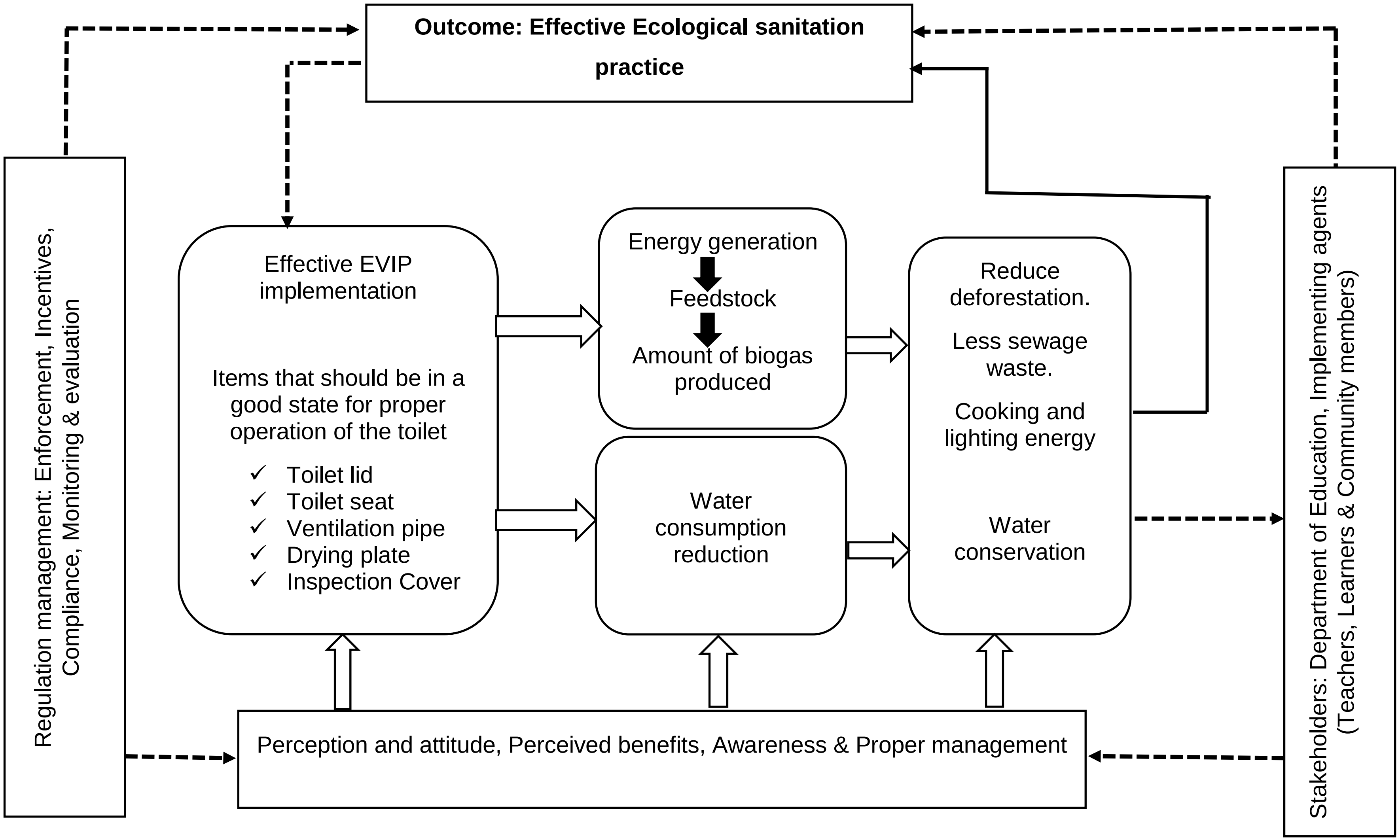

Figure 6.1: The Eco-WEDS Framework for sustainable energy production and water consumption reduction

