



MIDLANDS STATE UNIVERSITY

**Developing an integrated framework for sustainable solid waste
management at rural hospitals in Chirumanzu District, Zimbabwe**

BY

TAKUNDA SHABANI

R163056C

FACULTY OF SOCIAL SCIENCES

**A thesis submitted in fulfilment of the requirements of a Master of
Philosophy Degree in Geography and Environmental Sustainability to the
Department of Geography, Environmental Sustainability and Resilience
Building**

Supervisor: Doctor. V.T. Mutekwa

Abstract

Hospital solid waste management is a significant global challenge, particularly in developing countries where waste from hospitals often exceeds available resources. Zimbabwe, like many developing nations, struggles to manage solid waste effectively, especially in rural hospitals. Management of solid waste in financially and technically struggling rural hospitals is far from acceptable standards, presenting environmental and health problems. Despite presenting critical problems, management of solid waste from rural hospitals is an under-researched area in Zimbabwe. However, Sustainable Development Goals, Agenda 21 Chapter 21 complemented by Zimbabwe's Vision 2030 aspirations calls for appropriate management of solid waste from various sources encompassing rural hospitals. Sustainable management of solid waste from rural hospitals requires evidence based decisions supported by frameworks that guide approaches and systems towards sustainability. Consequently, this study focused on developing an integrated framework for sustainable solid waste management at rural hospitals in Chirumanzu district, Zimbabwe. It focuses on characteristics of solid waste, management strategies and associated environmental health risks, aspects essential to develop framework. Descriptive cross sectional research design which triangulates quantitative and qualitative paradigms was adopted. Data was collected using questionnaires, interviews, observations and from secondary sources. To complement these data collection methods and fully address all the study objectives, soil and water samples were collected and analysed. Quantitative data was analysed using Statistical Package for Social Sciences and Microsoft Excel while content analysis was used to analyse qualitative data. Results illustrated that major components of solid waste from rural hospitals encompass pharmaceutical, sharps, infectious, pathological, cytotoxic, radioactive, chemical and general waste. Generated solid waste illustrated both hazardous and non-hazardous materials, presenting the significance of solid waste segregation during waste management. Solid waste generation rate was 0.83kg per patient per day on average and quantity of solid waste was also proportional to number of patients. This implies that since population in the district is increasing at 1.2%, people who require health services is going to escalate, causing growth of generated solid waste. On average ST Theresa hospital generated 77.35% general waste, 22.65% hazardous waste whereas Holy Cross generated 79% general waste and 21% hazardous waste. Although quantity of hazardous waste is low, but it needs more attention since it causes more harm to human and the environment compared to non-hazardous waste. Mostly used solid waste storage receptacles included sharp waste containers made with rigid materials, pedal operated bins, metal and plastic buckets, plastic

bags and cardboard boxes. Indiscriminate storage of solid waste which translates to co-disposal of waste was common at these hospitals. Solid waste receptacles were mostly emptied on a daily basis at Holy Cross (78.2%) and ST Theresa (86.7%) though disposal of sharp containers was determined by quantity of sharps rather than number of days. Surveyed rural hospitals employ various solid waste disposal approaches namely open pits, burning, incineration, designated dumpsites and auto-way pits. Incineration was highly used at ST Theresa (44.8%) and Holy Cross (41.8%). Most disposal approaches employed at these hospitals are least prioritised by the waste management hierarchy, therefore, have potential to cause adverse environmental health effects. Solid waste management strategies at these rural hospitals are associated with air, water and soil contamination while potentially exposing people to various ailments and occupational hazards. Inappropriate management of hospital solid waste is attributed to low compliance to legal framework, lack of awareness among health workers, improper waste segregation and shortage of resources as well as lack of an appropriate guiding waste management framework. The scenario is exacerbated by application of unclearly defined waste management approaches where there is lack of clear definition of roles, deficiency of co-ordination coupled by giving less attention to strategies that promote sustainability. Major options to attain proper solid waste management at these rural hospitals encompass collaboration of all accountable stakeholders, raising awareness of health workers and investing in approaches which consider hospital solid waste as a resource. There is a need for the government to implement policies tailored for rural hospitals with insufficient resources. Most importantly, the proposed framework demonstrated possible alternatives to integrate and narrow the gap to reach sustainable solid waste management at rural hospitals. The research presents various relevance to real world scenarios since it has potential assists policy makers and pave route to attain global and local sustainable development goals. In the academic domain, the research can be used as a reference point by other researchers and learners. Characteristics of the framework enables accountable stakeholders to implement strategies which create safe and healthy rural environment through suppression of environmental health problems caused by solid waste from hospitals. Although the study's strengths outweigh its limitations but applicability of the framework to other rural and urban hospitals is limited since the framework was developed considering characteristics and needs of ST Theresa and Holy Cross hospitals.

Keywords: Rural hospitals, Hospital solid waste, Hospital solid waste management, Environmental health risks, Integrated framework

Declaration

I, Takunda Shabani, hereby declare that this study titled Developing an integrated framework for sustainable solid waste management at rural hospitals in Chirumanzu District, Zimbabwe is my original work and has not been submitted in part or in full, to this or any other university for the award of any degree or qualification. I confirm that all sources used in this thesis have been properly acknowledged and cited.

I further declare that the research conducted for this thesis has been carried out under the guidance and supervision of Doctor V.T. Mutekwa. To the best of my knowledge, the data collected, analysed and presented in this thesis is accurate and reliable. I declare that this thesis is a culmination of my own efforts, knowledge and skills acquired during my academic journey.

Signature:



Date: 19/08/2024

I Doctor V.T. Mutekwa, as the candidate's thesis supervisor, agree with the above statements and recommend submission of the research.

Signature:



Date: 19/08/2024

I Professor M. M. Matsa, being the Chairperson of Geography, Environmental Sustainability and Resilience Building Department, Faculty of Social Sciences, Midlands State University, concur with the above statements and recommend submission of the research.

Signature:



Date: 19/08/2024

Note to the Reader

This thesis adopted a paper-based approach and is arranged into six chapters. To satisfy demands of paper-based approach, the literature review section and research objectives were represented by published papers. Hence, the thesis consists of manuscripts which have been co-authored. However, the primary author was Takunda Shabani (an MPhil student at the time of reporting). Takunda Shabani was responsible for initiating the research idea, crafting research methodology, data collection and analysis as well as drafting the manuscripts. Doctor Timothy Vurayai Mutekwa (an academic supervisor at the time of reporting) during the research, therefore, he was part of the authors. Professor Steven Jerie (Faculty of Social Science) offered guidance to the student in the writing of the paper titled, “*Medical solid waste management status in Zimbabwe*”. Tapiwa Shabani, who assisted in field data collection for the whole study was included among the authors as indicated in the published manuscripts. Additionally, referencing styles in published papers were determined by requirements of the journal which published the paper.

Publications and Manuscripts

Takunda Shabani is the primary author on all articles that were published because he was involved in various significant roles during preparation of the papers.

1. **Shabani, Takunda.** and Jerie, Steven. (2023). Medical solid waste management status in Zimbabwe. *Journal of Material Cycles and Waste Management*, 25(2),1-16. <https://link.springer.com/article/10.1007/s10163-022-01578-4> (Springer) (Published)
2. **Shabani, Takunda.,** Mutekwa, Vurayayi. Timothy. and Shabani, Tapiwa. (2024). Solid waste characteristics and management strategies at ST Theresa (STT) and Holy Cross (HC) hospitals in Chirumanzu rural District, Zimbabwe. *Journal of Environmental Sciences Europe*. 36(1),1-27. <https://link.springer.com/article/10.1186/s12302-024-00882-0>. (Springer) (Published).
3. **Shabani, Takunda.,** Mutekwa, Vurayayi. Timothy. And Shabani, Tapiwa. (2024). Environmental health risks associated with solid waste management at rural hospitals in Chirumanzu District, Zimbabwe. *SN Social Sciences*, 4(2), 20. <https://link.springer.com/article/10.1007/s43545-023-00821-5> (Springer) (Published).
4. **Shabani, Takunda.,** Mutekwa, Vurayayi, Timothy. and Shabani, Tapiwa. (2023). Developing a Sustainable Integrated Solid Waste Management Framework for Rural Hospitals in Chirumanzu District, Zimbabwe. *Circular Economy and Sustainability*, 4, 1-35. <https://link.springer.com/article/10.1007/s43615-023-00313-x> (Springer) (Published)

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ACRONYMS

AA	Africa Agenda
Ad	Arsenic
CBA	Cost Benefit Analysis
Cd	Cadmium
CE	Circular Economy
COD	Chemical Oxygen Demand
Covid-19	Coronavirus Disease 2019
DMO	District Medical Officer
EC	Electrical Conductivity
EHT	Environmental Health Technician
EMA	Environmental Management Agency
FBC	Full Blood Count
Fig	Figure
GPS	Global Positioning System
GIS	Geographic Information System
HC	Holy Cross
HCD/S	Head of Cleaning Department/Supervisor
Hg	Mercury
HIV	Human Immunodeficiency Virus
AIDS	Acquired Immunodeficiency Syndrome
HM	Hospital Matron
Kg	Kilograms
LCA	Life Cycle Assessment

M	Metres
MCDMA	Multi-criteria decision making analysis
ME	Microsoft Excel
Mg/L	Milligrams/per litre
NDS	National Development Strategy
NSSA	National Social Security Authority
OPDCA	Observe Plan Do Check Act
P.H	Potential Hydrogen
Pb	Lead
PPE/C	Personal Protective Equipment/Clothing
SDGs	Sustainable Development Goals
SIHSWM	Sustainable Integrated Hospital Solid Waste Management
SPSS	Statistical Package for Social Sciences
STT	ST Theresa
TDS	Total Dissolved Solids
UN	United Nations
UNCD	United Nations Conference on Environment and Development
UNICEF	United Nations International Children's Emergency Fund
US EPA	United States Environmental Protection Agency
WHO	World Health Organization
ZIMSTAT	Zimbabwe National Statistical Agency
ZMoHCC	Zimbabwe Ministry of Health and Child Care
ZV	Zimbabwe Vision

Chapter 1: Introduction

1.1 Background to the study

Waste in any form is currently a worldwide issue that presents adverse socio-economic as well as environmental challenges if not sustainably managed. Generation of waste in substantial quantities coupled by inappropriate management techniques pose detrimental effects on ecosystems and human health (Vaish *et al.*, 2019; Ilyas *et al.*, 2019; Shabani and Jerie, 2023). In both developing and developed countries, less sustainable consumption patterns, population increase, urbanisation and industrialisation are among major drivers of waste generation and escalation (Liu *et al.*, 2019; Mavugara and Matsa, 2023; Shabani *et al.*, 2024). The global population was approximately 7.8 billion in 2020 and is projected to be around 10 billion in 2057 (Worldometer, 2020). This population increase and the associated activities to meet its requirements amplify the generation of liquid, solid and gaseous waste in all the regions of the world. Currently, there is a proliferation of greenhouse gases namely carbon dioxide, nitrous oxide, methane and carbon dioxide due to industrial activities, automobiles and from solid waste being disposed of in the environment (Madaleno and Moutino, 2021; Shikwambana *et al.*, 2021). Singh *et al.*, (2017) established that less than 5% of greenhouse gases in the atmosphere are emissions from waste management activities. These emissions contribute to the climate change problem leading to disasters that cause loss of lives, destruction of ecosystems and outbreak of diseases. This is supported by Duchenne *et al.*, (2021) and Quireshi and Rasool (2021) who argued that climate change impacts encompass outbreak of various ailments exemplified by water and sanitation diseases coupled by illnesses related to food shortages.

The occurrence of contemporary diseases such as cholera, typhoid, dysentery in most developing countries particularly those in Africa is worsened by poor waste management practices especially in urban areas (Qadri and Faiq, 2020; Tariq and Mashtaq, 2023). Owing to improper management of wastewater, concentration of pollutants in most water bodies has been found to be above World Health Organisation water quality limits (Karri *et al.*, 2021; WHO, 2022). The increasing wastewater footprint is now visible in urban areas that are experiencing water scarcity, adding burden to municipalities that are overwhelmed by solid waste management challenges. The world generated about 2.7 billion metric tonnes of solid waste in 2019, but the quantity is anticipated to grow to 3.40 billion metric tonnes by 2050 (Kaza *et al.*, 2018; World Bank, 2019a; Maalouf and Mavropoulos, 2023). These billions of metric tonnes

of solid waste constitute plastic, electronic, food waste, absorbent hygienic products as well as construction and demolition waste among others generated from various sources including construction and manufacturing industries, restaurants, agricultural activities, households and institutions such as hospitals (Kaza *et al.*, 2018; Abdel-Shafy and Mansour, 2018; Shabani *et al.*, 2024). Solid waste generated by educational and health institutions has become an increasing component of waste causing various management challenges in the contemporary world with diverse environmental and socio-economic impacts (Ugwu *et al.*, 2021; Shabani and Jerie, 2023). Difficulties in management of institutional solid waste is exacerbated by increase in the diversity and quantity of waste generated particularly from health institutions (Chisholm *et al.*, 2021; Shabani and Jerie, 2023).

Kwikiriza *et al.*, (2019) and Shabani *et al.*, (2024) argued that whilst the management of solid waste from both rural and urban hospitals is increasingly becoming a challenge, the pressure is acute in developing countries with limited resources and even worse at hospitals located in rural areas. Therefore, as hospital solid waste generation proliferates, so does the risks that they present to the environment and human well-being. This necessitates the crafting of innovative solid waste management approaches aimed at achieving sustainable hospital waste management that safeguards human health and the integrity of the ecological system. Management of solid waste from institutions encompassing hospitals needs comprehensive approaches and models which support application of various methods and inclusion of all stakeholders (Shabani and Jerie, 2023; Shabani *et al.*, 2023). This denotes that an integrated approach is essential to deal with hospital solid waste whose volumes are on an upward trend globally. Its management is problematic due to the rapidly growing population, its hazardous characteristics and associated disease outbreaks (Torkashvard *et al.*, 2020; Adelodun *et al.*, 2021). In hospitals, solid waste is generated during diagnosis and caring of patients (Rupani *et al.*, 2020) and consists on average 85% non-hazardous and 15% hazardous waste (Rahman *et al.*, 2020). The main components of hospital solid waste include pharmaceutical, pathological, sharps, chemical, infectious, radioactive, cytotoxic and general waste (Ali *et al.*, 2017; Kalogiannidou *et al.*, 2018). Mismanagement of hospital solid waste pollutes aquatic, terrestrial and atmospheric ecosystems and impacts human health negatively (Rahman *et al.*, 2020; Das *et al.*, 2021). Hospital solid waste management strategies should conform to internationally recommended World Health Organisation (WHO) standards to minimise its impact on the environment (Jerie and Tevera, 2014).

Waste management hierarchy processes namely disposal, treatment, recovery, recycle, reduction and prevention should guide hospital solid waste management worldwide to minimise its environmental risks (US EPA, 2020; Fletcher *et al.*, 2021). In Australia, techniques such as recycling are used to manage hospital solid waste (Joseph *et al.*, 2021), thus limiting the quantity that is disposed of in the environment. A combination of solid waste conversion to energy and recycling can significantly reduce the quantity of discarded solid waste (Tchobanoglous and Kreith, 2002). Institutional solid waste recycling, particularly waste from hospitals is at miniature stage in developing countries like Zimbabwe (Zikali *et al.*, 2022). Whilst the waste management hierarchy frameworks have potential to guide decision makers to achieve sustainability, they are silent about segregation, product life cycle and transportation (van Ewijk and Stegeman, 2016; van Ewijk, 2018). The Life Cycle Assessment (LCA) model is applicable in various situations including in the management of rural hospital solid waste. The model requires adequate, complete and up to date data, aspects that have made it effective in minimising the detrimental impacts of waste on the environment in Canada (Lesage and Samson, 2016; Khandelwal *et al.*, 2018; Zhou *et al.*, 2018). In countries like India and Mexico, its effectiveness has been limited due to weak policies and inadequate waste data (Gallego and Tarpani, 2019). The application of LCA in waste management has seen successes and failures being registered in different countries, but it has played a role in the evolution of solid waste management including institutional waste from hospitals. Its failure to quantify impacts of solid waste, quantity of waste generated, its associated drivers and strategies to overcome obstacles experienced constitute some of its main weaknesses (Karmperis *et al.*, 2013; Curran, 2014).

Zimbabwe, like other developing countries is struggling to utilise LCA effectively in sustainable solid waste management especially at institutions such as rural hospitals located in the countryside due to the lack of requisite expertise, material and financial resources as well as limited solid waste quantitative and qualitative data. LCA limitations and prerequisites paved the way for Multi-Criteria Decision-Making Analysis (MCDMA) to emerge among popular models (Soltan *et al.*, 2015; Coban *et al.*, 2018). MCDMA's popularity encompasses its ability to incorporate various stakeholders and approaches in solid waste management (Soltan *et al.*, 2015; Garcia-Garcia, 2022). Inclusion of all stakeholders facilitates sharing of ideas while adoption of various management techniques reduces the burden of managing waste from various sources including rural hospitals. MCDMA assists in evaluation of waste management approaches from generation to disposal (Adali and Tus, 2021; Muhammad *et al.*, 2021). This enables institutions like rural hospitals to prioritise sustainable waste management

approaches. Countries such as Australia, United States, Niger and Zimbabwe adopted the MCDMA in among other aspects selection of dumpsites (Kharlamova *et al.*, 2016; Adali and Tus, 2021). It has the potential to facilitate selection of environmentally friendly solid waste disposal techniques.

Utilisation of MCDMA in hospital solid waste management in developing nations is lagging due to resource deficiency and less effective policies (Aung *et al.*, 2019). Environmental risks associated with hospital solid waste in developing countries remain inevitable due to various challenges. The model's evaluation strategies are general since it is silent on the standards to follow (Coban, 2018; Garcia-Garcia, 2022). Consequently, it is difficult to make decisions using generalised information at rural hospitals. In order to achieve proper solid waste management, triangulation of models like MCDMA and Cost Benefit Analysis (CBA) is significant (Makarichi *et al.*, 2018). Integration of these models can facilitate sustainable management of solid waste from rural hospitals. The CBA model, although it sometimes incorporates some environmental aspects, it is much more inclined towards the evaluation of impacts of solid waste management strategies in monetary terms (Lam *et al.*, 2018; Ayeleru *et al.*, 2021). It is, therefore, more of an economic approach to solid waste management. The model enables adoption of low-cost approaches for remediation of polluted land (Das *et al.*, 2019; Soderqvist *et al.*, 2015) such as exhausted hospital dumpsites. Its common weaknesses are complications in valuing of management strategies due to currency volatility and the large amount of time required to carry out the exercise (Morissey and Browne, 2004; Karmperis *et al.*, 2013). These shortcomings can hinder its applicability in management of solid waste from rural hospitals, although it is worsened by shortage of resources in less developed nations. In developing regions, application of sustainable approaches to solid waste management is limited (Vergara and Tchobanoglous, 2012; Abdel-Shafy and Mansour, 2018) and African countries are the most affected. In Zimbabwe, the scenario is exacerbated by socio-economic and political problems (Mandeverere and Jerie, 2018) that hit the rural populace and institutions such as rural hospitals hardest.

In Zimbabwe, hospital solid waste management is mostly centred on traditional approaches (Taru and Kuvarega, 2005; Mangizvo and Chinamasa, 2008) that follow the basic practices of collection, treatment and disposal. Adoption of these approaches in rural areas is aggravated by a legal framework which gives less attention to rural hospitals, for instance Urban Councils Act (Chapter 29:15) supports urban areas only (Jerie, 2013; Makamba *et al.*, 2022) whilst the Rural District Councils Act (Chapter 29:13) is silent on waste management issues since rural

areas are assumed not to have waste management problems. Growth in Zimbabwe's population and the proliferation of diseases is leading to the increase in hospital solid waste generation as more and more people visit these institutions for treatment and caring for patients (UNDP, 2020). A total of 61.4% of Zimbabwe's population reside in rural areas (ZIMSTAT, 2022). Therefore, rural hospitals are experiencing an increase in solid waste generation since people resort to them for health services. Zimbabwe's health policy articulates that citizens must be within a radius of not more than 10 km from the nearest health institution (ZHDF, 2019) and health institutions are increasing in rural districts like Guruve, Insiza and Chirumanzu (ZHDF, 2019). Proper attention to solid waste from rural hospitals may help to mitigate potential environmental risks. In Zimbabwe little is known about institutional solid waste (Jerie, 2006), particularly solid waste from rural hospitals. Implementation of solid waste management models which suit rural hospitals is at infancy stage, translating to improper waste management.

Hospital solid waste is indiscriminately disposed of through open burning, dumping, open pits and incineration (Mangizvo and Chinamasa, 2008). These existing disposal approaches occupy the base of the waste management hierarchy ladder, and therefore are detrimental to environmental quality. The approaches affect air, water, soil, flora and fauna negatively (Jerie and Tevera, 2014; Jerie, 2016). In order to minimise environmental health risks in the 21st century and beyond, the Rio Declaration and Development Agenda 21 (UNCD) complemented by Sustainable Development Goals require that waste management be carried out in a socially, economically and environmentally sustainable manner (UNDP, 2015). Proper management of solid waste from various sources including rural hospitals is required to attain Zimbabwe's Vision 2030 goal of Zero waste and National Development Strategy 1 cross cutting objective of environmental protection and natural resource management (RoZ, 2020; Zikali *et al.*, 2022). Nonetheless, without a comprehensive integrated rural hospital solid waste management framework, efforts to attain global and local goals remain in vain. In order to overcome the complexity of solid waste management, various stakeholders, technologies and techniques should be integrated in an interactive and complementary manner (Tchobanoglous, 2009). Utilisation of integrated hospital waste management models of that nature is limited in developing nations like Zimbabwe more specifically in rural areas. Sustainable development requires institutions such as rural hospitals to develop their own sustainable waste management approaches and models (Rodrigues *et al.*, 2018). Most of the existing models including LCA, MCDMA, CBA and waste management hierarchy fail to properly address and incorporate real

world components namely drivers, quantity and quality, stakeholders, socio-economic and environmental aspects, yet these issues are essential to achieve sustainability (Thyberg and Tonjes, 2015; Shabani *et al.*, 2023). Therefore, this research focused on developing an integrated framework for sustainable solid waste management at rural hospitals in Chirumanzu district, Zimbabwe.