The framework Eco-WEDS entails the integration of two main pillars, namely: stakeholders and regulation management which collectively influence proper management, perceived benefits, awareness, perception, and attitude. The considered variables of the **regulation management** include enforcement, incentives, compliance, monitoring, and evaluation. In this context, the relevant stakeholders should enforce effective measures such as rigorous monitoring and evaluation methods which incorporate operational and maintenance standards. These standards serve as a base for ensuring compliance and ultimately achieve proper management of the sanitation facility i.e., an inspection system. In addition, effective implementation can be encouraged by introducing incentive programs of awarding schools that excel in the Ecological sanitation practice and such an approach can ultimately reshape the perception and attitude of the users. A concept of social influence should simultaneously be used as a compliance management system. Enforcement can also be achieved by thorough user education and awareness as noted in the knowledge-attitude-behaviour change theory by Matthews and Riley (1995). Awareness increases knowledge which can lead to reshaping attitude and subsequently influence the practice. The underlying assumption is that imparting knowledge on the perceived benefits, initiating incentives, implementing supportive regulations, and enforcing monitoring and evaluation tools for proper management and compliance, can collectively contribute to achieving the effective implementation of the EVIP.

The sanitation stakeholders (government and private sectors, learners, teachers, and community members) should not work in silos because the complexity of Eco-WEDS makes the multi-stakeholder approach a prerequisite for effective implementation. Therefore, at this phase of the framework, it is the collaborative and coordinated efforts of stakeholders to support the users to spearhead the effective implementation. In addition, as far as effective implementation is concerned, the framework notes that the key dimensions that influence the effective implementation are: Perception and Attitude, Perceived Benefits, Awareness and Proper Management.

The framework places emphasis on the concept that **Perception and attitude** plays a role to adapting to a new practice or new technology, especially where there is a lens of hygiene, cultural and religious barriers which shapes how users perceive and interpret a new practice. This was also supported by Daughton (2004:127), who reported that perception can be informed by feelings, ethics, preferences, and attitude. The findings of this study reported that the perception of the EVIP sanitation is rooted in culture and religion, which hinder the effective implementation, especially in the terms of nutrient and energy recovery. However, it is suggested that perceived benefits and awareness are likely to change the perception of the user and effectively implement and use the EVIP. The key principle in this regard is that if something is perceived as beneficial by the users, they are more likely to be receptive and willing to adapt, thereby enhancing the daily practice. As a result, if users are completely aware of the benefits and exposed to the benefits overtime, coupled with experience, they are likely to effectively practice and view the EVIP toilets as an Ecological sanitation technology that will assist in achieving Eco-WEDS.

Another factor captured by the framework is **Awareness.** The role of awareness abounds in the education and impartation of knowledge to the new users. When introducing a new concept or idea, awareness empowers users to make informed decisions and demystify the negativity mainly centred on a perception induced by culture or religion. As noted from the behavioural theory, awareness and user education are tools for behavioural change as the increased knowledge base on sanitation practice ultimately results to adoption. In addition, the core principle of the participation theory asserts that even though the change agents initiate the process, the ultimate beneficiaries of the development must be involved and be aware of the intervention, so they take ownership, thereby contributing to its sustainability.

If the users are not aware of the motive, perceived benefits, and management system of the technology, Eco-WEDS objective will not be achieved because culture and religion will be the foundation shaping their perception towards the EVIP toilet. Ecological sanitation has been perceived or portrayed as a temporary solution for the poorest of the poor as the systems are mainly developed and tested in rural settings, a case of the EVIP program within the schools in South Africa.

Therefore, raising the Ecological sanitation status through awareness programmes, inductions and targeted areas is imperative in order to achieve its social and environmental success because sanitation types seem to be classified according to economic status and such hinders adoption.