1.2 Statement of the problem

Zimbabwe's macro-economic deterioration since the beginning of the 21st century negatively affected many sectors of the economy including the health sector and its capacity to manage waste (Roets *et al.*, 2019; ZHDF, 2019). Inadequate resources, population increase and the high disease burden led to improper solid waste management at health institutions (UNDP, 2020). Most hospitals operate without comprehensive solid waste management frameworks which often translate to improper solid waste management. In cases where solid waste management frameworks exist, there is no clear definition of stakeholders' responsibilities or lack of adherence to the legal framework and recommended standards. As a result, rural hospitals usually adopt the traditional linear approach in management of solid waste that leads to hospital solid waste finding its way to open dumpsites creating several risks to humans and an already fragile environment. The COVID-19 pandemic that affected Zimbabwe and the entire world since 2019 led to increased volumes and diversity of hospital solid waste exacerbating the already existing waste problem in these institutions (UNDP, 2020; Shabani and Jerie, 2023) including those in Chirumanzu rural district. This increased burden overstretched solid waste management capacities at Holy Cross and ST Theresa hospitals. A scenario worsened by that in Zimbabwe, solid waste from rural hospitals is receiving less attention from policy makers and other responsible authorities since the assumption is rural hospitals are not affected by waste management problem. Therefore, already struggling Holy Cross and ST Theresa hospitals shoulder the additional burden of managing the increasing waste since Zimbabwe's waste management services are skewed in favour of urban hospitals while neglecting rural hospitals. This puts the rural environment which is generally less polluted at risk of being polluted by poorly managed institutional waste. Therefore, the need to maintain the high environmental quality of the rural environment and the health conditions of the rural populace cannot be over emphasised.

Existing solid waste management frameworks at these hospitals have proved to be ineffective as evidenced by poor waste storage, conveyance and disposal practices at the institutions. The

prevailing frameworks can be termed conventional since participation of various stakeholders is limited and less attention to approaches which support circular economy. Co-disposal of contaminated solid waste and containers of biological specimens with potential to carry micro-organisms is practiced at Holy Cross and ST Theresa hospitals. Plastics, glass containers, and sharp waste with the ability to last long in the environment is a common sight at hospital dumpsites. Humans and animals access the partially secured dumpsites with hospital solid waste including sharp and infectious waste, exposing them to various health risks. Limitations of the existing frameworks are demonstrated by utilisation of some disposal approaches found at the bottom of the waste management pyramid such as open pits, incineration and open-air burning. Frameworks used by Chirumanzu rural hospitals namely Holy Cross and ST Theresa have potential to cause detrimental impacts to aquatic, terrestrial and atmospheric ecosystems, thus hindering ability to achieve goals advocated for by SDGs and Zimbabwe Vision 2030. In order to attain sustainability in the realm of solid waste management, these rural hospitals must adopt a framework which considers pillars of sustainability, all stakeholder participation while taking into account characteristics of rural hospitals with low resources. It is, therefore, vital to assess the waste management challenges at the two institutions and develop an integrated framework that can be implemented for sustainable solid waste management at these rural hospitals in Chirumanzu district.

1.3 General and specific objectives

1.3.1 General objective

- To develop an integrated framework for sustainable solid waste management at rural hospitals in Chirumanzu district, Zimbabwe.

1.3.2 Specific objectives

1. To characterise hospital solid waste generated by rural hospitals in Chirumanzu district.
2. To evaluate hospital solid waste management framework utilised by rural hospitals in Chirumanzu district.
3. To analyse environmental health risks associated with solid waste management at rural hospitals in Chirumanzu district.
4. To integrate findings to produce a framework for sustainable solid waste management at rural hospitals in Chirumanzu district.

1.4 Significance of the study

Improper management of hospital solid waste causes detrimental effects to the environment while human health is not spared (Ahmad *et al.*, 2019). This is because traditional hospital solid waste management approaches have the potential to generate pollutants which hinder the ability of ecosystems to provide quality provisional, regulating, cultural and supporting services to humans and the environment. This impacts the well-being of the present and future generations who earn a living through extracting and utilising ecosystem services. The developed framework assists the Environmental Management Agency (EMA) to implement approaches which safeguard ecosystems from the negative impacts of hospital solid waste, so that humans continue to benefit directly and indirectly. Therefore, the research paves the way for Zimbabwe to attain Sustainable Development Goals (SDGs) notably goals (1) no poverty (2) zero hunger and (3) good health and well-being as espoused by Wood *et al.*, (2018) that ecosystems play a pivotal role in achievement of SDGs through provision of various services. Through proposing a sustainable framework, the study supports ecosystem protection, hence promoting attainment of SDGs 14 and 15 of life below water and on land respectively.

In Zimbabwe, aspects surrounding solid waste from rural hospitals is almost hidden to the glare of policy makers. A scenario illustrated by laws that provide more attention to urban areas as compared to rural areas. This is exemplified by the Urban Councils Act (Chapter 29:15) which is clear about management of solid waste from urban institutions including hospitals. The Rural District Councils Act (Chapter 29:13) lacks clear guidelines directed to institutions, since it is commonly argued that rural areas are spared of significant solid waste management problems. Nevertheless, there is some inaccuracy in existing assumptions since in reality management of rural hospitals' solid waste presents some complexities. This increases the vulnerability of the environment to pollution yet the rural environment is considered generally clean compared to urban areas. Therefore, a framework which supports nipping the problem of solid waste from rural hospitals whilst still in the bud is required. Proper application of the developed framework simplifies adoption of solid waste management techniques which safeguard purity of the rural environment.

Globally, hospital solid waste is given limited attention as compared to other types of solid waste (Tsai, 2021). In Zimbabwe management of solid waste from institutions like hospitals is traditionally overlooked by competent authorities and other statutory bodies such as the Environmental Management Agency and Local Authorities (Jerie, 2006). This implies that

development and implementation of sustainable hospital solid waste management frameworks is at miniature stage particularly in marginal districts. Hence, the research addresses the issue by developing a framework which can be used by the Hospital Environmental Health Departments to improve rural hospital solid waste management. Solid waste researches in Zimbabwe demonstrate the dominance of publications by Tevera (1991, 1993, 1996, 2000, and 2002), Jerie (2006, 2011, 2013, and 2014), Masocha (2003, 2004 and 2006) and Mangizvo (2003, 2008 and 2010) among others. However, these scholars focused on general municipal solid waste. As such, this research puts emphasis on hospital solid waste to cover the existing literature gap. Studies on hospital solid waste largely focused on management strategies in urban areas for instance Harare and Kwekwe by Taru and Kuvarega (2005) and Mangizvo and Chinamasa (2008) respectively. This demonstrated that existing researches are geographically confined to urban areas, hence little is known about rural areas. This motivated the researcher to focus on rural hospitals in Chirumanzu rural district. Existing studies are also centred on suggesting recommendations while neglecting development of frameworks which narrow the gap to attain sustainable waste management. This motivated the research to focus on developing an integrated sustainable framework suitable for managing solid waste from rural hospitals.

According to UNDP (2015) sustainability is achieved through partnerships of various stakeholders, as noted in goal 17. Hence, the developed framework has the potential to act as a catalyst for different stakeholders and organisations to work hand in hand when dealing with rural hospital's solid waste. Therefore, research results enable Zimbabwe Ministry of Health and Child Care, Environmental Management Agency, Hospital Environmental Health Departments and Local Authorities to collaborate and formulate strategies which support appropriate solid waste management at rural hospitals. Partnership of these stakeholders facilitates implementation of effective hospital solid waste policies, strategies and legislation as well as strengthening already existing management approaches. Thus, increasing the chances of attaining the Zimbabwe National Development Strategy 1's cross cutting objective of environmental protection and natural resources management. In order to achieve the goal of decent work, results have potential to enable the National Social Security Authority and hospital authorities to implement safety measures to protect those who deal with hospital solid waste at institutions and other areas.

The issue of proper solid waste management was articulated at Agenda 21 Earth Summit, notably chapter 21 and became more pronounced by the global Sustainable Development Goals

for instance goal 11 on sustainable cities and communities. Therefore, developed integrated sustainable framework for rural hospitals solid waste management can be tested and applied by institutions and organisations to achieve requirements of Agenda 21, SDGs and Zimbabwe's vision 2030. Additionally, besides creating a clean friendly environment, the framework emphasises the significance of waste recovery, recycling, reuse among other waste management Rs. Thus, putting emphasis on minimising the quantity of disposed solid waste from rural hospitals significantly while upholding economic growth through considering waste as a resource. Currently, Zimbabwe is moving towards the 'zero litter' goal (Masunungure, 2019; Tsaha, 2021; Rupapa, 2022). Therefore, by considering various aspects pinned on the developed framework, the country has potential to pursue its waste management goals. EMA (2007) and the Government of Zimbabwe (2013) concur that in the country every person has a right to a clean environment which is not harmful to health. Hence, the research data have potential to support the government to realise the rights of its citizens during implementation of solid waste management strategies. Research results were published as papers, for access by the public including policy makers, to promote their utilisation in formulation of policies related to solid waste management at rural hospitals. This indicated that results of the study have potential to draw attention of people including policy makers to rural institutions, since it puts obscure rural hospitals and other institutions into the limelight. Furthermore, research outcomes acted as a foundation to other researchers with curiosity to carry out additional research in the field of hospital solid waste. It also adds information to the already existing literature relating to hospital solid waste, particularly management of solid waste from rural hospitals.

1.5 Description of the study area

1.5.1 Profile of Chirumanzu district

The research focuses on developing an integrated framework for sustainable solid waste management at rural hospitals in Chirumanzu district namely ST Theresa and Holy Cross shown in Figures 1 and 2 respectively. Other hospitals in the district include Muvonde and Sanatorium, and nine clinics namely, Nyautonge, Chizhou, Siyahokwe, Mhende, Doroguru, Hwata, Hama, Chimbindi and Chengwena that provide mainly primary health care services whilst serious cases are referred to any one of the four hospitals. The district occupies 4.737 square kilometres of the Midlands province (Kori *et al.*, 2013). Kori (2013) further postulated

that the northern part of the district is covered by resettlement areas while the southern consists of communal settlements. The hospitals under study are found in communal areas of the district. Chirumanzu district lies between longitudes 19° 50' E and 30° 45' E and Latitudes 19° 30'S and 20° 20'S, in an area with average altitude of 1 200m above sea level (ZGLSD, 2016). Mugandani *et al.*, (2012) and Kori (2013) stated that the district is in agro-ecological region 3 that receives average rainfall of 650mm annually and average temperature of between 24°C and 30°C with occasional frost in winter. The rain season is usually from November to March and has been increasingly variable in recent years in line with contemporary climate change and variability. The existing climatic conditions allow people to practice subsistence farming, although food security is low due to poor soil fertility. Sandy loam soils in the district support diverse vegetation species such as *Brachystegia specieforms* (Musasa) (Marambanyika *et al.*, 2021), *Julbernadia globiflora* (Mutondo), and *Colophospermum* (mopane) and patches of grass (Fakarayi *et al.*, 2015).

Moreover, the district's population of about 95 272 grows at an average of 1.2% per annum and is composed of 45 589 males, 49 683 females and 24.556 households (ZIMSTAT, 2022). The continuous growth of the population and their need for health services add burden to hospitals leading to generation of large volumes of solid waste. The hospitals in the district are threatened by the economic meltdown of the country, therefore solid waste management systems are also impacted. Most of the people in the district are economically poor, a scenario illustrated by unemployment caused by lack of industries in the area and the fact that others are underemployed since they work for subsistence farmers who offered them an average of US\$45 salary per month and people's high reliance on subsistence farming as well as natural ecosystem services (ZIMSTAT, 2022). As a result, a large proportion of the people in the district resort to the mission hospitals since they offer health services at affordable prices. Moreover, health institutions in Zimbabwe are categorised into clinics at primary level which refer complicated cases to secondary level (district hospitals) which transfer to tertiary level (provincial hospital) and finally quaternary level (central hospitals that are found mainly in the cities of Harare and Bulawayo) (Ponesai *et al.*, 2015). ST Theresa and Holy Cross separated by a distance of approximately 27.8 kilometres are among secondary level hospitals. This implies that they receive patients from health institutions in the primary level category within the district and beyond. This adds pressure to the hospitals due to solid waste increase since they are located in communal areas with high population densities. ST Theresa and Holy Cross

were purposively selected for study since they are located in communal areas hence serve a large population which translates to hospital solid waste increase.

1.5.2 Physical geography of ST Theresa hospital catchment area

Figure 1 shows that ST Theresa hospital is located in the Southern part of Chirumanzu district, in the Midlands province. The hospital is situated near Charandura business centre and St Joseph's Mission in ward 8. The hospital is accessible by a gravel road which is 32 kilometres from Chaka to Charandura business centre. The major water sources in the area where the hospital is located are Mavhaire and Gurudze rivers, Bhambamba dam, Mbedzi dam and small streams like Mutorahuku. Mavhaire and Gurudze rivers flow and join Shashe river which later joins Tokwe river. ST Theresa hospital utilises water from drilled boreholes, however community people in the vicinity rely on boreholes and sometimes they fetch water from rivers and streams for domestic purposes. People who reside in proximity to ST Theresa's hospital also use water from hand dug wells with an average depth of nine meters, however they occasionally run dry during the dry season. Sandy loam soil with high infiltration capacity is the dominant soil type in ward 8. This permits free movement of nutrients and pollutants from different sources to reach underground water.

In terms of vegetation species in the area where ST Theresa is located, *Brachstegia specieforms* such as Musasa, *Julbernadia globiflora* for example Mutondo, and *Terminalia sericea* like Mususu are found. However, thorn bushes are part of the vegetation like *Ziziphus mucronata* for example muchecheni. Grass species found in the area include *hyparrhenia femitia*, star grass (*Cynodon aetheopicus*), and guinea grass (*Megathyrsus maximus*). Vegetation provides food to both domestic and wild herbivores. However, fruit trees like Matohwe (*Thespesia garckeana*), Nhunguru (*Flacourtia indica*), Nhengeni (*Ximenia caffra*) as well as Matamba (*Strychnos spinosa*) are found in the catchment where ST Theresa's hospital is found. Various bird species are found in ward 8 as demonstrated by existence of secretary bird, wattled crane, vultures (*Catharters*), Kori burstard and eagles (*Accipitridae*), crows (*Corvus ssp*) and red-whiskered (*Pycnonotus jocosus*). The area where the hospital is located accommodates foxes, spring hare, and squirrels, wild cats however monkeys and baboons are found in small numbers in the catchment of the hospital. Almost all these birds and wild animals are regarded as food

by local people and therefore their numbers are dwindling. In addition, use of stone traps during mouse (mbeva) (*Mus musculus*) gathering is rampant.

1.5.3 Socio-economic characteristics of ST Theresa hospital catchment area

ZIMSTAT (2022) postulated that a total population of 3 156 and 878 households is in ward 8 where ST Theresa is situated. The hospital was established in 1957 and is managed through partnership of Catholics and the Zimbabwean government. This suggests that ST Theresa is required to manage solid waste using environmentally and socially acceptable strategies following government environmental policies. Population size of ST Theresa catchment area was approximately 7 690 in 2016 (ST Theresa Annual Report, 2016). The population has increased due to high birth rate and escalation of immigrants who settle in the area. This suggests that ST Theresa offers services to a large number of people which also increase due patients transferred from other clinics and hospitals. In Chirumanzu district, ST Theresa receives patients transferred from clinics such as Doroguru, Hama, Chengwena, Mhende, Nyautonge and Chimbindi. Holy Cross also transferres other patients with complications to ST Theresa hospital. Attending to several patients with different health problems result in generation of various types of hospital solid waste which require an integrated framework to deal with the waste. ST Theresa hospital carries out major and minor operations, analysis of biological samples and caters for patients with intestinal and respiratory diseases, malaria, HIV and AIDS, COVID-19 among others. Hence, an integrated framework is essential to manage solid waste sustainably and suppress environmental risks associated with hospital solid waste generation and disposal at this hospital.

The hospital is equipped with approximately 80 beds found in different wards notably female, male, paediatric, maternity, isolation wards and departments such as administration, outpatient, family health clinic, laboratory, pharmacy, physiotherapy, doctors' offices and emergency rooms. This implies that a large number of people can be served at the hospital, therefore generation of high quantity diversity hospital waste is inevitable. Existence school of nursing for Registered General Nurses means an integrated framework for sustainable hospital solid waste management needed to cater for senior staff and student nurses. Furthermore, different types of religions are accepted in the area but most of the people are Christians for instance Catholics. This has eroded utilistaion of traditional medicine in curing diseases. Consequently, most of the people rely on hospitals for medical assistance, thus facilitating high generation of hospital solid waste. The district has poor infrastructure including type of roads and weak

communication network and this impedes link of rural hospitals with a number of organisations which supply or donate resources to other hospitals. Therefore, the hospital relied on inadequate resources hence large quantities of resources was directed to medical issues while little attention was given to solid waste management. ST Theresa catchment area accommodates people who practice subsistence farming where they grow different crops and keep various domestic animals. Mugandani *et al.*, (2012) stated that the production system is based on crops like legumes, small grain crops (finger millet, Sorghum) water melons, pumpkins, maize and vegetables. Moreover, growing of vegetables, beans, cabbages, and tomatoes is practiced utilising water from rivers and hand dug wells. Domestic animals such as goats, donkeys and cattle are reared and attentively herded during the farming season, however they ramble freely during the winter. This free movement may give domestic animals an opportunity to access any unsecured area including dumpsites.

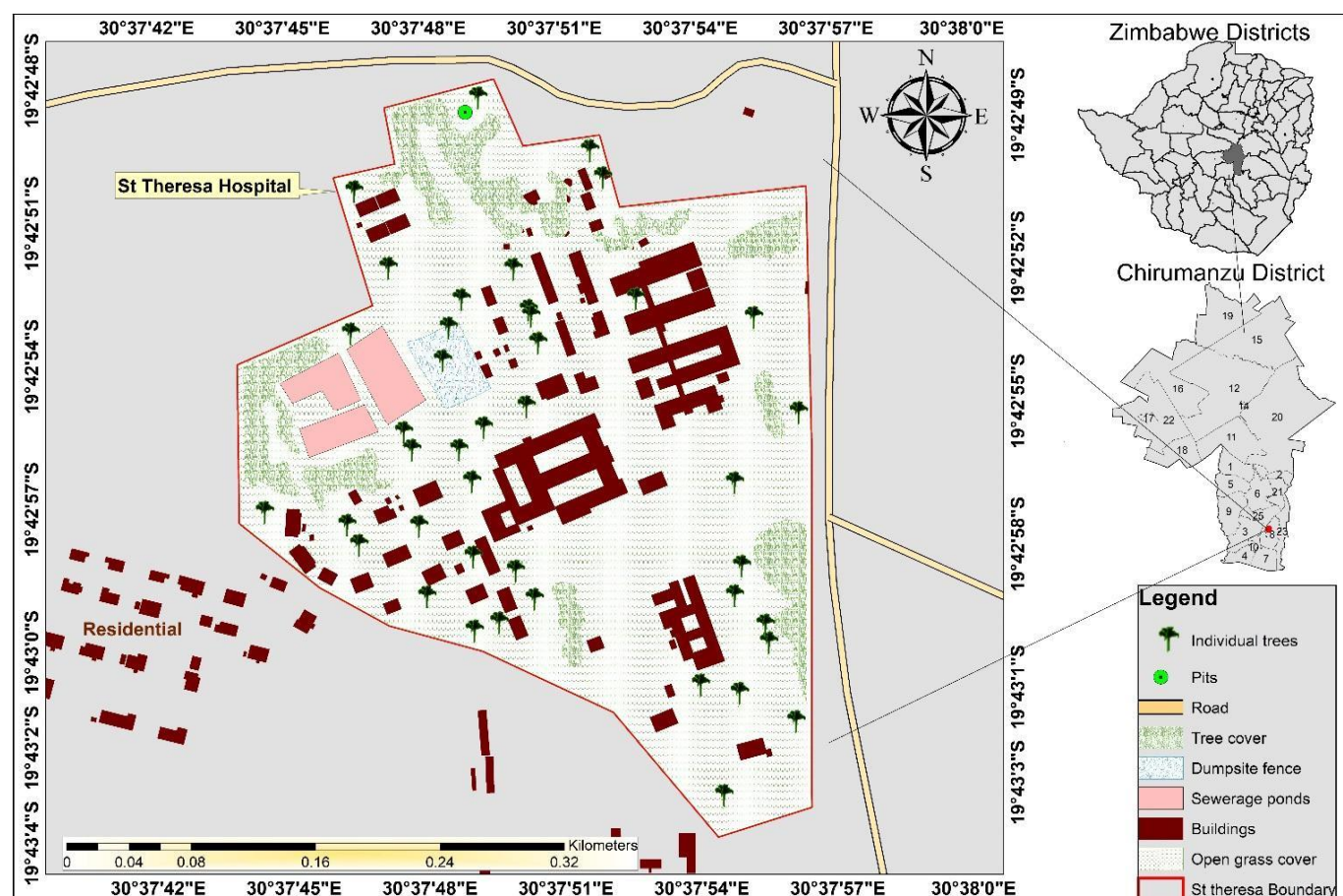


Figure 1. Location and characteristics of ST Theresa hospital in Chirumanzu district.