The Eco-WEDS framework also highlights that all the four direct factors (Perception and attitudes, Perceived benefits, Awareness, Proper management) which influence the effective implementation and usage are interconnected. In other words, the level of **Proper Management** of the EVIP fully relies on the perception and attitude of the users, perceived benefits, and awareness. Notably, the systems theory advocates for the involvement of the relevant stakeholders when managing sanitation as they play a crucial role in achieving the set objectives. Furthermore, Mensah (2020) put forth the proposal that for effective sanitation management, there should be a simultaneous implementation of both hardware (infrastructure management) and software (education and regulation). The Eco-WEDS framework also denotes that if the three factors (perception and attitude, awareness, and perceived benefits) are in place, proper management of the EVIP is guaranteed, resulting in the effective implementation and usage. Effective implementation is further dependent on toilet items being in good state as each item plays a crucial role in the functioning of the EVIP system. Therefore, proper management within the Eco-WEDS framework addresses more than one element of Ecological sanitation: integrated water resource management which addresses the water consumption reduction, economic development through energy generation also resulting to deforestation reduction, sustainable agriculture leading to the reduction of poverty, and environmental management by eliminating the pathogens in human faeces resulting from less flow of sewage through a concept of onsite renewal of waste to generate energy.

The framework further points out the success of the Eco-WEDS within the context of energy generation, which is influenced by the feedstock where the concept of sustainability is of significance. An indirect relationship between effective implementation and feedstock was indicated, which guarantees the accumulation of human faeces i.e., “feedstock’’, directly impacts on the sustainable generation of energy from human faeces. Feedstock plays an important role in the sustenance of the energy generation system.

6.3. Chapter summary

This chapter offers a comprehensive explanation of the development of the conceptual framework. It outlines the relationships between dependent and independent variables, as well as the parameters derived from the empirical evidence obtained through the outcomes of objectives 1-3. The key variables for the achieving Eco-WEDS is the effective implementation and feedstock, which suggests the sustainability of the ecological practice within the schools as energy generation is highly dependent on the feedstock.

In summary, the framework, inculcates that the effective management of Ecological sanitation technology is vital and such is aligned to the sustainability principles; protection of the environment, promoting public health through reducing waste disposal, and enhancing agricultural practice and fostering sustainable economic development through a water conservation practice where human waste is managed without using water and energy generation which reduces the rate of poverty and deforestation. The proposed framework offers the stakeholders an opportunity to achieve an effective ecological practice within the schools.

Notably, based on the framework the waste collected by the EVIP generates energy and on the other hand, it requires no energy for treatment as compared to the traditional flush systems, reducing the overall energy footprint through treatment. Environmental and economic aspects were considered when developing the Eco-WEDS framework and this indicates that the suggested system is sustainable, capable of enduring for an extended period, yielding economic benefits, and making a positive impact on the environment. The next chapter (Chapter 7) presents the summary of the research findings, research contribution to knowledge, research limitations, and areas of further research, recommendations, and conclusion.

CHAPTER 7: CONCLUSION, RECOMMENDATIONS AND CONTRIBUTIONS

This chapter provides a concise summary of the study findings, contribution to knowledge and recommendations, which serve as a bridge between the research findings and actionable steps. The chapter further indicates the limitations of the study and identify knowledge gaps for future research. The last section provides the conclusion of the study to synthesise the key elements of the study.

7.1 Introduction

With the on-going water and energy crisis in South Africa, it has become of significance to adopt practices aimed to conserve water and generate alternative energy to augment the supply. Ecological sanitation technologies have been developed and offer numerous benefits, including water saving and energy recovery but faces certain stigmas and challenges in its adoption. The key objective of this study was to develop a sustainable Ecological sanitation conceptual framework for water consumption reduction and energy generation to promote Sustainable Development Goals number 6 and 7, which aim to ensure “sustainable management of water and sanitation for all” and “provision of affordable clean energy” by the year 2030 respectively. The study was conducted at the schools within Limpopo Province where EVIP toilets that allow safe reuse of nutrients from human waste were introduced as a solution to eradicating pit toilets. However, it was noted that little is known about the success of the implementation in terms of both sustained use of the toilet and the reusing of human faeces.