Source: Geographic Information System map derived from Google Earth image by the Author.

1.5.4 Physical geography of Holy Cross hospital catchment area

Holy Cross hospital is located in ward 6, Chirumanzu district (Figure 2). The hospital is located at Holy Cross Mission near Machekano Primary School and Holy Cross High School. It is accessible by a gravel road which is about 18 kilometers from Chaka to Holy Cross. Natural sources of water in the catchment area include Nyautonge river and its tributaries. The hospital as well as people use drilled boreholes as a source of safe water, however community people also utilise shallow wells. The dominant soil type in the Holy Cross area is sandy loam soil. The ward is characterised by sandy soils and some small areas are covered with loam soils. The soils are associated with high infiltration capacity that paves the way for easy movement of nutrients and pollutants of any type to groundwater levels.

Vegetation species such as *Brachystegia specieforms* like Musasa and *Julbernadia globiflora* like Mutondo, *Sclerocarya birrea* Marula (Mupfuru), *Brachystegia boehmii* (mupfuti) and *Terminalia sericea* (Mususu) and patches of grass cover the area. However, Hute (*Syzgium cordatum*), Matohwe (*Thespesia garckeana*) and Matamba (*Strychnos spinosa*) are some of the indigenous wild fruits in the ward. This implies that indigenous fruits are part of the local people's diet. Ward 6 in Chirumanzu district is covered by different grass species for instance three-meter hyparrhenia femitia and elephant grass (*Pennisetum purpureum*), star grass (*Cynodon aetheopicus*) and guinea grass (*Megathyrus maximus*) among others. The dominance of grass provides grazing pastures for domestic animals and wild animals. Presence of numerous vegetation species facilitates existence of different bird species in the area for instance batelaur eagle, kori burstard, vultures (*Catharters*), grey crowned crane, wattled crane and secretary bird. Families of bird species including crows (*Corvus ssp*), eagles (*Accipitridae*) and red-whiskered (*Pycnonotus jocosus*) are found in the area. A number of fauna species are found in the area under study namely waterbuck, monkeys, spring hares, bucks, squirrels and baboons. Availability of these wild animals in the area enhances the diet of the people since they practice illegal hunting to supplement their diet.

1.5.5 Socio-economic characteristics of Holy Cross hospital catchment area

ZIMSTAT (2022) census survey shows that Holy Cross hospital is located in a ward with a total population of 3 478 with 937 households. Given that the population is increasing in wards around the hospital under study, demand for health services increases for instance the need to

be vaccinated against Covid-19 and outreach vaccination programs. This also adds substantial quantities of hospital solid waste for example sharp waste generated at Holy Cross hospital. The hospital was constructed in 1960 with a bed capacity of 50 found in various hospital female, paediatric, maternity and male wards. Departments like X-ray, laboratory, pharmacy, physiotherapy, family health clinic, doctors' offices, emergency rooms, outpatient, and administration department are found at Holy Cross hospital. Existence of various wards and departments which produce solid waste, demonstrate that different quality of hospital solid waste is generated.

Additionally, the noble reputation of the hospital and ability to provide services at affordable charges attracts patients from various wards in Chirumanzu district. All these situations enhance the quantity of solid waste generated, hence adding burden to waste management issues. Holy Cross is monitored through collaboration of the Government of Zimbabwe and Roman Catholic Church. This implies that these two assist each other in provision of human and financial resources, however the hospital is not spared by the economic problems in Zimbabwe. Therefore, hospital solid waste management approaches are affected. People in the catchment area of Holy Cross hospital practice crop production based on crops like maize, water melons and drought resistant crops while various vegetables are grown in gardens. Rearing of domestic animals is part of their activities as evidenced by keeping goats, sheep, cattle as well as donkeys. The animals are allowed to look for food freely during the dry season, therefore they can reach anywhere including dumpsites.

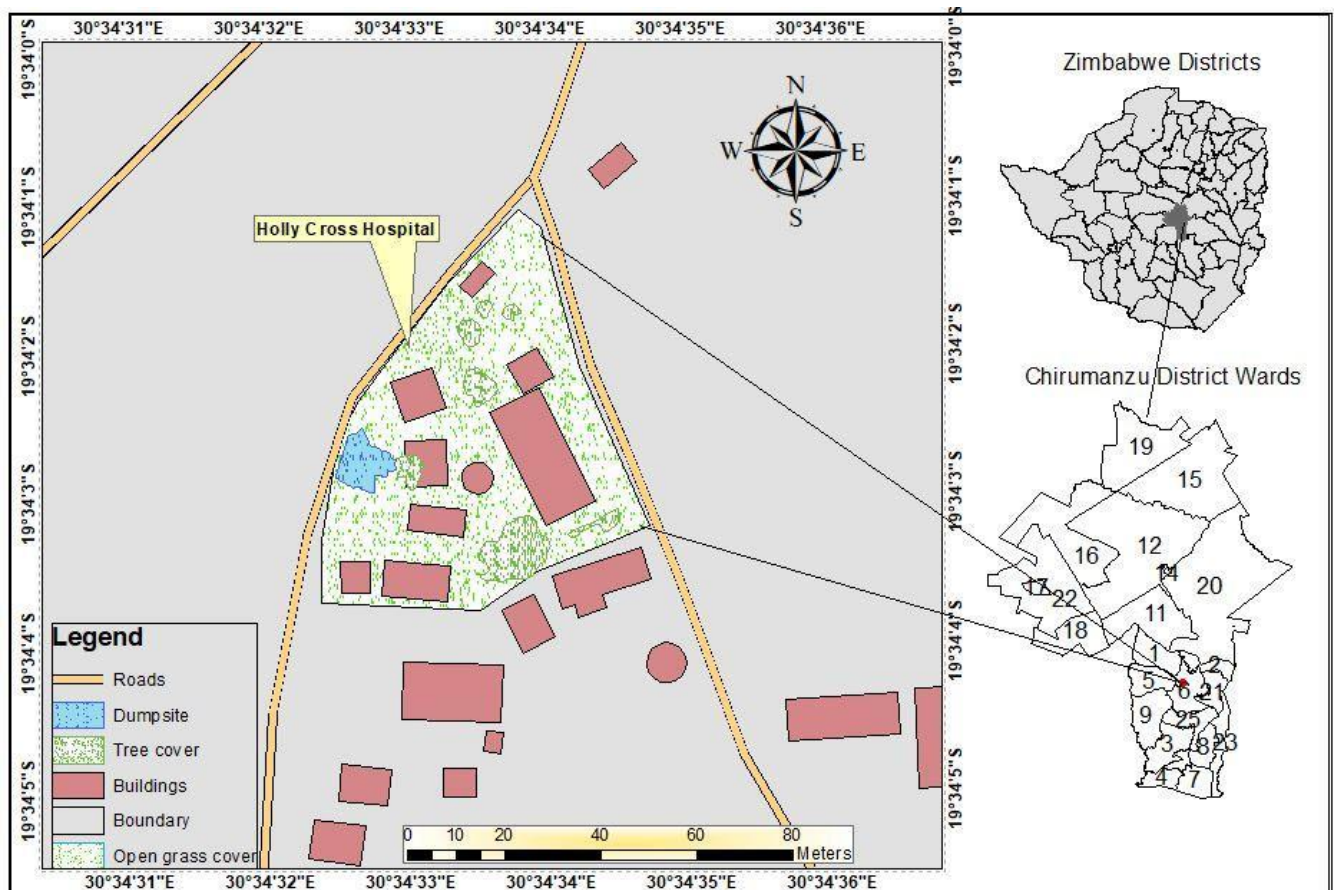


Figure 2: Location and characteristics of Holy Cross hospital in Chirumanzu district.

Source: Geographic Information System map derived from Google Earth image by the Author.

1.6 Conceptual framework

Solid waste management is a multifaceted process involving various activities including storage, collection, treatment, transportation, disposal and after care of disposal sites (Jerie and Tevera, 2014; Bhat *et al.*, 2018; Das *et al.*, 2021). This entails that proper management of solid waste including hospital solid waste requires an efficient network of various aspects and stakeholder participation. A number of models namely Life Cycle Assessment, Waste Management Hierarchy, Multi-Criteria Decision-Making Analysis and Cost Benefit Analysis were developed to guide solid waste management, but the problem of poor waste management with detrimental environmental impacts remains in both developed and developing countries (Ghinea and Gavrilescu, 2010; Karmperis *et al.*, 2013; Angelo *et al.*, 2017; Vlachokostas *et al.*, 2021). Additionally, most of the models are applied in developed countries' urban areas

(Morrissey and Browne, 2004; Ghinea and Gavrilescu, 2010; Marshal and Farahbakhsh, 2013). As a result, utilisation of the models in developing nations is still at an embryonic stage especially in rural areas.

Most of the models are complex, associated with weaknesses and require adequate resources when utilising them (Curan, 2014; Aung *et al.*, 2019; Gallego and Tarpani, 2019). A socially acceptable, affordable and more effective framework which meets characteristics of developing countries, particularly rural areas is essential. Existing models put much emphasis on economic and environmental aspects while giving less attention to social issues (Morrissey and Browne, 2004; Tsilemou and Panagiotakopoulous, 2006), yet social aspects need equal attention. Therefore, it is less beneficial to apply existing models in carrying out research focusing on developing an integrated framework for sustainable solid waste management at rural hospitals. Solid waste management aspects vary according to a country's legal, economic, political, social and administrative environments (Das *et al.*, 2021). This suggests that solid waste management structures, processes and procedures at institutions including rural hospitals may need to be hospital specific. Owing to scepticism surrounding applicability of existing models and distinctive characteristics of rural hospitals, a unique model is important to carry out this study effectively. Utilisation of a distinctive standard model proposed by the researcher facilitates attainment of meaningful results in the realm of solid waste management at rural hospitals.

Subsequently, the research was based on pillars of the conceptual framework (Figure 3) proffered by the researcher. It consists of various aspects that guide the research. Solid waste generation is influenced by numerous drivers including demographic, social, economic, technology and cultural (Estay- Ossandon and Mena-Nieto, 2018; Guven *et al.*, 2023). The study considers drivers as various factors and activities that result in generation of hospital solid waste. Therefore, by applying the model the researcher identifies essential factors contributing to solid waste generation and increase at rural hospitals. Implementation of sustainable solid waste management approaches involving development of integrated management models require adequate accurate data (Younes *et al.*, 2016; Mandevere and Jerie, 2018; Bui *et al.*, 2020). The framework (Figure 3), promotes identification of hospital solid waste characteristics generated at the hospitals, grouping solid waste into different major categories and their components. Through its use, hospital solid waste quantity, generation trends changes and causes of the changes (drivers) are unearthed. Moreover, this framework

assists in collection of comprehensive data linked to solid waste management approaches applied at rural hospitals. Management approaches looked at involve storage, treatment, transportation, disposal as well as solid waste minimisation techniques at rural hospitals. Das *et al.*, (2019) and Sharma *et al.*, (2020) concur that constraints in management of solid waste differs between rural and urban areas. This entails that there is a wide gap between challenges experienced by rural hospitals and urban hospitals. Hence, the framework acted as a guide to understand the gaps and challenges in management of hospital solid waste at rural hospitals. It paves the way to understand why rural hospitals are utilising existing solid waste management approaches and awareness of health workers to hospital solid waste legal framework.

In this research, the developed study framework (Figure 3) promotes a better understanding of guidelines and standards guiding hospital solid waste management nationally and internationally. Hospital solid waste is among significant contributors to environmental contamination while threatening public health (Ansari *et al.*, 2019; Das *et al.*, 2021). As a result, the nature of the model acts as a lens to recognise the state of the environment and human health in relation to prevailing solid waste management. State of the environment (terrestrial, aquatic and atmospheric ecosystems) and human well-being in this study was considered as impacts of the management approaches. The necessity of sustainable environmental management is initiated by several goals among them environmental protection, economic viability and social responsibility (Chams and Garcia-Blandon, 2019; Claro and Esteves, 2021). Components of the framework enable unearthing of pressures (internal and external aspects) that justify and push the need for an integrated solid waste management framework for rural hospitals (Figure 3). Information related to various components of the framework acted as a baseline for developing an integrated framework for sustainable hospital solid waste management at rural hospitals. The research further articulates opportunities (environmental, social, economic and political) that emanate from utilising the proposed integrated hospital solid waste management framework.

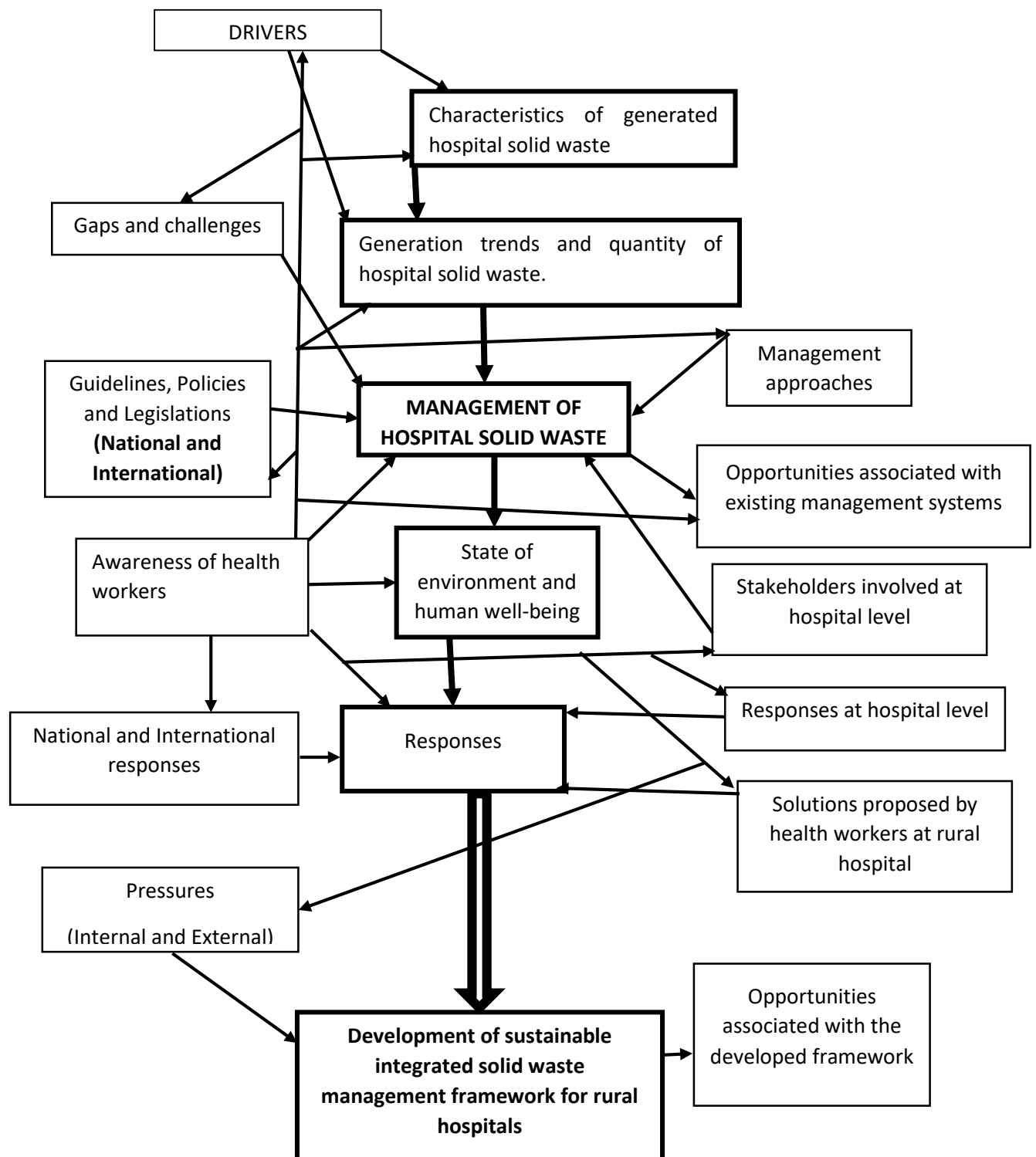


Figure 3: Conceptual framework of the study

Source: Developed by the author

1.7 Overall research methodology

1.7.1 Research philosophy

The research was based on pragmatic philosophical assumptions. Pragmatists believed that adequate research knowledge is accessed through endorsing plurality methods rather than embracing a sole technique (Kaushik and Walsh, 2019; Shah *et al.*, 2019). This implies that pragmatism requires the researcher to utilise mixed approaches of data collection which in this study are observations, interviews, questionnaires and secondary data sources. Pragmatist paradigm encompasses both deduction and induction reasoning approaches (Ragab and Arisha, 2018), thus enabling utilisation of positivism and interpretivism philosophical assumptions. Hence, pragmatic lenses offer the researcher room to use a research design which facilitates triangulation of quantitative and qualitative data collection, analysis and presentation methods. Pragmatic paradigm allows researchers to be innovative, coming up with new ideas as well as technologies (Kaushik and Walsh, 2019) through facilitating reviewing and criticism of existing quantitative and qualitative data (Baskarada and Koronios, 2018). Consequently, a pragmatic approach offered the researcher the opportunity to develop an integrated sustainable hospital solid waste management framework, which was essential for this research.

1.7.2 Research design

Research design refers to data gathering, analysis, interpretation, presentation and reporting procedures followed during research (Cresswell and Cresswell, 2018). Sovacool *et al.*, (2018) postulated that research design demonstrates how overall research methodology is carried out in a specific study. Considering these definitions this study regards research design as a complete framework demonstrating how numerous research techniques are used to accomplish the research. Hence, descriptive cross sectional research design that employs a mixed methods approach of qualitative and quantitative paradigms was adopted in data collection, analysis and presentation. Triangulation of qualitative and quantitative approaches increase the validity and reliability of research data since the techniques complement each other (Wali and Nwokah, 2016; Flick, 2020). Watkins (2015) and Leviit *et al* (2017) contend that qualitative research technique is inductive since it permits the investigator to assemble descriptive information. The researcher discovered participants' views on the hospital solid waste management framework through qualitative techniques. Qualitative elements used include observations, open ended questionnaire questions and semi structured interviews. Qualitative approach enabled gathering of data on characteristics of waste, management strategies and risks associated with existing

management framework. However, a quantitative paradigm was used to generate data on the quantity of hospital solid waste and collection of coordinates showing location of water sources, waste sites and soil sample points. Hypothesis testing such as the relationship between distance from the waste site and concentration of pollutants in the soil and water was done through quantitative methods.

1.7.3 Target population

According to Creswell (2012), individuals or organisations with characteristics that a researcher can identify and study are considered as the target population. Target population refers to a group of people who display characteristics and ability to provide sufficient information concerning the study's requirements (Cresswell and Poth, 2018; Casteel and Bridier, 2021). Considering these definitions, this study considered the target population as people who are capacitated with information on the topic under study. The target population includes two broad categories namely institutions, hospital departments and health workers at two hospitals under study. Targeted institutions and departments are Environmental Management Agency, Ministry of Health and Child Care, Hospital Cleaning Department, National Social Security Authority, Hospital Environmental Health Department. Targeted key informants from these institutions or department include Environmental Management Agency Officer (1), Hospital Environmental Health Technicians (2), Head of Cleaning Departments/Supervisor at the hospital (2), Hospital Matrons (2), District Medical Officer (1) and National Social Security Authority Public Health Officer (1). Interviews was used to collect data from 9 key informants. These key informants provide data on hospital solid waste characteristics, management framework, risks associated with management framework as well as approaches to reach sustainable waste management.

This study targeted 147 and 64 health workers stationed at ST Theresa and Holy Cross hospitals respectively (CDAHR, 2021) as questionnaire respondents. Joseph and Joseph (2016) postulated that health workers such as doctors and nurses provide direct services to patients while health workers like technicians and cleaners offer indirect services. Therefore, the questionnaire survey targeted 118 nurses, 3 doctors, 2 physiotherapists, 4 laboratory technicians, 2 radiologic technologists, 2 eye-opticians, 14 cleaners and 2 anaesthetists at ST Theresa hospital. Similarly, the questionnaire survey targeted 41 nurses, 1 doctor, 2 physiotherapists, 3 laboratory technicians, 2 radiologic technologists, 1 eye-optician, 12 cleaners and 2 anaesthetists at Holy Cross hospital. These health workers are involved in

activities leading to generation of hospital solid waste. Hence, they have information concerning waste characteristics, utilised waste management framework as well as environmental risks associated with hospital solid waste. Hospital departments, waste storage areas or containers and dumpsites were targeted during observations.