7.2 Summary of findings

The Section 27 report (2023) and EE (2023) noted that the Limpopo province schools are embedded with electricity, water, and sanitation challenges. Specifically, 133 schools do not have access to water, 210 schools still rely on pit toilets and out of a total of 4 239 schools, only 33 schools have uninterrupted electricity supply during load shedding. The Ecological sanitation drive within the schools in the Limpopo province necessitated the need to find sustainable solutions as the sanitation technology does not only offer a secure sanitation system but also presents economic and environmental advantages that schools can harness and leverage.

However, De Groot and Steng (2009:1) observed that adoption of new sanitation technology is unsuccessful because the benefits are not thoroughly communicated. Moreover, culture and religion inhibit the acceptance of sanitation technologies. This study also noted that the unsuccessful implementation of Ecological sanitation within the schools was attributed to various factors such as personal perceptions influenced by culture, religion and hygiene, and user education where thorough demonstrations were not incorporated to illustrate the perceived benefits. In addition, the Water Wheel, (2005:24) revealed that Ecological sanitation is perceived as a temporary and alternative sanitation technology, meant only for the poorest of the poor, which results to minimal practice. Similarly, within the context of this study, the fundamental idea behind Ecological sanitation was not fully explored as 99.1 % of the schools do not view the waste collected by the EVIP as a valuable resource but rather find themselves in a perplexing situation when the toilet is full. Also, the condition of the toilets not only hinders the proper functioning but has a major impact on the effectiveness of the toilet system and success of the Ecological sanitation approach. The shortcomings of the effective implementation of the EVIP sanitation technology necessitated the need to develop the Eco-WEDS conceptual framework which will assist in achieving both sustainable economic and environmental aspects. The study further suggested that to achieve Eco-WEDS, the following factors also play an essential role: awareness and thorough user education, exposure over time, proper management, perceived benefits, perception, and attitude.

The study further highlights the primary objective of providing sanitation with a 73 % water consumption reduction was achieved. The re-use of human faeces as a component of user sustainability in terms of the beneficial concepts to complete the Ecological sanitation system was not explored by the schools. But the study's BMP test revealed that the school's human waste could be used to generate energy. The accumulated biogas (66.62 m^3) produced by the faeces of 483 learners could be used for cooking and lighting in the school. Therefore, the biogas produced can provide sustainable support for the Ecological sanitation practice within the schools and the by-product will enable preparation of the feeding schemes' meals as 2 m^3 can burn for approximately 1 hour.

The findings align with the sustainable environmentally friendly approach principle of managing waste through onsite renewal. The empirical results of this study suggests that the effective implementation of Ecological sanitation can generate energy and reduce water consumption. This implies that Ecological sanitation provides solution to sustainable utilisation of water and provision of clean energy.

7.3 Recommendations

Based on the findings of the study, the following recommendations are central to the critical factors and support systems for the successful adoption and implementation of Ecological sanitation. The study findings have revealed fundamental implications that propose potential interventions that can support and promote the adaptation and utilisation of the Ecological sanitation technology. The recommended interventions include:

- Awareness and user education has been identified as a factor hindering effective implementation. Thus, initiatives should focus on creating awareness and providing education on the benefits of Ecological sanitation technologies, such that the users adapt regardless of the pre-perceived ideas. The initiative can be achieved through awareness campaigns, workshops, and educational programmes targeting school administrators and learners. In addition, the concept of people-orientated strategies should diligently be practiced as the end users play a critical role during the planning phase.

- There are grey areas in terms of standards of operating and maintaining the EVIP toilets. As a result, implementing supportive regulations and standards can play an important role in promoting Ecological sanitation practices. The study revealed that once the EVIP has been installed, no inspections take place, and no one is accountable to ensure effective implementation. On that basis, this study recommends the design of generic as well as tailor made guidelines for the proper operation and maintenance of the EVIPs.