1.7.4 Sample size and its determination

According to Sekeran (2003) a sample is a representative of the entire population or objects to be studied. Corbin and Struss (2015) view the sample as a limited quota of the targeted study elements considered for the research. Hence, this study considers the sample as a minority group of participants extracted from the majority and capable of representing the total population. Required sample size for questionnaire survey at each hospital was determined using Taro Yamane (1967)'s formula at 95% confidence level with +/-5% margin of error. Therefore, the following formula was utilised to calculate sample size for each hospital.

$$n = \frac{N}{1 + N(e)^2}$$

Where:

n = sample size

N = total population

e = margin of error 0.05 (±5%)

Therefore, sample size for questionnaire survey was 105 at ST Theresa hospital and 55 at Holy Cross hospital (Table 1). Consequently, 160 questionnaires were administered for the study. ST Theresa and Holy Cross hospitals consist of health workers focusing on different tasks as shown by the target population. Hence, after determining required sample size, stratified sampling procedure followed by dividing health workers into groups according to their occupation at hospitals. Representatives of each strata was proportionally determined basing on strata size using Bowley (1926)'s following formula: $\frac{\text{Required Sample Size}}{\text{Population size}} \times \text{stratum size}$. Questionnaire respondents from each stratum were selected using a simple random sampling method. Individuals for each strata were numbered and a computer generated random table was used to select strata representatives of each strata.

Table 1: Sample size for questionnaire survey

Hospital name	Number of health workers	Grouping of workers according to their occupation	Required sample size using Taro Yamane formula $n = \frac{N}{1+N(e)^2}$	Sample size to represent each strata $\frac{\text{Required Sample Size}}{\text{Population size}} \times \text{strata size}$	Total
ST Theresa	147	Nurses 118, Doctors 3, Laboratory technicians 4, Physiotherapist 2, Radiologic technologist 2, Anaesthetists 2, Eye optician 2, Cleaners 14.	105	Nurses 86, Doctors 2, Laboratory technicians 3, Physiotherapist 1, Radiologic technologist 1, anaesthetists 1, Eye optician 1, Cleaners 10.	105
Holy Cross	64	Nurses 41, Doctors 1, Laboratory technicians 3, Physiotherapist 2, Radiologic technologist 2, anaesthetists 2, Eye opticians 1, Cleaners 12	55	Nurses 35, Doctors 1, Laboratory technicians 2, Physiotherapist 2, Radiologic technologist 2, anaesthetists 2, Eye opticians 1, Cleaners 10.	55
Total questionnaire respondents					160

Source: Field data (2023)

Key informants to participate during the interviews were selected using a purposive sampling approach. Selection of interviewees in this research was grounded on their ability to provide data relevant to the study (Table 2). Chirumanzu District Medical Officer (DMO) was included since the individual is responsible for managing all hospitals in the district. Environmental Management Agency (EMA) district Officer who monitors hospitals in terms of solid waste management was involved as key informant. One Environmental Health Technician (EHT) at each hospital, Head of Cleaning Department/Supervisor at each hospital and Hospital Matron

(HM) situated at each hospital was selected using purposive sampling as key informants. These individuals are equipped with knowledge regarding characteristics of hospital solid waste and existing management framework. Hospital solid waste threatens the safety of health workers (Ali *et al.*, 2017; Das *et al.*, 2021), therefore one National Social Security Authority (NSSA) Public Health Officer was part of interviewees. Table 2 presents justification for selecting the mentioned key informants.

Table 2: Organisation where the key informant is attached, Personnel and Justification for selecting the interviewee.

Organisation where the key informant is attached	Personnel	Justification for selecting the interviewee The interviewees are capable to provide information concerning :
Ministry of Health and Child Care	District Medical Officer	1. Hospital solid waste types. 2. Hospital solid waste management framework. 3. Environmental and health risks associated with hospital solid waste. 4. Can provide information regarding possible management strategies that can be implemented.
Environmental Management Agency	District Environmental Management Agency Officer	1. Role of Environmental Management Agency in hospital solid waste management. 2. Strength and weakness of existing solid waste management framework. 3. Environmental risks associated with mismanaged hospital solid waste 4. Strategies to protect the environment from hospital solid waste
Hospital Environmental Health Department	Environmental Health Technician	1. Nature of hospital solid waste 2. Limitations and strengths of waste management framework. 3. Hospital solid waste management guidelines at hospital level.

		4. Challenges encountered in hospital solid waste management. 5. Environmental risks that emanate from improper management of hospital solid waste as well as strategies to minimize the risks.
National Social Security Authority	Public Health Officer	1. Roles and responsibilities of National Social Security in hospital solid waste management. 2. Safety, health and environmental issues related to hospital solid waste management and approaches to reduce the risks. 3. Safety legislation related to hospital solid waste management.
Ministry of Health and Child Care	Hospital Matron	1.Type of hospital solid waste 2. Hospital solid waste management framework at hospital level 3. Barriers to adopt sustainable management of hospital solid waste. 4. Hospital solid waste management future plans
Hospital Cleaning Department	Cleaning Head of Department/ Supervisor	1.Types of hospital solid waste 2. Environmental health problems associated with hospital solid waste. 3. Strength and limitations of the existing solid waste management framework. 4. Problems which hinder application of proper hospital solid waste management methods.

Source: Author (2023)

1.7.5 Data collection methods, procedures and instruments

1.7.5.1 Field survey of dumpsites location and characteristics

Collection of geometric and attribute data including coordinates indicating waste disposal sites location was done using Global Positioning System (GPS). Location of critical environmental attributes notably water sources, land uses like farming and residential areas was done using Global Positioning System coordinates. A handheld portable Global Positioning System (Garmin Series 76s) with 3 meter precision was utilised to collect the coordinates. Coordinates showing location of features were attained by going round the study area with a Global Positioning System receiver acquiring coordinates of points of interest. Longitudes and latitudes figures was used to locate position of the waste sites and water sources at each hospital under study.

1.7.5.2 Observations and waste quantification

In order to guarantee continuous collection of accurate data during observations, one of the hospital personnel involved in waste management was trained to be a research assistant. The research assistant was trained on how to carry out participant observations. An observation checklist with parameters to be observed and space to record data was used during field observations. Data on hospital solid waste characteristics, storage, conveyance systems, and disposal as well as treatment points was gathered through observations using a checklist. Hospital solid waste handling behaviour of the subjects involved in the waste management chain was detected using observations. A research assistant was trained to collect data concerning types of waste reused by health workers. A digital camera was used to capture photographs of storage containers or areas, conveyance systems, disposal areas and treatment facilities during observations.

Collection of data regarding quantity of hospital solid waste generated per patient and solid waste generated during days of data collection at each hospital was done. Plastic bags or bin liners were distributed to the targeted departments, so that health workers stored waste. Data on the quantity of hospital solid waste generated was collected from 07 March to 14 March 2023. Determination of solid waste quantity and composition after 7 days present to minimise ambiguity since Jerie (2014) adopted it to collect accurate data during solid waste research. Different hospital solid waste types were loaded in labelled plastic bags (bin liners) with support of research assistant. During loading of solid waste in plastic bags segregation was

carried through a hand sorting approach, since it is regarded as the accurate strategy to collect reliable data (Gu *et al.*, 2015; Noufal *et al.*, 2020). A digital weighing scale was used to weigh each plastic bag in order to determine the weight of solid waste. Quantity of solid waste obtained during the weighing process was recorded in a notebook. Ahmed (1997)'s formula: Waste Generation Rate = Average Waste Production /Patient/day X Total Number of Patients admitted (**$WGR = AWP/P/D \times T \text{ No of } P$**), was utilised to quantify solid waste generated by the hospital in relation to admitted patients per day. Characterisation of hospital solid waste in different categories was done using WHO and UNICEF (2015) approach. Therefore, hospital solid waste was grouped into infectious, pathological, chemical, sharps, cytotoxic, pharmaceutical, radioactive and general solid waste. Types of hospital solid waste under each category was recorded on solid waste characterisation form.

1.7.5.3 Flora and fauna survey

In terms of flora survey, the researcher focused on shrubs, trees and grass since they are responsible for offering various services to fauna. Barker (2009) and Buckland *et al.*, (2001) concur that line transect survey is suitable for monitoring vegetation species with patchy distribution. Therefore, for flora survey line transect survey was adopted since study areas are characterized by sparse savanna vegetation. However, quadrants were placed along the line for easy data collection and quantification. Roshni *et al.*, (2022) highlighted that studying of species composition and diversity is mostly done following a 320m transect line drawn from a pollutant source. The line was drawn considering downslope direction and wind direction, since these factors play a pivotal role in movement and direction of pollutants plumes (El-Kilani *et al.*, 2010; Matthieu *et al.*, 2014). Placing of the quadrant along the line was carried out using Roshni *et al.*, (2022)'s procedure (Figure 4). The selected point acted as the center of the quadrant during quadrant drawing. Quadrant size was determined using the Roshni approach of 5 x 5 for shrubs (less than 1.37m) and 10m x 10m for trees (1.37m and above). The quadrant size for grass was adopted from Barker (2001)'s method of 1m x 1m. In order to obtain species composition physical counting of species was done to obtain frequency and convert it into percentage. Data on flora demonstrated the effect of dumpsite pollutants on vegetation composition, diversity and their possible accumulation in the food chain threatening public health.

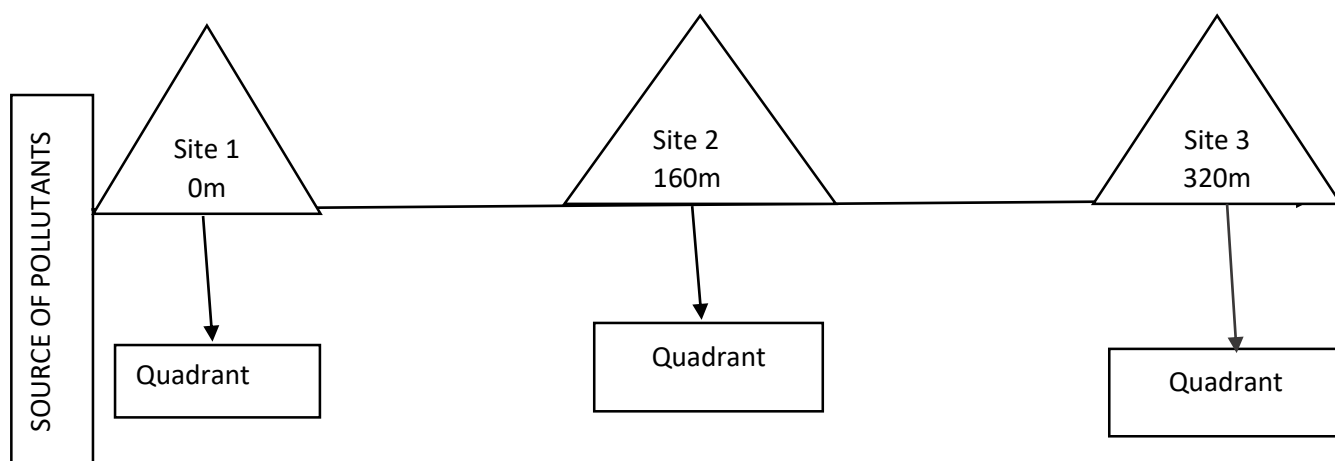


Figure 4: Vegetation sampling design diagram

Source: Roshni *et al.*, (2022)

Data concerning fauna namely birds, wild animals as well as domestic animals which consider waste sites as food sources was collected utilizing an observation checklist. Observation checklist was utilised to collect data regarding name of animal species, nature of waste they consume and categories of animals in terms of domestic or wild animals. In order to ensure continuous fauna observations, one hospital personnel who acted as research assistant was trained on the type of data to be collected during fauna survey and how to record. Collection of data on type of waste they consume necessitates predicting of health risks that may affect fauna and how pollutants accumulate in the food chain. Fauna frequency of visit was collected through physical counting during fauna survey. Data collected during flora and fauna surveys was recorded in a notebook.

1.7.5.4 Soil sample survey

Pollutant concentration commonly varies in soil samples collected at 10 meters (m), 30 meters and 60 meters from the waste site due to pollutants attenuation (US EPA, 2009). Hence, soil samples to determine concentration of contaminants were collected following a 60 m transect line at points which are 10m, 30m, 60m from the dumpsites for comparative analysis. However, for this study another soil sample 0m was located at the edge of the dumpsite to understand concentration of pollutants within the dumpsite and draw valid conclusions during comparison. In order to access the soil easily the transect line was drawn from the waste site

edge 0m following downslope direction. This direction was selected based on wind direction and water flow direction, since these are major parameters which determine pollutants movement and deposition (El-Kilani *et al.*, 2010; Matthieu *et al.*, 2014). Pollutants like metals are to a larger extent found in topsoil, usually 0-5cm (Pikula and Stepien, 2021). Therefore, all samples were collected at a depth of 5cm at different points using soil sampling stainless hand Auger. In order to use the hand Auger properly, the researcher followed US EPA hand Auger use procedures (US EPA, 2020). The collected soil samples were packed in 1kg polythene bags. The bags were sealed properly to avoid contamination of the soil and labelled with water resistant ink showing date, parameters to be tested and name of the hospital.

1.7.5.5 Water sample survey

According to the US EPA (2020) pollutants have the potential to spread up to 500 meters from the dumpsites. Therefore, water samples were collected in March and May 2023 from groundwater sources within a radius of 500 meters from the dumpsite centre. A focus on groundwater was driven by Burri *et al.*, (2019)'s view that the current anthropocene era is witnessing ground water quality deterioration. However, water source with least distance from the waste site and the one with highest distance from Holy Cross and ST Theresa hospital dumpsites were purposively selected, translating to 2 water samples at each hospital under study. The purpose for selecting these water sources is to enable determination of the spatial distribution of pollutants in ground water around the dumpsites used by each hospital under study. In order to disinfect borehole outlets methylated spirit was applied and ignited using a burner as articulated by EPA (EPA, 2003). This process was carried out to avert contamination of water samples. The containers used for sample collection were washed by hydrochloric acid and rinsed with de-ionised water to be contamination free. Consequently, water samples were collected utilising labelled brown polythene sterile 1 Litre containers. The containers were branded using water resistant ink indicating date, sample name, parameters to be tested. The researcher prepared a tabular form detailing the same data revealed on the containers. The water samples were stored in a cooler box and transported to a laboratory for analysis before 24 hours (APHA, 2015).

1.7.5.6 Questionnaire survey

A semi structured questionnaire with open and closed ended questions was used to collect data in order compare the responses and get in-depth data concerning study objectives. English language was used to design the questionnaire since most of the health workers are holders of tertiary academic certificates. Questionnaire pre-test survey was carried out using 10% to check

its effectiveness (Perneger *et al*, 2015). Hence, 10% which translates to 16 questionnaires of the total questionnaires was used for pilot study at ST Theresa hospital. Preliminary questionnaire surveys enabled the researcher to use the feedback to edit and amend the research instrument to suit research requirements. This concurs with Perneger *et al.*, (2015) that pretesting of research instruments is necessary to detect inappropriate questions that need to be removed or improved and estimate the overall time required to carry out the entire questionnaire survey.

The researcher adopted a self-questionnaire administration approach to maximise percentage of response rate and detection of non-verbal clues like respondents' facial expressions. From 7 March to 14 March 2023, a total of 160 questionnaires were administered to nurses, doctors, laboratory technicians, physiotherapist, radiologic technologist, anaesthetist, eye opticians and cleaners (Table 1), since 105 questionnaires were used to collect data at ST Theresa while 55 was utilised at Holy Cross hospital. Hence, stratified sampling procedure (Table 1) was applied to avoid over representation or misrepresentation of certain groups. Questionnaire respondents were divided into stratas according to their occupation and representatives for each group were selected using simple random sampling through visiting their working departments or offices. Individuals for each strata were numbered and a computer generated random table was used to select strata representatives. This opinion is supported by Hamed (2016) and Berndt (2020) that accuracy in terms of respondents' representativeness is achieved through stratified simple random sampling. Table 1 demonstrated questionnaire sample size and participants to represent each strata at ST Theresa and Holy Cross hospitals.

Questionnaires were used to solicit demographic data such as gender and level of education, since these can affect practices and perceptions of an individual towards hospital solid waste management. Therefore, it provides a baseline for data analysis. Data regarding hospital solid waste characteristics, existing management framework as well as environmental risks was also collected through questionnaire survey. Aspects of hospital solid waste management training, policies and legislation was collected using questionnaires. Questionnaires were used to collect data on health workers' perceptions concerning existing solid waste management framework and challenges experienced by hospitals. Questionnaires were also used to gather data regarding potential hospital solid waste management approaches that can be adopted by hospitals to achieve sustainability.

1.7.5.7 Interviews

Qualitative technique utilises purposive sampling and interviews which are semi structured (Gopaldas, 2016). Consequently, semi structured interview guides with open ended questions were utilised to solicit data from purposively selected key informants. Interviews were used to gather data on hospital solid waste characteristics, management framework, challenges in waste management and environmental risks associated with hospital solid waste. Issues relating to hospital solid waste legislation, policies as well as strength and limitations of hospital solid management framework was collected through interviews. Direct formal conversations were applied to gather data from key informants' interviews. Face to face interviews were employed in order to gather non-verbal actions and verbal data. It gave room for precise arguments between the researcher and interviewee, thus facilitating collection of actual facts about the study. Collected data was written in a notebook and phone recordings were done if the interviewee grants permission to the researcher to record. In order to increase the confidence of key informants, the researcher arranged to visit interviews at their workplaces.

Chirumanzu District Medical Officer participated among the interviewees since the individual is responsible for monitoring hospitals in the district. The cadre have ability to know hospital solid waste characteristics, management strategies, challenges faced by rural hospitals and environmental risks that emanate from management strategies employed by these hospitals. The District Medical Officer can provide information concerning loopholes, merits associated with waste management frameworks utilised at the hospitals and ways to improve the existing system. The Environmental Health Technician is an instrumental figure in the implementation of innovations concerning hospital solid waste at hospital level. Hence, data concerning the nature of hospital solid waste and challenges faced by hospitals in trying to implement effective waste management strategies, was gathered from the Environmental Health Technician at each hospital. The personnel is also able to provide information about the risks of mismanaged hospital solid waste and how to strengthen the used frameworks to curb the environmental risks. The district Environmental Management Agency Officer responded to an interview, because these officers are equipped with knowledge on legislations and policies governing hospital solid waste management.

Environmental Management Agency Officers provided data regarding challenges to achieve proper hospital solid waste as well as impacts of the waste to the environment. Environmental Management Agency officers are environmentally conscious therefore the officer provided

vital information on how to protect the environment from hospital solid waste. Public Health Officer from National Social Security (NSSA) was purposively selected to provide data on safety, health and environmental issues related to management of hospital solid waste. Public Health Officer from National Social Security (NSSA) responded to questions. Furthermore, information concerning roles and responsibilities of NSSA in hospital solid waste management through interviews. Hospital Matrons stationed at each hospital participated as interviewees since they know the nature of hospital solid waste, solid waste management strategies utilised by the hospital. Matrons are familiar with issues concerning challenges and constraints in hospital solid waste supervision, therefore responded to questions. Lastly, the Cleaning Head of Department at each hospital responded to interview questions since they are crucial figures in monitoring hospital solid waste from point of generation to disposal. Therefore, highlighted some of the weaknesses associated with the current waste management framework and challenges they are facing in hospital solid waste management. Justification for selecting the mentioned key informants are summarised in Table 2.

1.7.5.8 Secondary data sources

Qualitative and quantitative secondary data on hospital solid waste characteristics, legislation, policies, management strategies and environmental risks was obtained from already published literature and grey literature. Published literature was retrieved from Google Scholar, Scopus, websites and PubMed among other sources. Published literature sources in the university library were consulted. Words typed on search engines as key words include hospital solid waste, hospital solid waste management approaches, frameworks and environmental health risks associated with the strategies among others. Grey literature on hospital solid waste was retrieved from Zimbabwe Ministry of Health Childcare (MoHCC), National Social Security Authority and Environmental Management Agency websites. However, at hospital level data was retrieved from unpublished hard copies or soft copies. Secondary data was essential for supplementing data collected through primary sources notably observations, questionnaires, interviews as well as experiments. Already published literature assisted the researcher to find research gaps in this study. In order to gather information concerning already existing solid waste management frameworks secondary data sources were highly used. Thus, facilitating development of a sustainable integrated hospital solid waste management framework for rural hospitals.

1.7.6 Methods of data analysis, procedure and presentation techniques

1.7.6.1 Quantitative data analysis, procedure and presentation

Quantitative data obtained during research was analysed using Statistical Package for Social Sciences (SPSS) and Microsoft excel. The initial stage was data coding through assigning numbers to responses for easy capturing and enabling the computer to understand easily. This was followed by entering the codes corresponding with questions and responses into excel sheet and exported to SPSS 25.0 for analysis at 95% confidence level. Descriptive statistics such as mean, frequencies and mode were used to show response rate particularly questionnaire respondents. Analysis of hospital solid waste quantity average, maximum and minimum values was carried out through descriptive analysis. Association between number of patients and quantity of hospital solid waste generated was tested using Pearson Chi-square test. The decision rule is if Chi-square value (χ^2_{cal}) is less than 0.05, there is an association hence we reject Null hypothesis (H_0) and accept Alternative hypothesis (H_1) and if χ^2_{cal} is greater than 0.05 there is no association therefore we accept H_0 and reject H_1 .

Electrical conductivity and P.H are usually utilised to characterise concentration of pollutants in water, however, water organic content is commonly measured through analysis of chemical oxygen demand (Kamaruddin *et al.*, 2013). In order to monitor water quality of sources vulnerable to a dumpsite parameters like total dissolved solid are considered, therefore, collected water samples were subjected to laboratory analysis to test P.H, electrical conductivity, chemical oxygen demand and total dissolved solids. Mohiuddin (2011) goes on to say that leachates which occur as a result of biochemical reactions is rich in organic content and solubilizes several metals like zinc (Zn), lead (Pb) arsenic (Ad), cadmium (cd), nickel (Ni) chromium (Cr), mercury (Hg), Copper (Cu) and Selenium (Se). Consequently, soil and water samples collected were submitted to the laboratory to be tested for lead (Pb), Arsenic (Ad), mercury (Hg) and cadmium (Cd) levels. The study focused on these metals because the World Health Organisation postulates that they are among 10 major chemicals with potential to affect human well-being (WHO, 2020). T-test was used at $p < 0.05$ and 95% confidence level to compare pollutants concentrations in soil samples collected from various distances from hospital waste sites. Results from water and soil samples analysis were analysed by comparing with standards of water and soil quality recommended at national and global level notably WHO.

Coordinates of waste sites, water sources and land uses captured using Global Positioning System were analysed utilising ArcGIS 10.8. All the points captured were exported to ArcGIS for the data processing. ArcGIS pre-processing, data analysis, preparation editing and output generation of the data was applied for digitizing proximity, overlay analysis and database creation. Proximity analysis between the waste disposal sites, water sources and land use patterns was carried out using the buffering technique. This supported the investigator to analyse the severity of waste site to the water sources in the vicinity and determine environmental attributes at low, medium and high risk. Pollution risk intensity maps were created based on critical parameters like water sources, land uses and residential areas. The features on the map were presented as polygons. In order to manage large amounts of GIS data efficiently and effectively, a GIS based multi-criteria technique was used. Vector data pre-processing operations such as digitization and clipping were performed.

Furthermore, ArcGIS 10.8 tools such as buffer, Euclidean distance, and weighted overlay were used for GIS-based analysis. Primary data for the study included raw images (Landuse-Land cover raster data and DEM download from USGS Earth Explorer). Landsat 8 image dated 10 June 2023 with 30m resolution 10 m was resampled and used to prepare primary input thematic maps like land-use/land-cover (Vegetation, built-up, cultivation and water). Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) digital elevation data of 30 m resolution were used to generate (slope). Raster data pre-processing operations such as resampling and masking were performed. In the field, open dump sites and water points were collected using hand held Garmin GPS. All input datasets were georeferenced to WGS 84/ UTM Zone 36S coordinate system and reclassified giving weights (slope-25%, Landuse/cover-25% and proximity-50%), and new risk maps were generated based on Weighted Overlay. Spatial geodatabase was designed to include the input datasets, their derived datasets, weighted analysis maps, and the final result. The shape files were exported to the corresponding feature data sets and the raster files were exported as individual raster datasets in the geodatabase. The flowchart of the methodology is shown in Figure 5.

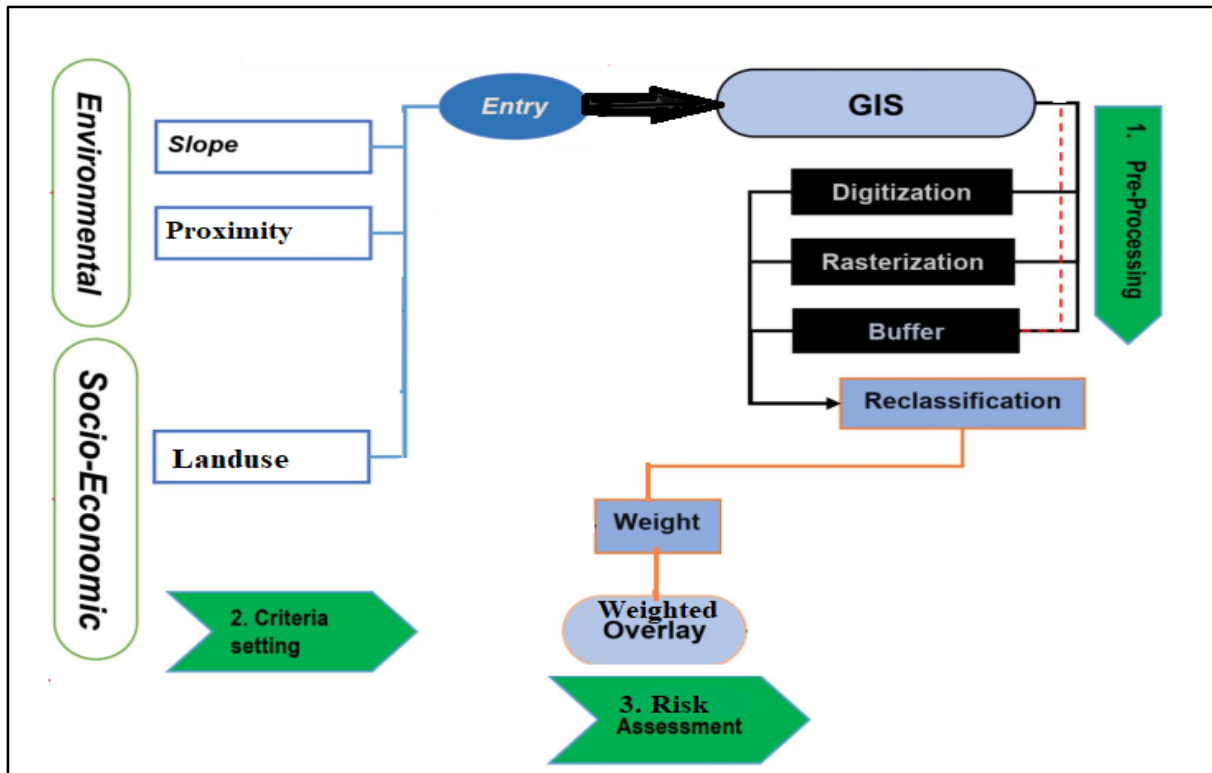


Figure 5: Risk map creation flowchart

1.7.6.2 Qualitative data analysis, procedure and presentation

Qualitative data collected from primary data sources namely observations, interviews, and questionnaire open ended questions and from secondary sources was analysed through content analysis. Qualitative data on hospital solid waste characteristics, management approaches, management challenges and environmental risks was checked for completeness and subjected to content analysis. The researcher classified data into themes based on meanings and relationships in order to carry out content analysis. Therefore, enabling the researcher to examine and summarise qualitative data in order to draw valid conclusions. In order to strengthen the narratives, expressive and persuasive language was used to present qualitative data. Direct and indirect quotations were used to present special quotations with meanings which may be distorted if subjected to analysis. Hospital solid waste management framework was analysed by benchmarking the management process relevant national and international standards and guidelines and waste management hierarchy.

1.8 Thesis outline

1.8.1 Overview of the thesis structure

The thesis consists of six chapters, from chapter one to six. The thesis adopted a paper-based approach, therefore literature review section and objectives were published as papers and are presented as chapters in this thesis. Each chapter serves its unique purpose, although there is a relationship and some inevitable overlaps of information amongst the chapters. In the published chapters the primary author was **Takunda Shabani**, (an MPhil student). Breakdown of the research chapters is as follows:

1.8.2 Chapter 1

The chapter presents background to the study, statement of the problem as well as research objectives and study area information. It also provides information related to conceptual framework, significance of the study and presents the thesis outline.

1.8.3 Chapter 2

Chapter 2 is a presentation of literature review paper which was based on secondary sources. The review paper was titled, “**Medical solid waste management status in Zimbabwe**”. The paper was published in the journal of Material Cycles and Waste Management (**Springer**) as:

Shabani, Takunda. and Jerie, Steven. (2023). Medical solid waste management status in Zimbabwe. *Journal of Material Cycles and Waste Management*, 25(2), 1-16.
<https://link.springer.com/article/10.1007/s10163-022-01578-4>

1.8.4 Chapter 3

This chapter presents information related to objectives one and two of the research. The manuscript was published in the Journal of Environmental Sciences Europe (**Springer**) as:

Shabani, Takunda., Mutekwa, Vurayayi. Timothy. and Shabani, Tapiwa. (2024). Solid waste characteristics and management strategies at ST Theresa (STT) and Holy Cross (HC) hospitals

in Chirumanzu rural District, Zimbabwe. *Journal of Environmental Sciences Europe*. 36(1),1-27. <https://link.springer.com/article/10.1186/s12302-024-00882-0>

1.8.5 Chapter 4

The chapter puts much emphasis on one of the research objectives namely: To analyse environmental health risks of hospital solid waste management strategies employed by rural hospitals in Chirumanzu district. The paper with information related to the objective was published in the journal of SN Social Sciences (**Springer**). The manuscript was published as:

Shabani, Takunda., Mutekwa, Vurayayi. Timothy. and Shabani, Tapiwa. (2024). Environmental health risks associated with solid waste management at rural hospitals in Chirumanzu District, Zimbabwe. *SN Social Sciences*, 4(2), 20. <https://link.springer.com/article/10.1007/s43545-023-00821-5>

1.8.6 Chapter 5

The chapter encompasses information related to objective four which focuses on developing an integrated framework for sustainable hospital solid waste management at rural hospitals in Chirumanzu district. The paper was published in the journal of Circular Economy and Sustainability (**Springer**) as:

Shabani, Takunda., Mutekwa, Vurayayi. Timothy. and Shabani, Tapiwa. (2023). Developing a Sustainable Integrated Solid Waste Management Framework for Rural Hospitals in Chirumanzu District, Zimbabwe. *Circular Economy and Sustainability*, 4, 1-35. <https://link.springer.com/article/10.1007/s43615-023-00313-x>

1.8.7 Chapter 6

This chapter combines issues highlighted in chapter 1 to 5. Therefore, it sums up the research by providing a synthesis of the study, conclusion as well as recommendations considering aspects emphasised in other chapters.

1.9 Conclusion

This chapter provided a foundation of the entire research by presenting the background to the study highlighting historical and contemporary developments in the study. It also articulates the statement of the problem which was investigated in this research. Following the statement of the problem, research objectives which offer a roadmap for the research are outlined while the conceptual framework which guides the research is presented. The chapter justified the study indicating significance of the research in addressing challenges, informing decision makers and its contribution to existing knowledge. Description of the study area highlighting physical and socio-economic characteristics of the broad district and the immediate localities in which the two study hospitals are located was included in this chapter. This chapter also covers overall research methodology encompassing pragmatic philosophical research philosophy, design, target population, sample size as well as data collection, analysis and presentation methods. Research ethics including seeking permission to carry out the research, informed consent, confidentiality and anonymity are shown in this chapter. Lastly, the chapter provides structural organisation of the thesis, outlining brief contents and order of the chapters from 1 to 6.

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Chapter 2

Medical Solid Waste Management Status in Zimbabwe

Shabani Takunda¹ and Jerie Steven¹

¹Midlands State University, Department of Geography, Environmental Sustainability and Resilience Building, P. Bag 9055 Gweru, Zimbabwe.

Corresponding Author: Shabani Takunda, Email: shabstaku@gmail.com

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Abstract

In Zimbabwe, management of medical solid waste is emerging as a visible dilemma. This is attributed to population explosion as well as outbreak of diseases and spread of already existing diseases which accelerate volume of medical solid waste generated by medical facilities. Consequently, the overarching objective of this paper was to review medical solid waste management status in Zimbabwe utilising published documents. The literature demonstrated that medical solid waste generated in Zimbabwe encompasses pathological, pharmaceutical, chemical, infectious, cytotoxic, sharps and general waste. Management approaches used by medical facilities are marred with inappropriateness as shown by storage, collection, conveyance and disposal of non-segregated waste. Verdicts of the study depict that open pit dumping, landfills, incineration, burying, open burning, Auto-way pits and open dumpsites are discarding strategies used. However, these strategies pose water, air and soil pollution, therefore, impacting the ecosystem and humanity. Findings indicated that infectious diseases, respiratory diseases, gastro-intestinal problems and injuries emanate due to poor management of medical waste. The roots of unsafe management of medical solid waste include inadequate finance, weak enforcement of legislation, ignorance among health workers and waste workers as well as non-participatory approach in decision making. Zimbabwe is recommended to direct funds to medical solid waste, increase awareness of health workers through trainings and education and reinforcing enforcement of legislation linked to medical solid waste among others.

Keywords: Zimbabwe · Medical solid waste · Medical solid waste management practices · Environmental health risks

2.1 Introduction

Medical solid waste is viewed as disposed waste generated from activities such as health protection, diagnosis, treatment, dental and scientific research [1–3]. However, this type of waste is also generated at household level during utilisation of dialysis, insulin injections and animal treatment in rural areas [4, 5]. This implies that medical solid waste is confronting both rural and urban areas, hence demand attention. Medical solid waste generated in most continents like Africa consists of 85% non-hazardous and 15% hazardous waste [6–8]. In view of this, a large percentage of medical waste is similar to general municipal solid waste. Nevertheless, owing to insufficient separation medical solid waste turns into entirely hazardous waste [9, 10]. Therefore, medical solid waste requires proper separation from generation to disposal sites to minimise quantity of hazardous waste. A view upheld by Vasistha et al. [4] is that proper management of medical solid waste is essential to protect the environment and uphold human health. Medical solid waste comprises of sharps, pathological, toxic medical chemicals, cytotoxic, medical radioactive, pharmaceutical, infectious and general waste [6, 11, 12]. Considering these various characteristics of medical solid waste, its increase has potential to cause injuries, pricks and infectious diseases to people.

Currently, the globe is subjected to growth of medical solid waste quantities due to epidemic diseases like Covid19 [10, 13]. This was observed in India where medical solid waste volume raised from 0.5 kg to 4 kg per patient per day while in China it explodes to 6kg per bed per day [13]. Henceforth, besides increasing number of patients at medical facilities, diseases accelerate medical solid waste generation. Upsurge of medical solid waste is due to high hospitalisations and use of personal protective equipment such as masks, gloves and gowns [14, 15]. Proliferation of medical solid waste means sustainable management to curb dire environmental impacts is vital. Medical solid waste is regarded as the 2nd perilous waste after radiation waste [2, 3, 16]. This means improper monitoring of the waste have potential to hinder achievement of sustainable development. Medical solid waste can impact water, soil, biodiversity, air and environmental aesthetic value negatively globally if improper management strategies are applied [8, 17] while humanity is also affected [4, 18]. Globally, at least 5.2 million human beings lost their lives annually due to diseases emanating from poorly managed medical solid waste [19]. Medical solid waste mismanagement is linked to nosocomial diseases, gastro-intestinal diseases, skin disorder [8] infectious diseases hepatitis

B, C, HIV and AIDS [4, 14, 20]. In order to quell these health risks, health institutions must implement eco-friendly management strategies. However, in Africa apt management of solid waste including medical solid waste is difficult due to social, political, economic challenges and waste increase [21]. Consequently, a myriad of challenges need to be suppressed in order to achieve sustainable medical solid waste management.

Approximately, 67,740 health institutions are in Africa [7] and generate about 282,447 tonnes of medical solid waste yearly [8]. Nevertheless, medical solid waste generation trends may have increased due to Covid-19. These quantities call for vast financial, skilled personnel, effective planning and implementation of rigorous approaches. However, these necessities are inadequate in African countries [22, 23]. Therefore, proper management is rare, presented by indiscriminate disposal of medical solid waste [1, 20]. Bulky volume of medical solid waste is discarded in open pits, poorly constructed landfills, dumpsites as well as low standard incinerators without treatment [23, 24]. This is indicated in Zimbabwe where solid waste including medical waste is monitored by incapacitated municipalities [25, 26]. This revealed that committed government which supports municipalities is necessary to achieve proper medical solid waste management in African countries including Zimbabwe. The Government of Zimbabwe (GoZ) is constructing health facilities to safeguard wellbeing of its citizens who are around 16.53 million as stated by Zimbabwe Statistics and World Bank in 2017. Consequently, the population facilitate high generation of medical solid waste by seeking assistance from health facilities. This concurs with Torkashvard [27] that growth of population upsurge quantity of solid waste, mainly medical solid waste. Zimbabwe is under threat of diseases associated with poor sanitation such as typhoid, cholera, malaria [10, 12, 14]. In addition, United Nations Development Program [28] revealed that over spilling of Covid-19 into Zimbabwe accelerate generation of medical solid waste since it escalates utilisation of personal protective equipment. Therefore, population growth and high disease prevalence are among the drivers of medical solid waste increase in the Zimbabwe.

Solid waste explosion in Zimbabwe, however, fails to correspond with the prevailing waste management systems [29, 30]. Hence, medical solid waste is affecting the already overburdened solid waste management systems in Zimbabwe. This is because medical facilities in Zimbabwe generate a mixture of both hazardous and non-hazardous solid waste [31, 32]. In the Zimbabwean context, improper management of medical solid waste is ascribed to fragmented weakly enforced solid waste policies and legislations [5, 26, 33]. Nonetheless,

regardless of medical solid waste growth and existence of various management challenges in Zimbabwe its literature is limited compared to the quantity generated. This prospect drives the review to focus on medical solid waste management status in Zimbabwe as a general objective, although it was guided by the following specific objectives: analyse the characteristics of medical solid waste generated, examine medical solid waste management approaches and assess potential environmental risks associated with the management approaches. Attention was also be given to proffering of an integrated sustainable model for medical solid waste management in Zimbabwe.

2.2 Study area

The Zimbabwe is a landlocked nation occupying about 390,757 square kilometre area in Africa [33] between latitudes 15–23° S and longitudes 25–34° E [34]. Zimbabwe shares frontiers with Zambia, Mozambique, South Africa and Botswana [34]. Koppen–Geiger climate classification denotes that Zimbabwe experiences subtropical climate with hot wet summers and cool dry winters [33, 35]. The country is divided into 5 regions basing on precipitation and temperature experienced in the area [36, 37]. Zimbabwe received an average of about 670 mm of precipitation per annum whilst temperature is around 15 °C to 25 °C [38]. Zimbabwe Statistics and World Bank (2017) postulated that Zimbabwe’s population is approximately 16.53 million. Like any other country in Africa, people in Zimbabwe are affected by numerous types of diseases such as HIV and AIDS, tuberculosis and poor sanitation diseases such as cholera [39, 40] and Covid19 [28]. Consequently, they resort to medical facilities for assistance. The entire population is served by 214 medical facilities excluding smaller clinics [41], thus accelerating medical solid waste generation at the facilities. Medical solid waste increase adds burden to a country which is struggling with municipal solid waste [42–44]. This initiates the review to merely concentrate on medical solid waste management status in Zimbabwe.

2.3 Methodology

The study was grounded on already published literature on medical solid waste management. Similarly, general solid waste literature with aspects of medical solid waste was involved, since medical solid waste literature is limited in Zimbabwe. Articles published in English were reviewed to reach the goal of the review paper. In Zimbabwe, all types of solid waste

management are regulated by the Environmental Management Act [Chapter 20:27], effluents and solid waste disposal regulations, 2007. Therefore, the literature published from 2007 to current date was reviewed during the study. However, Taru and Kuvarega's research [31] was included since the research pave way for other researches linked to medical solid waste in Zimbabwe. The search was carried out utilising a combination of related key terms such as medical solid waste, clinical solid waste, healthcare solid waste and solid waste among others. However, medical solid waste management approaches and environmental health risks associated with the strategies were part of the keywords. Published articles, journals, abstracts, thesis, book chapters and books were retrieved from Google Scholar, Sage Publications, Springer, Science Direct, African Journals Online, Scopus, Web of Science Publications and PubMed. Development of an integrated sustainable management model for medical solid waste management was based on the literature contextualised in Zimbabwe. Although it was guided by the Deming circle, a systematic review of published literature offers an understanding of medical solid waste management status and opportunity to proffer recommendations.

2.4 Types and characteristics of medical solid waste

In Zimbabwe, medical solid waste is produced by households, hospitals, clinics during patient treatment, diagnosis, caring and immunisation [31], in form of pathological, pharmaceuticals, sharps, radioactive, toxic chemical waste, infectious waste, cytotoxic waste and general waste [20, 46]. Hence, medical solid waste generated by health institutions, households and elderly care facilities in Zimbabwe consists of hazardous and non-hazardous solid waste. This coincides with Ali et al. [9], Rahman et al. [45], and WHO [54] that medical solid waste consists of 85% non-hazardous and 15% hazardous waste. This means Zimbabwe produces medical solid waste similar to other countries as demonstrated in Table 1, hence need enhanced management approach. Pathological waste produced consists of body parts, human tissues detached during surgery, operations and autopsy, placentas, and fetuses from stillbirths [46, 54]. World Health Organisation [15] opines that pathological waste is infectious due to existence of virus and bacteria in human tissue samples. Therefore, proper handling of pathological waste should be mandatory among health workers in Zimbabwe to curb spread of infectious diseases. In Zimbabwe, expired drugs, contaminated drugs and their containers disposed in the country are considered as pharmaceutical waste [47, 48]. Nevertheless, pharmaceutical waste quantity is always low in Zimbabwe due to financial crisis which

facilitates proper planning when purchasing and utilising drugs. Sharp waste includes needles, syringes, blades, broken glasses, knives, scalpels, infusion sets and pipettes [20, 31]. Considering these categories of medical waste in Zimbabwe proper management is the only way forward to minimise health risks such as sharp injuries, cuts and pricks. Sharp waste may cause injuries, thus facilitating spread of diseases such as HIV and AIDS, and hepatitis B and C; hence, special care is recommended when dealing with medical sharp waste [49, 50].