- The perceived benefits of Ecological sanitation practice are not effectively conveyed to the users. Therefore, supporting pilot or demonstration projects within schools and communities is essential to ensure full participation of all stakeholders.

The projects can showcase the benefits of Ecological sanitation technologies, promoting wider acceptance and adoption. The findings of this study have demonstrated that the human faeces collected by the EVIP toilet has a potential to produce biogas. As such, incorporating community project demonstrations could trigger positive attitude towards the adoption of Ecological sanitation to accrue the economic benefits, in this case energy generation.

- The state of the toilets within the schools necessitates for enforcing effective measures for proper management and use. This can be achieved by implementing monitoring and evaluation methods which involve establishing a comprehensive framework to assess the proper management and impact of the Ecological sanitation systems.

- To encourage the adoption of new technology, particularly in public setting like schools, it is crucial to attract the users. One effective approach is to institute incentive programs which recognise and award schools that excel in the Ecological sanitation practice. Such an incentive can motivate other schools to follow suit and adopt to the technology, a concept of social influence.

- The study findings suggested that Ecological sanitation practice is a sustainable practice beneficial for both environmental and economic purposes. Therefore, to promote and effectively manage this practice, there is a need to integrate Ecological sanitation principles and technologies into national and local sanitation policies.

- There is a need for a collaborative effort from stakeholders (users, government and private sectors). Each party plays a critical role in the interconnected value chain is interconnected in order to ensure effective implementation. The government and private sectors acts as enforcement agents through managements systems while the users spearhead the implementation process guided by these systems.

By implementing the above interventions, decision makers can create an enabling environment that aims to support the adoption and effective implementation of Ecological sanitation technologies, resulting to improved sanitation practice, resource efficiency and environmental sustainability.

7.4 Research contribution to knowledge

This research provided specific recommendations for the Department of Education and practitioners within the Eco-schools so that they achieve effective implementation of EVIP with associated economic and environmental benefits. The research also provided an opportunity to improve knowledge as existing research on EVIP toilets only focused on environmental benefits that include compositing and other factors such as safety, privacy and social factors (Sguazzin & Lombrana, 2023; Van Wyngaardt, 2018; Tshivhase 2016; Scott, 1998; Banister *et al.,* 1999).

Over and above, this research has made a valuable contribution to addressing practices that promote water conservation through water consumption reduction. This is pertinent to countries like South Africa which is expected to reach a water deficit of 17 % by 2030 based on the water usage. This research has closed the gap of excessive use of water by flush toilets by proposing the effective implementation of EVIP, waterless technology that encourages water conservation and could eventually change the country's designation as a water-stressed area. The Ecological sanitation practice through water saving will enable an integrated approach of achieving Sustainable Development Goals number 1, 2, 3 and 6.

In addition, the research contributed knowledge to the ongoing conversation of alternative clean green energy, which is also enshrined in the 7th Sustainable Development Goal and the 2023 State of the Nation Address (SONA) in South Africa. Previous studies on the EVIP toilets did not integrate the benefit of energy recovery while addressing load shedding challenges which adversely affect schooling activities. However, this study has successfully demonstrated that human waste collected from the EVIP toilets can produce energy that can sustain the school's daily activities that rely on energy. Furthermore, to avoid load shedding in South Africa, it is imperative to keep the demand needs below 30 000 MW. Partially or entirely having the schools off the Eskom grid through energy generated from human waste, will make strides in reducing load shedding. Therefore, this research has not only contributed to meeting energy demands through recycling human waste but also addressed environmental concerns through reducing load of waste from dysfunctional systems by introducing onsite waste recycling system.