Table 1: Categories of medical solid waste and examples

Medical solid waste category	Examples
<i>Hazardous medical solid waste</i>	<i>Examples</i>
Sharps waste	Needles, syringes with attached needles, blades, knives, pipettes, broken glasses, infusion sets
Pathological waste	Human tissues, organs, body parts, unused blood products and body fluids
Chemical waste	Laboratory reagents, film developer, disinfectants, heavy metal gadgets such as clinical thermometers and blood pressure gauges
Infectious waste	Soiled gloves, cotton wool, swabs, beddings, dressings, specimen containers and plaster caster
Radioactive waste	Contaminated glassware, absorbent paper, and unsealed radio nuclides
Pharmaceutical waste	Expired drugs, contaminated drugs and drug left overs
<i>Non-hazardous solid waste</i>	<i>Examples</i>
General waste	Stationary, kitchen utensils, food waste, soft drink bottles and uncontaminated empty boxes

Source: [2, 6, 49, 54]

In the Zimbabwean context, infectious waste comprises of soiled dressings, surgical gloves, bandages, sponges as well as swabs contaminated by excreta, blood and fluids from patients with communicable and contagious diseases in isolation, surgical wards and theatre [20, 31]. Currently, infectious waste explodes due to high use of personal protective equipment (gloves,

gowns, masks, goggles, and boots) in Zimbabwean hospitals owing to Covid-19 outbreak [28]. As a result, stakeholders like Environmentalist and Health and Safety officers should coordinate to craft measures to protect both the environment and health workers from infectious waste. Utilisation of nuclear medicines, unsealed radionuclides and therapeutic procedures in Zimbabwe facilitate generation of radioactive waste [20]. Yves-Chartier [12] indicated that equipment (glassware, packages, absorbent paper) contaminated by radioactive substances during the diagnosis process are included as medical radioactive waste. This type has potential to cause genetic mutation and cancer to health workers in Zimbabwe, therefore, require close attention. Pressurised containers which include oxygen cylinders, aerosol and air fresheners containers are among medical solid waste. This simply means different methods are required to manage various types of solid waste from medical sector in Zimbabwe.

Jerie [51] revealed that medical toxic chemical waste consists of containers with remains of clinical chemicals, sterilant, disinfectants, reagents, solvents as well as heavy metals like mercury from batteries. Hence, medical facilities in Zimbabwe produce medical toxic chemical waste since chemical containers, broken clinical thermometers and blood pressure gauges with mercury are part of the waste. General medical solid waste is generated from administration offices such as papers, plastic containers, as well as food waste from the kitchen and visitors who brought food, flowers to their admitted relatives [20, 31]. This suggests that medical facilities in Zimbabwe produce certain quantity of solid waste with similar characteristics to household waste, therefore, can be reused or recycled. Solid waste is considered non-hazardous if it is not mixed or get in contact with hazardous waste [49, 50]. Therefore, improper segregation of medical waste in Zimbabwe hinders application of reuse and recycle strategies, since the waste became wholly hazardous. Zimbabwean hospitals generate cytotoxic drugs and their metabolites as part of cytotoxic waste. This clearly denotes that medical solid waste requires attention owing to existence of various categories of waste.

2.5 Medical solid waste management in Zimbabwe

In Zimbabwe, medical solid waste is managed as general municipal solid waste especially in urban areas. This is supported by Nhubu and Muzenda [52] and Nhubu et al. [53] definition of municipal solid waste which encompass medical solid waste is managed by or on behalf of municipalities.

2.5.1 Storage and segregation of medical solid waste

Studies by Tsiko and Togarepi [46] indicated that solid waste generated in hospital wards is put in small containers or boxes and they are emptied in large containers placed in the corridors. When the containers in the corridors are full with mixed medical solid waste, they are conveyed to storage site [31]. This suggests that medical solid waste storage in Zimbabwe is marred with confusion, since the storage process may expose humanity to health risks. As a result of continuous emptying of medical solid waste into containers placed in the corridors, their capacity will be exceeded resulting in spilling of waste to the floor [20]. Thus, exposing various groups of people to pricks, injuries, piercing and infections from poorly stored waste. Hence, there is need for medical facilities in the country to have separate areas (rooms) for solid waste storage before conveyed from onsite to waste site.

Taru and Kuvarega [31] opined that in the Zimbabwean context, medical solid waste is stored indiscriminately since infectious waste and sharps are mixed with pathological waste. However, medical solid waste should be segregated in different colour-coded stiff containers with bin liners and lids during storage in a secured place [7, 15]. Sharps are always stored in any container which is available and mixed up with other types of waste for instance pharmaceutical and infectious waste [20]. This goes against the view of World Health Organisation [54] and Zimbabwe Ministry of Health [55] that sharp waste should be stored in puncture proof containers which can be sealed when it is full. Taking into account the above, medical solid waste segregation is full of chaos since despite that medical solid waste is different it is indiscriminately stored and disposed. This coincide with Mangizvo and Chinamasa [20] that in Zimbabwe general solid waste generated is collected and disposed together with medical hazardous waste haphazardly. This suggests that segregation of medical solid waste should be done at initial stages of waste management chain like storage, to enable collection and disposal of segregated waste.

2.5.2 Collection and conveyance of medical solid waste

Tsiko and Togarepi [46] observed that collection and transportation is done utilising wheeled trolleys from points of generation (hospital departments and wards) to onsite areas of temporary storage. Medical solid waste is conveyed from areas of generation to final discarding areas,

namely landfills, dumpsites and point of incineration by municipalities' waste trucks [20, 46]. Consequently, participation of medical solid waste generators in management of medical solid waste from cradle to grave is lagging behind in urban hospitals, since the burden shifted from medical sector to incapacitated municipalities. Municipalities collect medical solid waste to ensure that areas under their jurisdiction are not contaminated by solid waste as stipulated by the Urban Council Act (Chapter 15:09) [56, 57]. However, the situation begs to differ in rural areas since medical waste generators manage medical solid waste from collection to disposal because they are not beneficiaries of the Act. This implies that legislations and Acts that cater for medical solid waste management in rural areas are prerequisite in the Zimbabwe.

In the Zimbabwean context, medical solid waste collection is inefficient owing to delays, due to shortage of capacity as a result of lack of dump trucks, finance and fuel. Collection rate of solid waste encompassing medical waste in Zimbabwe is approximately 60% [53, 58]. This coincide with Haregu et al. [59] who revealed that collection of solid waste by municipalities in less industrialised countries is always less than 70%. Efficient collection of municipal solid waste in including medical solid waste in Zimbabwe is hindered by fuel, financial and transport deficit [53, 60]. This shows that economic challenges in Zimbabwe crippled efficient collection and conveyance of medical solid waste, therefore, averting the ability to reach sustainable development goals. Solid waste in Zimbabwe should be collected at least twice per week due to climatic conditions in the country [26, 61]. This means frequent collection of medical solid should be carried out in Zimbabwe, to avert odours from decomposing waste. However, in Zimbabwe, solid waste including medical solid waste is collected to areas of final disposal once a week or once a month due to fuels' shortages [29, 31, 42]. This means collection of medical solid waste in Zimbabwe fail to conform to World Health Organisation guidelines. Postponement of medical solid waste collection gives pathological waste opportunity to decompose, hence exposing the environment and human health at risk.

Heaping of uncollected waste is witnessed at medical facilities and households in Zimbabwe. As a result, scavenging domestic, wild and stray animals tear and open waste containers, hence exposing themselves to health problems. During deployment of waste trucks, no specific routes are followed; therefore, collection is done haphazardly [26, 62]. Consequently, sometimes other suburbs and institutions are skipped; therefore, medical solid generated in those areas' facilities will suffer since waste is not collected. Continuous accumulation of uncollected solid waste at onsite area creates conducive environment for breeding of cockroaches, rats and flies

which speeds the spread of waste-related diseases [25, 51]. This depicts that uncollected medical solid waste facilitates the occurrence of waste-related diseases; therefore, efficient collection rate is a mandatory. Nevertheless, municipalities argued that inadequate collection of solid waste including medical solid waste in Zimbabwe is ascribed to underfunding and limited co-operation of rate payers [26], although Zimbabwean residents conclude that funds misuse and misallocation by municipalities that exacerbate inefficiency collection of waste [53] and medical solid waste is not spared. This suggest that inappropriate collection of medical solid is a result of blame game between the city fathers and residents, hence they must work together to achieve efficient waste collection.

2.5.3 Disposal of medical solid waste

In Zimbabwe, about 90% of solid waste, including medical waste is disposed in indiscriminate state [26, 58]. This revealed that sustainable alternatives such as recycle, reuse and prevention need to be applied in medical waste management in Zimbabwe, to minimise quantity of waste disposed. Approximately, 40% of solid waste encompassing medical solid waste is disposed in an illegally manner along road edges, in drains and open spaces [53, 58]. This implies that a certain proportion of medical solid waste is also destined in undesignated disposal sites, thus exacerbating occurrence of environmental health problems. Taru and Kuvarega [31] revealed that medical solid waste disposal approaches utilised in Zimbabwe include open dumping, burying, open pits, and burning. This is pathetic since most the approaches used to dispose medical solid waste forms the base of solid waste management hierarchy. Makarichi et al. [57] pointed out that 37.6% of solid waste from different sources is burned through uncontrolled open burning at generation point in Zimbabwe. This point out that medical solid waste is also disposed through open burning which can be controlled or uncontrolled burning since it is capable to reduce quantity of waste as well as destroying pathogens, virus and bacteria.

In addition, Jerie and Musasa [46] asserted that incineration is highly utilised to dispose medical solid waste. Considering the mentioned approaches, it is clear that Zimbabwe is still utilising the least desired strategies to dispose medical solid waste; therefore, a road map to reach upper part of the waste management hierarchy is required. Strategies namely plasma, gasification as well as electro-thermal deactivation of medical waste can be used to treat and dispose medical solid waste in Zimbabwe than solely relying on incineration. Ferreira and

Veiga [63]; Rana and Ganguly [64] and Vasistha et al. [4] concur that medical facilities resort to incineration because it is capable to reduce the quantity of medical solid waste by about 80%, detoxification and destroy pathogens. In less developed nations, incineration is viewed as a golden approach, although utilisation of low standard incinerators result in spike of emissions in the atmosphere [9, 17]. This is exemplified by Mangizvo and Chinamasa [20]'s studies in Kwekwe which demonstrate that the incinerator used for medical solid waste disposal was operating inadequately owing to collapse of furnace lining. In addition, overloaded non-segregated solid waste limits the efficiency of incinerators since non-combustible and wet waste is resistant to incineration [20, 31, 52]. Therefore, none ash residues of medical solid waste such as glasses, sharp waste and containers finds their way to disposal sites, exposing informal waste collectors to injuries.

Nyakatswau et al. [48] argued that solid waste in Zimbabwe is collected by municipality dump trucks to be discarded in official dumpsites despite difference of their origin, type or potential environmental effects. Hence, medical solid waste with its hazardous characteristics is also transported to dumpsites together with other general solid waste. This generally means policies and legislations which support segregation of medical solid waste at initial stages is required to achieve proper disposal. Approximately, 90% of solid waste generated in cities is conveyed to dumpsites for instance Pomona in Harare [52, 58], this means medical solid waste is not spared. As evidenced by this a large volume of medical solid waste is disposed, therefore, recycling and reuse is rarely practised in Zimbabwe. This goes with Taru and Kuvarega [31] who postulated that medical solid waste generated by Parerenyatwa medical facilities is transported and discarded on dumpsites. Nevertheless, besides increasing environmental health risks, medical solid waste is partly speeding exhaustion of dumpsites which are already dying a slow death. This is demonstrated by the Pomona dumpsite which was projected to be closed in 2020, since solid waste was exceeding its capacity [52]. Consequently, Zimbabwe must not focus on collect and dispose approach when dealing with medical solid waste.

Moreover, medical solid waste generated by rural areas is discarded in open pits in Zimbabwe owing to its low costs. However, this approach can be a potential source of infection to public health and exacerbate cropping of different environmental problems if poorly managed [51, 65]. In addition, openly discarded medical solid waste is exposed to blowing wind, thus accelerating rate of cross infection to the nearest residential areas. A view upheld by Jerie and Zulu [66] that residential areas located less than 500 m from the dumpsites are vulnerable to

problems associated with solid waste. Infectious medical solid waste is supposed to be treated utilising autoclaving system and chlorine to disinfect it before being disposal in Zimbabwe [20]. Nevertheless, these strategies cannot be applied frequently due to financial constraints; therefore, despite being a major emission generator, incineration remains the only option. This congruent with Tanyanyiwa [60] and Chapungu et al. [67] that failure to adopt or utilise sustainable waste treatment or disposal in Zimbabwe is attributed to limited finance.

Zimbabwe like other least industrialised nations, utilises landfilling as an alternative to dispose medical solid waste; however, the dilemma is they are operated like open dumpsites. In developing nations, approximately 50% of collected solid waste is discarded through poorly controlled landfills [59, 68]. Landfills in Zimbabwe are like dumpsites since solid waste is non-compacted, not covered by soil and landfills lack leachate and gas control systems owing to limited funds and lack of experts [56, 57]. This implies that pollutants from decomposed medical solid waste can potentially cause deleterious impacts to the environment. Municipality solid waste on dumpsites is always exposed to open burning [42, 62]; therefore, medical solid waste is also burned at rural and urban health facilities. Therefore, medical solid waste is also destroyed through open combustion in Zimbabwe [20, 31]. In rural hospitals, Auto-way pits are also utilised to dispose pathological waste, but the problem is sharps and infectious waste mixed with pathological waste [20], hence finds their way into auto-way pits.

This minimises effectiveness of otto-way pits as an alternative to dispose pathological waste. In addition, most of the times the Auto-way pits are not lined, this gives the leachates from Auto-way pits opportunity to pollute groundwater as well as soil. Unlined solid waste disposal sites produce leachates, acids and ions which contaminate soil and ground water [50, 56]. In Zimbabwe rural medical facilities, burying of waste is usually practised [65]. From the above, it is not an exaggeration if one argues that most of the approaches utilised to dispose medical solid waste in Zimbabwe are far from the recommended standards to reach sustainability. Currently, disposal of solid waste including medical waste is problematic in Zimbabwe due to waste increase, sub-optimal infrastructure and absence adequate waste data [57, 58]. However, Tanyanyiwa [60] and Nhuhu and Muzenda [52] noted that disposal solid waste including medical waste is emerging as a problem due to Not-in-My-Backyard syndrome. This principle increases difficulties to locate medical solid waste dumpsites since people are aware of environmental health risks associated with improperly monitored dumpsites.

2.6 Environmental health risks associated with medical solid waste management

Medical solid waste generated by health institutions may pose dire impacts to the environment, especially if the least desired discarding approaches are used [6, 9, 46]. This means flora and fauna as well as water sources, soil and air in Zimbabwe are at risk owing to improper medical solid waste management. According to Ali et al. [9], Askarian et al. [6] and Ansari et al. [49], non-treated medical solid waste release toxic pollutants and pathogens such as bacteria and viruses in the natural environment. Thus, exposing different fauna species with access to the dumpsites to viral and bacterial diseases. This is inevitable in Zimbabwe where most of the dumpsites are unsecured [46]. Inadequate incineration of medical solid waste with polyvinyl chloride results in air contamination by dispersing carbon monoxide, dioxide, nitrous oxide, furans and dioxins in the atmosphere [31, 41, 50]. This illustrates that improper management of medical solid waste is increasing human carbon footprint in Zimbabwe. This is the reason why medical facilities are regarded as the 5th emitter of greenhouses gases at global level, generating approximately 4.4% [7, 9, 49]. As a result, improper solid waste management including medical waste management in Zimbabwe accelerates climate change [52, 58]; therefore, medical solid waste management cannot be neglected in Zimbabwe. Moreover, humans who inhale toxic gases from medical solid waste may suffer from chronic and acute respiratory diseases such as tuberculosis, coughing alongside cancer [6, 49, 51].

In Zimbabwe, less effective incinerators are utilised to dispose medical solid waste [20, 31]. This implies that partially burnt solid waste such as sharps and bottles always find their way to the dumpsites and speedy exhaustion of dumpsites. Therefore, in the Zimbabwean context methods such as granulation, shredding, pulverisation, grinding and crushing with potential to reduce volume of waste which is not suitable for incineration. Medical facilities incinerate clinical thermometers, fluorescent tubes, blood pressure gauges and electrical gadgets which contain carcinogenic heavy metals such as mercury, cadmium, lead, copper and zinc [2, 9, 49]. Hence, human beings are vulnerable to neurological disorders, genetic mutation and blood pressure due to exposure to heavy metals. Disposed medical solid waste was found to generate copper, zinc, mercury, lead, cadmium and chromium [1, 9, 23]. However, the non-biodegradable characteristics of heavy metal increase its accumulation in the environment causing health problems to human beings [51]. This suggest that people who reside in proximity to medical solid waste incineration sites can be affected by various types of cancer

such as colon cancer, since medical waste is a source of heavy metals. In addition, leachates containing heavy metals and pollutants from decomposed result in water pollution which later cause ulcers to people [27, 51]. It implies that cost-effective as well as environmentally friendly strategies must be used to dispose medical waste to reduce quantity of heavy metals in the environment. Pollutants from medical waste and excessive radiation from incineration affect birth weight of unborn babies (foetuses) and catalyse occurrence of down syndromes [11, 31, 51]. This means medical solid waste incineration affects pregnant mothers, yet in rural areas of Zimbabwe, incineration is done at hospitals. Inefficiency solid waste collection in Zimbabwe is increasing ability of medical solid waste to cause dire impacts. This is because inadequate collection forces residents to turn to open burning [26, 56] and this also infiltrate to medical facilities since they will be trying to reduce volume of uncollected waste. However, uncontrolled burning of medical solid waste produce smoke which act as nuisance to people and contaminates the air. Contaminated air causes eye irritation, bronchitis, dry cough, tuberculosis and asthma [51, 68]. Hence, burning of medical solid waste has potential to diminish humanity's wellbeing.

In Zimbabwe, medical solid waste is dumped in open pits which are improperly managed, thus increasing breeding of diseases vectors and environmental pollution. Open pits and open dumping create favourable breeding sites for mosquitoes, rats which cause malaria and rat-bite fever, respectively, alongside flies which transmit dysentery, typhoid and cholera [51, 67]. Therefore, medical facilities, which are considered safe places, are now fuelling outbreak of diseases relating to poor solid waste management in Zimbabwe. Improper management of solid waste including medical solid waste also contributed to 2008–2009 outbreak which led to the deaths of approximately 3.500 people [39, 69]. Furthermore, medical solid waste disposed in open pits are easily accessible by domestic dogs, goats, birds and cats, and this exacerbate cross infection to residential areas. Domestic animals like dogs always collect anything they pick to residential areas [20], thus increasing vulnerability of people to risks associated with medical solid waste namely infectious diseases. Decomposition of solid waste including medical waste on landfills and dumpsites generates leachates, acids and heavy metals which contaminate water and soil [52, 57]. This advocates that decay of medical solid waste on landfills pose dire impacts to water and soil quality; therefore, flora is not spared. Dissolved minerals from landfills and dumpsites cause water-borne diseases such as typhoid, cholera, and dysentery [70], as well as propelling growth of water hyacinth in water sources [26, 58]. As a result of disposal of medical solid waste on poorly engineered landfills and dumpsites, water

contamination is inevitable in Zimbabwe. Pomona, Chitungwiza and Golden Quarry dumpsites in Zimbabwe lack mechanisms that reduce infiltration of leachates to groundwater [57]; hence, ground water pollution is inevitable. Therefore, Zimbabwe as a country should put emphasis on constructing waste sites which impede free leachate movement.

Incineration of solid waste specifically medical solid waste produce ashes with high toxic heavy metals and organic contaminants with potential to pollute ground and surface water [53,71,72]. This revealed that it is vital for Zimbabwe medical sector to eliminate or reduce toxicity of incineration residues and ashes before disposing into landfills. Pollutants and heavy metals are absorbed by plant roots and trans-located to edible fruits and roots [73]. Given this, pollutants from medical solid waste find their way into the food chain since browsers and humans always survive from green plants and fruits. However, ingestion of fruits or roots containing pollutants increase occurrence of ulcers, cancer and diarrhoeal diseases [73]. A view upheld by Ansari et al. [49] that impurities of medical solid waste in soil can pose various abdominal pains. Therefore, soil contaminated by medical solid waste pollutants can accelerate abdominal pains in Zimbabwe since geophagy is rampant. Landfills are known generators of irritating odours and methane gas, a greenhouse gas which accelerate global warming [70]. Besides causing health problems, decomposed medical solid waste speeds up global warming, thus facilitating climate change. Mobile refuse trucks pollute the air since they utilise petrol or diesel which produce greenhouse gases [53], similarly medical solid waste refuse trucks produce toxic gases such as nitrous oxide, sulphur dioxide and hydrocarbon particles. Thus, increasing global warming and respiratory problems to people in the vicinity. Studies in Kwekwe show that open trucks which enable medical solid waste to fall were used to convey waste to incineration site [20]. Falling solid waste including medical solid waste result in land pollution [26, 74], if it remains unpicked, visual pollution increases. Therefore, strict handling of medical solid waste and monitoring of dumpsites is required in Zimbabwe to avert appearance of medical waste as nuisance. Visual pollution diminishes aesthetic value of the environment [26], thus impacting tourism which a source of income in Zimbabwe. Therefore, apart from being an eyesore, medical solid waste hinders economic growth in Zimbabwe since it minimises in flow of tourist since they shun waste. This means utilisation of proper well-serviced vehicles is required when ferrying medical solid waste to minimise air pollution and land pollution. Cuts, puncture, and injuries caused by disposed sharps such as needles and broken glasses cause easy penetration of fungi, virus and bacteria into human system [20, 51]. Therefore, medical sharp waste has potential to increase spread of Hepatitis B, C, HIV and

AIDS, Ebola and Covid-19 since they contain viruses from infected people. A view upheld by Ramteke and Sahu [13] and World Health Organisation (WHO) [15] that medical sharp results in injuries and cuts which increase transmission of Hepatitis B and C, HIV/AIDS and Covid-19. In 2018, HIV, hepatitis B and hepatitis C new infections caused by infected sharp waste like syringes was approximately 260,000, 21 million and 2 million, respectively [75].

In addition, medical solid waste contaminated by infectious saliva, blood and body fluids increase spread of infectious diseases [2, 10]. This means in Zimbabwe, health workers, waste collectors, patients and public are under threat since they are always in contact with medical solid waste with various types of infectious waste such as sharp waste. In Zimbabwe, people are exposed to anthrax due to contact with medical waste generated during treatment of domestic animals. Children and scavengers who access dumpsites with medical waste without safety gear are also vulnerable to infectious diseases. Health workers and waste collectors in Zimbabwe took safety gear for granted and became more vulnerable to injuries and infections caused by medical sharp waste. This is supported by [76, 77] that solid waste workers specifically informal workers (scavengers) are exposed to various waste-related injuries or diseases since they work without required personal protective equipment. In addition, sharp waste also contains biological pathogens which cause diseases like tetanus [50, 51]. This means scavengers who look for valuable materials from dumpsites and children who use medical solid waste dumpsites as playgrounds are at risk of being infected by infectious diseases since they are always not vaccinated. Competition of informal waste collectors and dogs to reach consumable, reusable and recyclable medical solid waste at the dumpsites expose human beings to injuries and being bitten. Jerie [51] postulated that human beings may be bitten by stray dogs during scavenging activities, hence became infected by rabies. Occupational risks like musculoskeletal disorders affect people who deal with lifting of objects such as loading and offloading of materials [43, 51]. This implies that medical solid waste workers in Zimbabwe are affected by hands, wrist and shoulder injuries as well as upper, lower back pain alongside chest pain due to loading and offloading. Therefore, dealing with medical solid waste speeds lives of the waste workers to the grave unknowingly, hence strict legislation should be implemented to protect waste workers. In Kwekwe, Zimbabwe, medical solid waste collectors are always transported in the same truck with solid waste [20]. Consequently, the workers are exposed to infectious diseases which they also ferry to their families since they went home with their infected clothes. Open dumpsites are known as sources of spiders, scorpions, odours, houseflies, rats and cockroaches which can affect nearest residential areas [67, 70]. As such,

proper Environmental Impact Assessment is required when siting medical waste dumpsite. This is because households located less than 500 m from waste sites are under threat of problems that emanate from the sites [66]. This denotes that medical solid waste sites in rural areas pose numerous problems to people since they are located within the health premises. Njaya [78] observed that solid waste which rots quickly attract disease-transmitting organisms and vectors, thus impacting human health. Therefore, medical solid which consist of wet cotton wools, swabs, soiled bandages, pathological waste quickly decompose especially under high temperatures, hence generating odours, disease vectors.

Informal waste collectors inhale, ingest and absorb residues of chemicals such as fluorine, chlorine, deinking and cleaning detergents into their systems resulting in liver and kidney damage [51, 79]. As a result, medical solid waste collectors' health is affected since medical facilities are major homes of chemicals in Zimbabwe. Solid waste workers are exposed to health problems since they always contact medical toxic chemical and medical radioactive waste [19, 43, 46]. Therefore, activities involved in medical solid waste management in Zimbabwe from cradle to grave expose humanity to numerous health risks; however, the likelihood and severity differ. A view which corresponds with Ghafuri [80] results obtained through Preliminary Hazard and Risk Analysis and Risk Assessment Matrix is that segregation of medical waste is a high-risk activity, while collection, treatment alongside discarding are medium risk events. This is presented in Table 2. Analysis goes on to demonstrate that pathological, infectious and sharp medical solid waste are considered as source of high risk [80] as shown in Table 2. Considering findings in Table 2, Zimbabwe's health workers, waste collectors, community as well as the environment cannot escape risks associated with medical solid waste easily. Therefore, crafting of an integrated medical solid waste management model to capacitate co-ordination among different stakeholders paves a way for Zimbabwe to reach sustainability.

Table 2: Risk analysis of medical solid waste management

Medical waste management stage	Hazard identification	Risk Likelihood x severity = risk
Storage and segregation	Hazards emanate from heavy metal waste, genotoxic and cytotoxic waste. Affected by biohazards	4x4=16
Collection and conveyance	Cross-infection to other areas around the medical facilities causing occurrence of diseases. Health and waste workers are vulnerable to health risks and the public is not spared	3x4=12
Treatment and discarding	Contamination of the environmental components. Incidences of sharp injuries among workers and the public. Micro-organisms from disposed waste results in health threats	4x3=12

Source: [80]

2.7 Medical solid waste legislation and policies in Zimbabwe

Management of solid waste is a burning issue which was discussed at the Agenda 21 and the current Sustainable Development Goals. Consequently, Zimbabwe is giving attention to medical solid waste to achieve sustainability by 2030 [81]. In year 2012, Zimbabwe Ministry of Health and Child Care guided by the World Health Organisation protocols implemented guidelines for discarding pharmaceutical waste. However, the guidelines' loophole is lack of waste reduction approaches and penalties imposed to those who fail to conform to the guidelines. Hence, medical waste in form of pharmaceutical waste remains a challenge in Zimbabwe. Zimbabwe's Ministry of Health and Child Care informed medical facilities that they must acquire consent from the appropriate authority or manufacturer before discarding expired drugs [47, 55]. The Ministry of Health and Child Care indicate the roadmap of monitoring medical solid waste generation to disposal, in the handbook entitled "Infection Prevention and Control Handbook, Written by Doctor Gwinji in 2013. In view of this, Ministry

of Health and Child Care is eager to contain risks associated with medical solid waste, but to due various challenges, their efforts remain in vain. In addition, Ministry of Health and Child Care handbook does not show how waste minimisation strategies can be applied.

Reviewing of worldwide conventions directed to medical solid waste management denote that Zimbabwe signed the Basel Convention, Stockholm Convention and Rotterdam Convention [28]. The country is a signatory of Bamako Convention as well as Minamata Convention. In addition, Basel convention which focus on trans-boundary movement and management of hazardous waste was ratified in 2012 by Zimbabwe. The Basel convention is centred on minimising dire impacts associated with hazardous waste including medical solid waste. Therefore, by being a signatory of this convention, Zimbabwe is willing to conform to sustainable management of medical solid waste. Moreover, in trying to deal with hazardous radioactive and chemical waste, Zimbabwe is part of countries who signed Bamako convention. Considering characteristics of medical solid waste, it is not excluded in the convention; therefore, Zimbabwe is following goals of Bamako convention to monitor the waste properly. However, despite being member of the conventions, failure of Zimbabwe to conform is ascribed to inadequate finance. There are also no clear objectives on how hazardous waste such as medical waste can be recycled or how resource recovery can be applied.

Zimbabwe signed, and ratified, the 2012 Stockholm convention. The convention encourages eradication or reduction of persistent organic pollutants through apt management of waste piles. Hence, medical solid waste is not spared since incineration and open burning is used to dispose waste in Zimbabwe. Under Article 5 and Annex C, members of the convention are required to avoid disposal methods that produce persistent organic pollutants mostly dibenzofurans and polychlorinated dibenzo-p-dioxins. Hence, Zimbabwe must fit in medical solid waste disposal strategies and structures that meet the demands of Stockholm convention. Moreover, Zimbabwe is guided by Minamata convention when dealing with materials that contain mercury. This implies that medical solid waste such as batteries, fluorescent lamps, dental amalgams and clinical thermometers are managed through requirements of the convention. This will enable the country to move towards sustainable development goals. Medical facilities produce containers with residues of chemicals such as detergents, reagents and other materials contaminated by chemicals [20, 51]. By being a member of Rotterdam convention, therefore, Zimbabwe is expected to deal with medical solid waste in a way that reduce detrimental impacts of chemical waste.

In the Zimbabwean context, specific Acts and Statutory Instruments related to medical solid waste does not exist. However, the legal framework for medical solid waste monitoring is grounded on the Environmental Management Act Chapter 20:27. The Act urges and encourages proper management of solid waste in Zimbabwe, and medical solid waste is not spared. However, the Act neglect aspects such as solid waste reduction, segregation as well as recovery approaches. Statutory Instrument 6 of 2007 on waste and solid waste and Statutory Instrument 268 of 2018 on hazardous waste offer regulations which encourage proper management of solid waste, including medical solid waste [82]. Although, statutory instrument fails to indicate clearly how various solid waste generators will be enforced to practise proper management of waste. The acts offer room for formulation of environmental quality standards and issues linked to environmental sustainability notably management of all types of solid waste. Nevertheless, it fails to consider vital issues like how integrated solid waste management can be achieved. Environmental Management Act 20:27 criminalise pollution of the environment by individuals, formal and informal industries and medical facilities are not spared. Therefore, for medical facilities in Zimbabwe to be free from polluter paying principle, they must act according to requirements of Environmental Management Agency. Nevertheless, the fines imposed on medical facilities are very low; therefore, improper management of medical waste perpetuate. Zimbabwean Government [83] and De Gobbi [84] Environmental Management Agency Act 20:27 and 2013 Constitution of Zimbabwe Section 73 stipulates that every person has the right to a non-hazardous environment. Hence, if medical facilities fail to discard solid waste in an appropriate manner, they will contravene to the law. However, the problem is that environmental rights are centred on human beings while ignoring other environmental attributes affected by poorly disposed waste. Under Sections 55–56 of the Act institutions who produce polluting materials must conform to environmental quality standards. This suggests that health institutions are not spared since they generate solid waste which deform quality of the environment.

Zimbabwe also utilises Hazardous Substances Act Chapter 15:05, Statutory Instrument 10, of 2007 to monitor hospital solid waste [32]. The Act indicates that generators of hazardous waste are responsible for sustainable management of the waste. With this in mind, medical facilities in Zimbabwe are accountable for proper management of medical solid waste. Transportation of medical solid waste in Zimbabwe is guided by Hazardous Substances Act which stipulate that hazardous waste should be conveyed in specific vehicles. However, in Zimbabwe,

multipurpose vehicles are used [20]. This is attributed to inadequate waste trucks as well as fuel. The major loophole of Hazardous Substances Act is that it is silent about the three Rs of solid waste management which are recycle, reuse and reduce. Hence, medical solid waste is mostly destined in disposal facilities. Urban Councils Act, Chapter 29:15 Statutory Instrument 68 of 2021 subsection 1 of section 4 shows that municipalities are responsible for offering waste collection services in urban areas [52, 85]. This means medical facilities in urban areas benefit while rural health institutions deal with their own solid waste, although rural medical facilities produce medical solid waste with characteristics to waste from urban hospitals. In this view of this, an act directed to marginal areas must be crafted. In addition, Urban Council's Act provides generators of medical waste in urban areas opportunity to be mere participants in management of their waste. As such, adding burden to already ill-equipped municipalities, thus exacerbating mismanagement of medical waste. Nevertheless, the major weakness of the Act is failure to highlight the consequences a council will face if it failed provide waste services to areas in its jurisdiction. Moreover, it does not include solid waste management approaches a council should apply after collection; therefore, councils mostly relied on collection and disposal approach.

Zimbabwe also applies the Public Health Act Chapter 15:09, this act deals with the control of emission and disposal of waste to reduce outbreak of diseases. The Public Health Act Chapter 15:09 forms the basis for healthcare and environmental health service. The Act shows that individuals and organisations must utilise waste management approaches that reduce negative health impacts to the public for instance infectious diseases. This suggests that medical facilities have to conform to the requirements of Public Health Act, when disposing medical solid waste. Ineffectiveness of Public Health Act is ascribed to its failure to indicate clear standards and procedures in solid waste management. Consequently, adoption of proper management of medical solid waste remains at miniature stage. Environmental Management Act Chapter 20:27, Statutory Instrument 72 of 2009 is also vital for air pollution control. According to subsection 4, Section 63 of the Act, individuals, industries and institutions involved in activities which emit pollutants into the atmosphere are included. Hence, medical facilities who incinerate or burnt medical solid waste is not spared. According to Statutory instrument 72, height of emitting chimney should be 50 m or taller than all the buildings at any institution. This guides health institutions when constructing chimneys of their incinerators. However, in Zimbabwe, hospitals always fail to conform the standard; hence, they are liable to heavy fines. The atmospheric pollution act gives Environmental Management Agency

authority to inspect emission structures, this means hospital incinerators are also inspected. Emission samples are also tested using blue, green, yellow and red bands. If incinerator emissions are above the required colour bands, medical facilities will be susceptible to polluter pays principle. Although, the penalties and cost of remediation are unexceptionally very low. In addition, occupational health and safety legislation such as Statutory Instrument 68 of 1990 supported by the 1996 Factories and Works Act Chapter 14:08 protect employees including health workers against workplace injuries by promoting safe work environments [48, 86]. This implies that medical solid waste generators, handlers and collectors are also protected since medical waste is hazardous. Factories and Works' Act fail to address its objectives fully since it does not provide waste handling procedures and standards. In order to protect the general public, all organisations and individuals urged to discard or destroy pharmaceutical waste using strategies which are harmless to humans and their surroundings [48, 55]. This advocates that in the Zimbabwe, medical facilities are supposed to monitor management of medical solid waste from cradle to grave. However, the situation begs to differ since municipalities are responsible for management of medical waste from collection to disposal.

2.8 Proposed integrated sustainable model for medical solid waste management

In the Zimbabwean context, medical solid waste mismanagement is omnipresent. This means there is need for a sustainable model to act as a pathway to achieve apt management of medical solid waste. As a result, an integrated sustainable model was crafted basing on the Deming OPDCA Circle of improvement. In the OPDCA abbreviation, O is for Observation, whereas P is planning, while D stands for Do, C represents Check and A is Act. OPDCA circle is considered as an effective strategy for improvement by [87, 88]. This implies that to improve medical solid waste management, the OPDCA system must be adopted for proper decision making and enhancement of existing strategies. The proffered model in Fig. 1 demonstrates that different stakeholders for instance Ministry of Health Care, Environmental Management Agency, Hospital Environmental Health Departments as well as Local Authorities must observe the status of medical solid waste management through researches and site visits. This assist in figuring out the strength and loopholes of existing medical solid waste management approaches. Observations enable medical solid waste experts to know who is slacking and what is lacking in medical solid waste management. Unearthing of environmental health risks

associated with the management approaches provide enough information to utilise during planning.

Effective planning on medical solid waste management in Zimbabwe requires inclusion of different stakeholders. In order to establish real achievable goals towards medical solid waste management, various people from community to national level must be encompassed. A team comprising of people from different fields establish strategies and processes to be carried out to reach the required results. This suggests that numerous environmental experts, ministries, organisations as well as legal experts must be involved. Ministry portfolios included in the framework are: The Environment, Climate Change, Tourism and International Trade is included because medical solid waste can impact the environment, accelerate climate change. As well as minimise inflow of tourist from other countries since solid waste deform attractiveness of the environment. In addition, no single investor is attracted by an eye sore environment, thus affecting international trade. This implies that Minister of this Portfolio should be part of medical solid waste management planners. Furthermore, Finance and Economic Development Minister is one of the key stakeholders to facilitate the planning process. This is owing to the minister's ability to do budgets and distribute finance to development processes in the country, including finance required to improve medical solid waste management. The Minister of Health and Child Care must be encompassed in planning since the cadre is responsible for monitoring all the medical facilities in Zimbabwe. This means the minister is expected to have knowledge of existing medical solid waste management approaches. Challenges which hinder adoption of sustainable strategies at hospital level are also known by the minister and Hospital Environmental Department. The Minister of Higher and Tertiary Education Science and Technology Development should be part of the planners. This is because the minister has power to deploy solid waste experts from universities to deal with medical solid waste issues. Ministry of Justice Legal and Parliamentary Affairs minister and his/ her legal team assist Environmental management Agency to craft legislations and laws related to medical solid waste management.

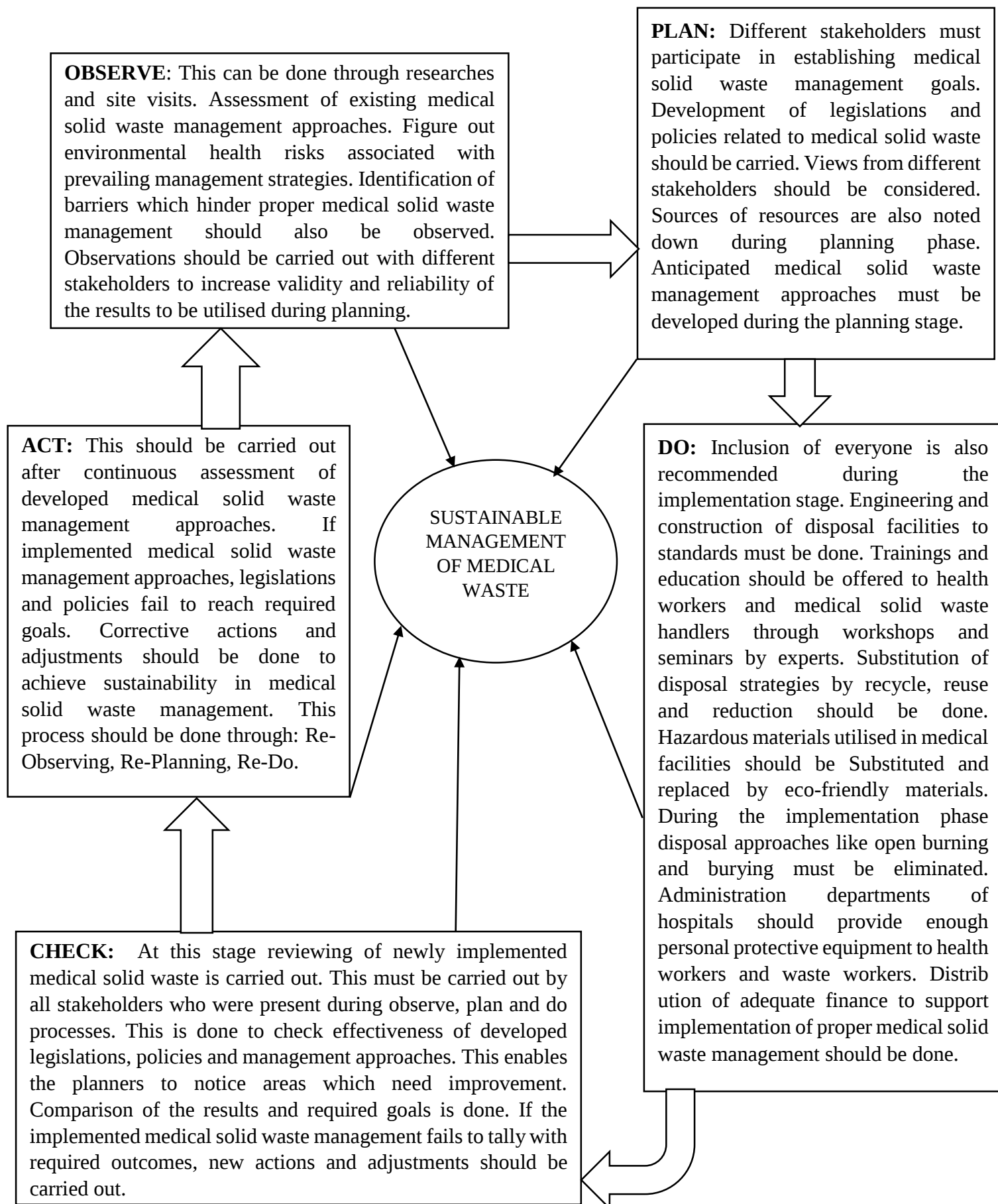


Fig. 1: Conceptual model for sustainable medical solid waste management. **Source:** Authors

The Local Authorities who deal with solid waste from collection to disposal in urban centres are governed by Minister of Local Government and Public Works. Solid waste budgets and by-laws crafted by Local Authorities are utilised after approval from the Local Government and Public Works minister. During the planning phase, health workers who are responsible for generation of medical solid and hospital cleaners must be involved. Similarly, the community people who are vulnerable environmental health risks that emanate from poorly managed medical solid waste should be present during planning. The reason is that National Social Security Authority (NASSA) is responsible protecting workers from workplace injuries. Planning enables financial and other resources desired in medical solid waste management to be put together before the implementation process. In addition, stakeholders involved in the planning stage should play a pivotal role in achieving sustainable management of medical solid waste. Those who are responsible for offering training and education to health workers must play their role for instance Hospital Environmental Health Departments. Enforcement of the developed medical solid waste legislations should be carried out by EMA. To achieve objectives highlighted during planning, finance directed to medical solid management should be pumped in. Engineering issues should be implemented effectively so that medical solid waste incinerators, landfills and auto-way pits are constructed to standards. This minimises contamination of air, water and soil which emerge as a result of poorly constructed disposal structures.