Besides, the use of human waste for energy generation will assist in reducing the use of fuelwood thereby promoting forest preservation. Literature indicates that studies on EVIP toilets capture relevant issues such as socio-economic, operations, benefits of compositing, health and hygiene related, however, the common critique is that the conceptualisations are not sufficiently grounded on frameworks but on practice. This study integrated the benefit of energy recovery to the already examined benefits, ensuring that the solution is not only driven to address waste disposal when the toilet is full but also works towards reducing water consumption, pollution, and deforestation. Consequently, the study developed a sustainable Eco-WEDS framework that the schools can adopt, enabling the Ecological sanitation system to serve as an effective tool for addressing social, economic, and environmental challenges.

7.5 Limitations of the study

This study experienced several limitations, which are outlined as follows:

- Previous studies have reported that the diet of an individual affects the volume of biogas produced from human faeces. However, even if this study collected the sample substrate of human faeces at one school, other schools within the Limpopo province and beyond the borders of South Africa could use the same parameters to generate equivalent amounts of energy.

- The water consumption rate was obtained from a situational analysis where an individual responsible for water and sanitation in the school provided the consumption rate based on their personal experience as the schools did not have water meters. The situational analysis does not indicate the actual consumption but rather an estimated consumption.

7.6 Areas of further research

Although efforts have been made through this study to estimate the amount of biogas that can be produced from human waste, the study has unearthed areas of further research.

(i) Analysis of the bio slurry

According to Mata-Alvarez *et al.* (2000:9), it is recommended that after the anaerobic digestion process, biological analysis of the bio-slurry/residue must be done. However, this study did not perform further biological analysis of the 'cow dung' slurry. As such, future studies should consider biological analysis of the slurry. Such biological analysis of the bio slurry could determine the absence of micro-organisms if the product is used as fertilizer. This approach aims to close the ecological loop by safeguarding the environment through a sustainably managed practice which recognises the bio slurry as a resource.

(ii) Design of a prototype

The existing EVIP system toilet in the schools is not designed to integrate the water reduction and energy generation process. Therefore, there is a need to develop and design a prototype for the schools, aimed at achieving both water conservation and energy generation.

7.7 Conclusion

The main objective of this study was to develop an Ecological sanitation framework aimed at reducing water consumption and generating energy. The main research question was to determine factors that can contribute to achieving effective implementation with the overarching goal of attainting favourable outcomes in both environmental and economic aspects. The first research objective assessed the effective implementation of EVIP toilets in terms of condition, assertiveness of proper use and the reuse of the human waste. The second objective evaluated the potential of water reduction when using the EVIP toilet.

The third objective estimated the amount of biogas that can be produced from the human waste collected from the EVIP toilet while the fourth objective analysed the study findings of question 1-3 to develop a framework. The results indicated that the schools generally perceived the EVIP toilet primarily as a sanitation facility rather than a system to close the ecological loop.

Nevertheless, this study suggests that increasing awareness, accumulating experience in line with the perceived benefits and continued practice over time will yield positive outcomes as concepts better known induces adaptation and effective practice. The Ecological practice within the schools achieved a 72 % water consumption reduction. However, the findings of the study revealed that the waste-to-energy concept was not exploited within the schools. The study findings observed that the human waste collected from the EVIP toilet has a sustainable potential to produce biogas that can be used to prepare the daily feeding scheme meals and provide lighting throughout the schooling period.

In conclusion, effective implementation of Ecological sanitation hinges on several factors such perceived benefits, management, awareness, perception, and attitude. These key factors informed the development of the Eco-WEDS framework with the aim of achieving both economic and environmental benefits. The ecological practice of energy generation at the school is regarded as sustainable. The BMP test demonstrated that energy generation viability is guaranteed due to the population size of the school, which ensures consistent source of input materials (feedstock). This research suggests that sanitation approaches must be resource focused instead of waste focused as it recommends the concept of onsite renewal of waste within the schools. Such a practice recognises the potential value of human waste rather than viewing it solely as a problem on how to dispose it. This shift can lead to more sustainable and environmentally friendly practices.

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Appendix 1: Survey Questionnaire

Objective 1

The following questionnaire will be administered at the 108 schools within the Capricorn District in the Limpopo Province regarding the effective implementation of EVIP latrines.

Ethical consideration: Participation is voluntary and respondents can withdraw at any time. Respondents will not be exposed to any form of harm either physically or psychologically. Privacy and identity of the respondents will be safeguarded. This implies that the information will be kept confidential. I would appreciate if you could provide answers to these questions to the best of your ability. NB: Please, Provide answers and cross(x) in the appropriate box next to the question.

Questionnaire ID ☐ Date…………………

1. Number of EVIP toilets?	0-5	6-10	11-15	<15

2. How long has the school used the EVIP toilets?	1-2 years years	3-6 years	7-9 years	<10

3. Does the school reuse the waste from the EVIP toilets?	Yes		No	

If answer 3 is yes, do you use the waste for;

Manure	Energy generation	Other

If answer 3 is no, you don't use the waste because;

Not hygienic	Not aware that it can be reused	Religion	Cultural

4. Does the school have a vegetable garden?	Yes		No	

5. Does the school have a feeding scheme?	Yes		No	

If answer at number 5 is yes, what does the school use as a source of energy?

Electricity	Gas Stove	Wood	Other

6. What is the conditions of the EVIP toilet (Tick where applicable) (Include pictures)

Toilet lid is broken	
Toilet seat is vandalised	
Inspector cover is damaged	
Ventilation pipe is damaged	
Drying plate is damaged	
Roof is dilapidated	

7. Was the school inducted on how to use the toilets?	NO	YES

If answer 7 is no, how is proper usage of toilets ascertained? Tick where applicable

Use common sense	
Contact those who are knowledgeable	
Ignore the proper usage	
Other	

8. What happens when the toilet is full? Tick where applicable

The school removes the waste	
Contact the Department of Education	
Pour acid	
Pour water to dissolve the waste	
Do nothing, close it and dig another one	

Perceptions of using human waste

9. Human waste has benefits for humans, such as energy generation.	Agree	Disagree	I don't know

10. If you disagree in question 9, state the reason. (Tick where applicable)

Hygiene reasons	
Cultural reasons	
Personal reasons	
Other	

11. Human waste should be used for energy generation "heating and cooking"?	Agree	Disagree	I don't know

12. If you disagree in question 9, state the reason. (Tick where applicable)

Hygiene reasons	
Cultural reasons	
Personal reasons	
Other	

13. Human waste can be used to fertilize soil in a vegetable garden	Agree	Disagree	I don't Know

14. I will never consume crops that used composted human excrement	Agree	Disagree	I don't know

15. Crops can be killed when fertilized with human waste	Agree	Disagree	I don't know

Appendix 2: Interview Questions

Objective 2

The potential of Ecological VIP for water consumption reduction?

Interview Schedule

Questionnaire ID: ______ Date: ______

PREAMBLE: Introduction, purpose and confidentiality statement read before any session.

The interview questions to be directed to the 108 school

Principal or personnel responsible for water and sanitation at the school. The purpose of these interviews is to understand the nature and rate of water consumption before and after the implementation of EVIP latrines. The information obtained will be kept confidential and will only be used for academic purposes.

Guiding questions for the school Principal or responsible person for the schools water and sanitation.

The potential of Ecological VIP for water consumption reduction?

1. Briefly, explain what is the nature of water supply and demand within the school?
2. What is/are the main sources of water at the school?
    - Ground water (Boreholes)
    - Municipal water
    - Other
3. What are the main use of water within the school?
    - Flush toilets
    - Drinking
    - Cooking/ feeding schemes
    - Gardening

4. Kindly elaborate on the rate of water consumption before the use of EVIP

- Water meter records (If not available at the school, Water Service Provider will be approached)
- Use of a situational analysis

5. Kindly elaborate on the rate of water consumption after the use of EVIP

- Water meter records (If not available at the school, Water Service Provider will be approached)

- Use of a situational analysis

6. Has the school experienced low water consumption after the implementation of EVIP

7. Any additional information regarding the use of EVIP and water consumption

Appendix 3: Fieldwork and experiment

Objective one and two (Survey's and Key informant interviews)

Vandalised items of the EVIP and indicating the instructions of using the toilet

EVIP toilets

Source of energy used at the schools

Objective 3 (Estimating biogas produced from human waste collected from EVIP)

Collection of moist samples and slurry (Inoculum)

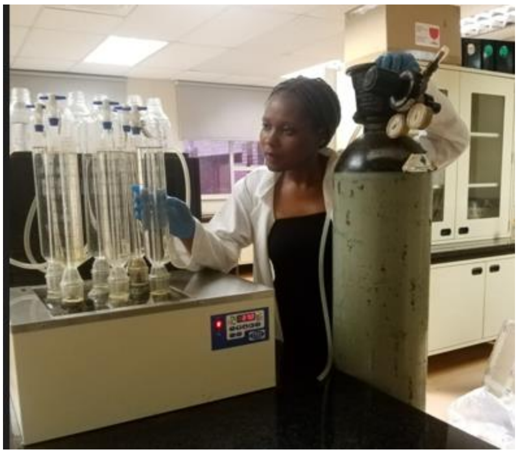
PH testing of Substrate

Substrate placed in the oven, 24h period

Weighing of substrate, 2 decimal scale.

Substrate after being removed from the oven

Muffle Furnace and residue



Six Composition tanks filled with slurry (400ml)

Degassing of the slurry

Preparing samples and setting up of the anaerobic digestion process

Appendix 4: Limpopo province nutritional feeding scheme menu

MENU

Monday

Rice: 509 X 40g/1000 = 20 Kg per day

Fish: 509 X 60g/400 = 509 per day

Butternut: 509 X 60/1000 = 31 per day

Tuesday

Samp : 509 X 40 g/ 1000 = 20 kg per day

Beans: 509 X 35 g / 1000 = 18 per day

Cabbage: 509 X 60 g/1000 = 31/ 2.5 =12 each

Wednesday

Maize: 509 X 45 g/1000 = 22 kg

Milk : 509 X 200/1000 = 101

Fruit: each per learner

Thursday

Maize: 509 X 45 g/1000 = 22 kg (20 + 3 kg)

Soya : 509 X 30 g / 1000 = 18 per day

Cabbage : 509 X 60 g/1000 = 31/ 2.5 =12 each day

Friday

Maize: 509 X 45 g/1000 = 22 kg

Fish: 509 X 40 g/400 = 509 per day

Butternut: 509 X 60 g/1000 = 31 / 2.5 = 12 Each day

Appendix 5: Ethical clearance

NWU®
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NOORDWES-UNIVERSITEIT
YUNIBESITI YA BOKONE-BOPHIRIMA

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Web: http://www.nwu.ac.za

Senate Committee for Research Ethics
Tel: 018 299-4849
Email: nkosinathi.machine@nwu.ac.za

ETHICS APPROVAL LETTER OF STUDY

Based on approval by the **Faculty of Natural and Agricultural Sciences Ethics Committee (FNAS-REC)**, the Faculty of Natural and Agricultural Sciences Ethics Committee hereby **approves** your study as indicated below. This implies that the North-West University Senate Committee for Research Ethics (NWU-SCRE) grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

Study title: An Integrated Eco-Sanitation Framework for Water Consumption Reduction and Energy Generation. Capricorn District, Limpopo Province
Study Leader/Supervisor: Prof LG Palamuleni
Student: L Tlhoaele

Ethics number:	N	W	U	-	0	1	7	8	3	-	2	0	-	A	9
	Institution				Study Number						Year			Status	

Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation

Application type: Single **Risk Category:** Minimal

Commencement date: 01/02/2020
Expiry date: 30/11/2023

Approval of the study is initially provided for a year, after which continuation of the study is dependent on receipt and review of the annual (or as otherwise stipulated) monitoring report and the concomitant issuing of a letter of continuation.