During the Do phase, supplied finance should be used to purchase environmentally friendly resources to be used in hospitals. This implies that medical materials which are not eco-friendly are substituted to reach sustainability. Incineration should be substituted by processes like steaming which deactivate viruses and bacteria on medical solid waste. Elimination of disposal strategies which results in high environmental pollution and risks. This can be exemplified by eliminating uncontrolled open burning and burying of medical solid. Medical facility administrations should provide enough Personal Protective Equipment to health workers and waste workers to safeguard them from health problems associated with medical solid waste. Therefore, medical facilities administration departments must safeguard wellbeing of workers to reduce occurrence of injuries and health problems related to medical solid waste. At this stage, participation of every individual or group of people as well as applicability of developed strategies should be evaluated through checking. Information gathered during the implementation phase is evaluated to compare the results with the anticipated outcomes. This suggests that 'Checking' of effectiveness of planned and implemented medical solid waste

management strategies is carried out. The Checking process facilitates to figure out the changes brought by newly implemented approaches as well as areas which need further improvement. This reviewing stage enable planners to check successfulness of newly initiated medical solid waste policies and legislations. If loopholes are discovered during reviewing of invented medical solid waste management strategies, new plans can be implemented. At this stage, if non-conformity or problems are noticed in terms of medical solid waste management, apt actions or adjustments are carried out. If the implemented medical solid waste management approaches fail to meet sustainability, the barriers are investigated. Therefore, re-observing of medical solid waste management from generation to disposal is done followed by altering issues noted during planning phase as shown in Fig. 1.

2.9 Conclusion

Reviewed literature depicts that nature of medical solid waste generated in Zimbabwe encompasses pathological, sharps, pharmaceutical, chemical, radioactive, cytotoxic, infectious waste as well as general waste. Medical solid waste generation is driven by population increase which exacerbates the number of people to be dealt with at medical facilities. Moreover, outbreak and spread of various types of diseases such as HIV and AIDS, malaria, tuberculosis, Covid-19, typhoid alongside cholera increases the volumes of medical solid waste. Management of medical solid waste from point of generation to disposal shows ineffectiveness and inefficiency in Zimbabwe. This is exemplified by indiscriminate storage of sharps and other types of solid waste in single containers. Medical solid waste overloaded bins are stored in wards and corridors releasing odours to health workers, patients and visitors. Onsite conveyance of mixed medical waste is carried out using trolleys and wheel burrows while multipurpose trucks ferry medical solid waste together with general waste to offsite disposal sites. In Zimbabwe, inapt monitoring of medical solid waste is occurring owing to lack of resources, inadequate know how among those who deal with waste, non-existence of clear medical solid waste laws and policies coupled by low enforcement of environmental legislations. Medical solid waste in Zimbabwe is transported using multipurpose vehicles and disposed in improperly engineered landfills, dumpsites, substandard incinerators as well as open burning. However, rural hospitals also utilise open pits and burying of medical solid waste in open spaces. Disposal approaches utilised compromise the quality of the environment by posing air, soil, water contamination and flora and fauna is impacted since the pollutants

accumulate in the food chain. Leachates from dumpsites, Auto-way pits and landfills contaminate soil and water, whereas odours and gases pollute the air. Medical solid waste affects humanity indirectly since polluted water result in gastro-intestinal problems while incineration and open burning accelerate occurrence of respiratory diseases. The study revealed that medical solid waste management system has potential to cause occupational risks for instance musculoskeletal problems like shoulder pain to those who load and offload the waste. Health workers are also vulnerable to injuries posed by sharp waste, if they handle waste without safety gear. Similarly, waste collectors, children and scavengers are under threat of injuries, pricks associated with sharp waste since they visit unsecured dumpsites. The review shows that sharp injuries expose people to different viral and bacterial diseases such as Hepatitis B, C, HIV and AIDS and tetanus. Hence, it is anticipated that the developed model may be used as a foundation to build sustainability in medical solid waste management.

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Chapter 3

Solid Waste Characteristics and Management Strategies at ST Theresa (STT) and Holy Cross (HC) Hospitals in Chirumanzu Rural District, Zimbabwe

Takunda Shabani¹, Timothy Vurayayi Mutekwa¹ and Tapiwa Shabani¹

¹Midlands State University, Department of Geography, Environmental Sustainability and Resilience Building, P. Bag 9055 Gweru, Zimbabwe.

Corresponding Author: Shabani Takunda, Email: shabstaku@gmail.com

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Abstract

Management of solid waste from rural hospitals is among major problems affecting developing countries. This is mostly attributed to inadequate data related to quantity and quality of hospital solid waste. Similarly, information related to rural hospital solid waste characteristics and management is limited in Zimbabwe. However, SDGs complemented by Zimbabwe Vision 2030, NDS 1 advocates for sustainable solid waste management. Hence, enough data related to characteristics of solid waste from rural hospitals are required to attain sustainability. This research focuses on hospital solid waste characteristics and management strategies at STT and HC rural hospitals. Descriptive cross sectional research design which triangulates qualitative and quantitative paradigms was utilized. Interviews, observations, questionnaires were used to collect data. Quantitative data were analysed using Statistical Package for Social Sciences whereas qualitative data were subjected to content analysis. Solid waste generated at STT encompasses non-hazardous (77.35%), hazardous waste (22.65%). At HC solid waste consists of non-hazardous (79%) and hazardous waste (21%). Respondents at STT (70.4%) and HC (72.7%) noted that solid waste was increasing. Solid waste was increasing due to various factors namely high use of disposable materials at HC (35.1%), STT (42.5%) and increase of patients at HC (30%) and STT (29.7%). Solid waste was indiscriminately stored in various types of containers although pedal operated bins and sharp containers were highly used at STT (72.4%) and HC (69.1%). Waste receptacles were transported to disposal sites using wheelbarrows and manual handling. Open pits and burning were among disposal strategies but incineration was regarded as the golden approach at STT (44.8%) and HC (41.8%). Inappropriate hospital solid waste management was due to shortage of finance at STT (38.1%) and HC (30.9%) and unawareness among health workers. Although it was worsened by lack of all stakeholder participation at STT (79.0%) and HC (76.4%). Consequently, the study recommended application of strategies which support circular economy, integrated approach, raising awareness of health workers and provision of enough resources to rural hospitals.

Keywords: Rural hospitals, Hospital, Solid waste, Management strategies, Management challenges, ST Theresa (STT), Holy Cross (HC)

3.1 Introduction

Hospital solid waste refers to waste generated during diagnosis, medication, treatment and caring of patients with various health problems [5, 69]. Hospitals generate solid waste of different nature since patients with different ailments are served. Solid waste from hospitals includes hazardous and non-hazardous waste consisting of 15% and 85% respectively [42,67]. A certain fraction of hospital waste is capable of causing more health risks to people and the environment. Although, a large proportion constitutes solid waste similar to general household domestic waste. Hazardous solid waste from hospitals includes pathological, infectious, toxic chemicals, radioactive, sharps, cytotoxic and pharmaceutical waste [10, 84]. Hazardous solid waste from hospitals is regarded as the 2nd most deleterious after nuclear and radioactive waste, as stipulated by 1989 Basel Convention (Annex et al. [106]). Non-hazardous hospital waste which is referred to as general waste include non-contaminated empty boxes, papers, plastics and food waste from the kitchen [20, 41]. General solid waste remains non-risk if not mixed with hazardous waste like pharmaceutical waste. Pharmaceutical waste includes contaminated and expired useless drugs or medicines, vials, serum and vaccines generated by hospitals [42, 59]. Pharmaceutical waste is generated in both urban and rural areas since location of hospitals and medicine use have no geographical boundaries.

Hospitals generate pathological waste including human tissues, organs and body parts [42] and disposed still fetuses as well as placentas [39]. Pathological waste also encompasses health and unhealthy body parts examined in laboratories by pathologists. Studies revealed that weight of detached body parts varies from a small number of grams to kilograms [42]. This implies that pathological waste adds a certain quantity of waste to solid waste generated at rural hospitals, particularly infectious waste. Sharp waste namely pipettes, nails, syringes, knives, scissors, needles, blades, infusion sets, razors and scalpels are generated at hospitals [41, 86], including at rural hospitals. Hospitals are sources of chemicals produced during patients' treatment procedures and cleaning [84, 85]. Generation of chemical waste from rural hospitals is inevitable since chemicals are highly used. Discarded hospital Personal Protective Equipment/ Clothing (PPE/C) like aprons, boots, gloves, goggles and face shields are considered as infectious waste [84]; Wang et al. 2019). Infectious hospital solid is labelled as hazardous owing to its potential to cause diseases to people [68], Wang et al. 2019). Ali et al. [7] and Hossain et al. [36] concur that hospitals produce materials contaminated by radioactive

substances and materials generated during vitro analysis and therapeutic procedures. Hospital radioactive waste contains radio nuclides with decomposing periods of hours to years [65]. Considering, hazardous waste from hospitals pinning of approaches which support circular economy is among difficult tasks.

General waste can be recycled or reused easily if efficient solid waste segregation is carried out at hospitals. This is less applicable since proper hospital solid waste management is still at miniature stage in developing nations not sparing the issue of segregation [19, 20]. Despite different physical characteristics hospital solid waste is managed together, making application of reuse difficult at rural hospitals. In developed countries such as Canada and the United Kingdom hospital solid waste is usually segregated and stored in recommended containers [5, 79]. As a result of proper waste separation processes like recycling, reuse and recovery are easily applied. Indiscriminate storage of hospital solid waste is common in developing countries such as Pakistan [5] and Zimbabwe [77, 78]. This scenario is worse at rural hospitals located in developing nations like India (Vitthal et al. [101]), Uganda [45], Malawi (Mmanga et al. [100]) and rural hospitals in Zimbabwe are not spared. Application of sophisticated strategies is difficult in Zimbabwe due to financial shortages, increase of waste, limited availability of data related to hospital solid waste quality and quantity [74–78]. The scenario is worse at rural hospitals since they receive little attention from policy makers and researchers. Management of hospital solid waste from rural hospitals usually follows a traditional linear approach which focuses on collection to disposal. Solid waste from rural hospitals is disposed into open pits, auto-way pits and through incineration, open burning, burying and open dumping [77, 78]. Most of the utilized strategies occupy the base of the waste management hierarchy hence can result in environmental problems.

Solid waste management strategies used at rural hospitals have potential to cause air, water, soil contamination while disturbing characteristics of existing vegetation. Human health is also at risk since health workers and waste scavengers are exposed to sharp waste injuries translating to occurrence of various infectious diseases including Hepatitis, Tuberculosis, HIV and AIDS. Inappropriate management of solid waste from rural hospitals has the potential to facilitate outbreak cholera, typhoid, dysentery, malaria since dumpsites serve as breeding sites for various vectors. This signifies little attention and knowledge related to rural hospital solid

waste characteristics is limiting ability to reach demands of Sustainable Development Goals (SDGs) in Zimbabwe. Although solid waste from rural hospitals presents environmental health problems little is known about the nature of solid waste generated and existing management techniques. Even the legal framework offers less attention to rural institutions encompassing rural hospitals. Urban Councils Act (Chapter 29:15) supports urban areas only (Jerie, [98]; [48] whilst the Rural District Councils Act (Chapter 29:13) is unclear about waste management in rural areas owing to the assumption that rural areas are spared by waste management problems. Nearly incapacitated rural hospitals shoulder the burden of managing the increasing waste since waste services are skewed in favour of urban hospitals while neglecting rural hospitals. To worsen the scenario, studies related to aspects surrounding hospital solid waste characteristics are geographically confined since they focus much on urban hospitals as compared to rural hospitals. Issues surrounding understanding of solid waste characteristics and management from rural areas are still at an embryonic stage in Zimbabwe. This exposes rural environments which are generally less polluted at risk of being contaminated by poorly managed institutional waste. Therefore, the need to maintain the high environmental quality of the rural environment cannot be overemphasised.

To achieve sustainability in the realm of hospital solid waste management in rural areas of Zimbabwe, enough data are required. Therefore, this study puts emphasis on hospital solid waste characteristics and management strategies at rural hospitals in Chirumanzu district, Zimbabwe. The study was guided by specific objectives namely: (1) To characterize hospital solid waste generated by rural hospitals in Chirumanzu district. (2) To evaluate hospital solid waste management framework utilized by rural hospitals in Chirumanzu district. Results and recommendations of this study pave a route for proper management of hospital solid waste. This enabled the country to achieve SDGs namely good health and well-being, life on land, life below water and sustainable cities and communities among others. Understanding aspects surrounding hospital solid waste and management strategies speedy attainment of Zimbabwe National Development Strategy 1 (NDS 1) objective of environmental protection. Research findings facilitate collaboration of all responsible stakeholders in implementing policies which support proper management of solid waste from rural hospitals. Appreciation of the nature of solid waste and management strategies reduce difficulties in developing frameworks which support sustainable management of rural hospital solid waste.

3.2 Materials and methods

3.2.1 Description of the study area

The research was carried out in Chirumanzu rural district located in the Midlands province, Zimbabwe. Chirumanzu occupies 4.737 square kilometres of the Midlands province (Kori et al. [97]). The district is in agro-ecological zone 3, receiving average rainfall of 650 mm annually with average temperature between 24° and 30°C [56]. The district is mainly covered by sand-loam soil which supports vegetation species such as *Brachystegia specieforms* like Musasa [51], *Julbernadia globiflora* like Mutondo, and *Colospermum* (mopane) [52] and patches of grass (Fakarayi et al. [99]). People in the district practice subsistence farming. Moreover, population in the district grows at 1.2% per annum and its population is around 95 272 with 45 589 males, 49 683 females and 24.556 households [92]. Continuous growth of the population and need for health services add burden to hospitals since a large volume of solid waste is generated. Chirumanzu's population is served by clinics namely Nyautonge, Chizhou, Siyahokwe, Mhende, Doroguru, Hwata, Hama, Chimbindi and Chengwena. Rural hospitals in Chirumanzu district include ST Theresa, Holy Cross, Muvonde and Sanatorium. Nevertheless, the study focuses on ST Theresa (STT) (Fig. 1) and Holy Cross (HC) (Fig. 2) hospitals which are in wards 8 and 6, respectively. Total population of ward 8 is approximately 3 156 while ward 6 houses 3 478 people [92]. ST Theresa hospital was constructed in 1958 with bed capacity of 80 while Holy Cross hospital was constructed in 1960 with a bed capacity of 50. The two hospitals consist of different wards notably female, male, paediatric, maternity, isolation wards and departments such as administration, outpatient, family health clinic, laboratory, pharmacy, physiotherapy, doctors' offices and emergency rooms. This implies that a large number of people are served at these hospitals, therefore, generation of different types of solid waste in high quantities is inevitable. Holy Cross and ST Theresa hospitals were purposively selected since these hospitals also receive patients from health institutions in the primary level within the district and beyond. The hospitals are located in communal areas with high population density hence they serve a large proportion of people translating to generation of more solid waste.

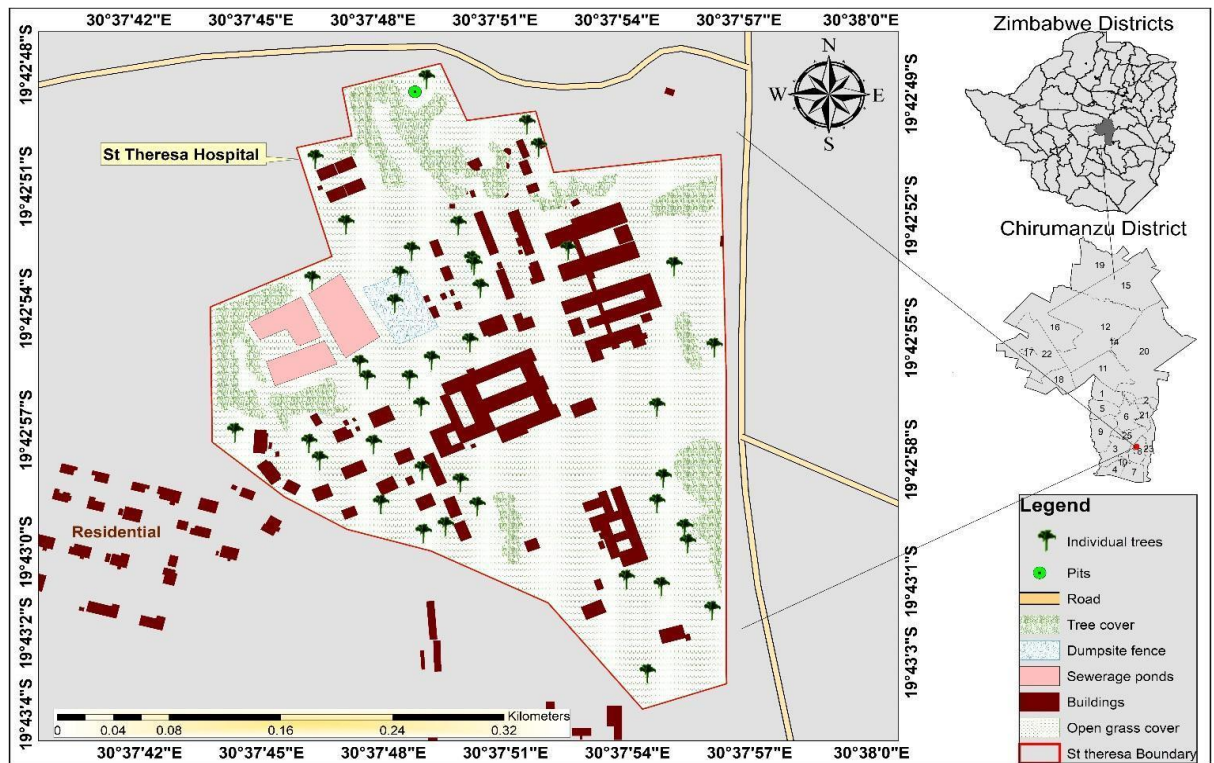


Fig. 1: Location and characteristics of ST Theresa hospital in Chirumanzu district.

Source: Geographic Information System map derived from Google Earth image by the Author

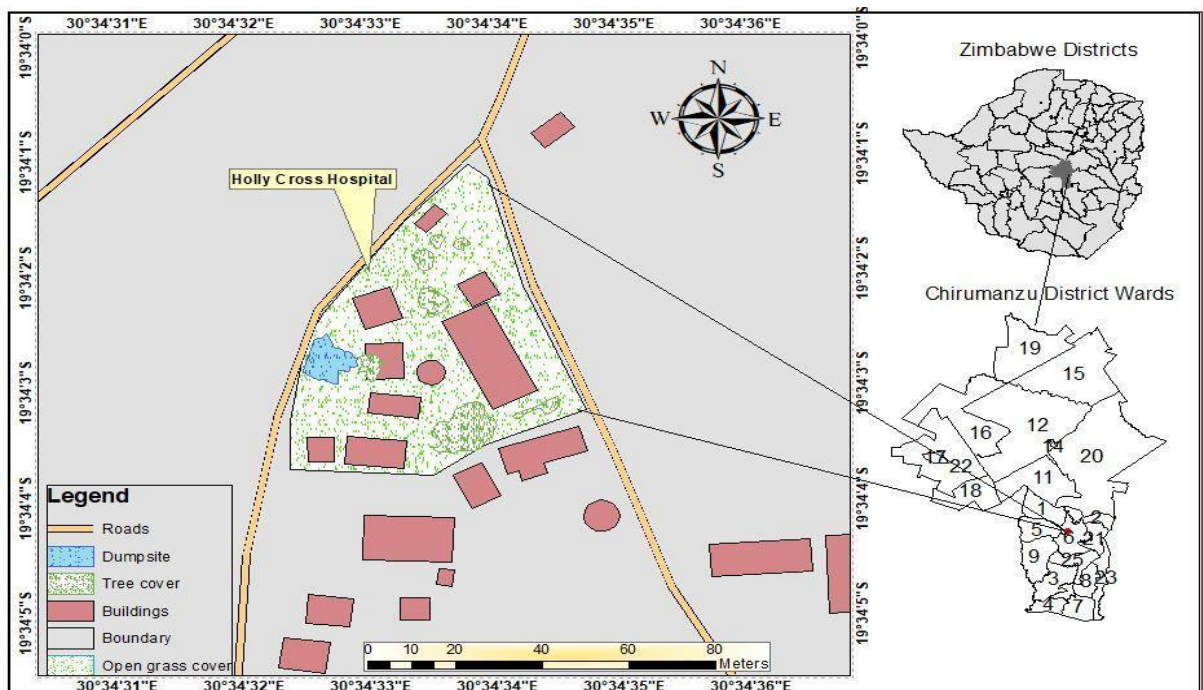


Fig. 2: Location and characteristics of Holy Cross hospital in Chirumanzu district.

Source: Geographic Information System map derived from Google Earth image by the Author

3.2.2 Research methodology

3.2.2.1 Research design

Research design refers to a complete framework demonstrating how numerous techniques are used during research. Descriptive cross sectional research design that employs qualitative and quantitative paradigms was adopted in data collection, analysis and presentation.

3.2.2.2 Target population and sample size

The study targeted health workers namely nurses, doctors, physiotherapists, laboratory technicians, radiologic technologists, eye-opticians, cleaners and anaesthetists at STT and HC hospitals as questionnaire respondents. Questionnaire survey targeted 147 and 64 health workers at STT and HC, respectively (Table 1). Sample size for questionnaire survey was determined using Taro Yamane [89] formula:

$$n = \frac{N}{1 + N(e)^2} \cdot$$

Where:

n = sample size

N = total population

e = margin of error 0.05 (±5%)

After using Taro Yamane's formula, sample size was 105 at STT and 55 at HC hospitals (Table 1). After determining required sample size, stratified sampling procedure was applied to divide health workers into groups according to their occupation at hospitals (Table 1). Representatives of each stratum were proportionally determined following Bowley [16]'s formula: $\frac{\text{Required Sample Size}}{\text{Population size}} \times \text{stratum size}$. Questionnaire respondents from each stratum were selected using a simple random sampling method. Individuals for each stratum were numbered and a computer-generated random table was used to select strata representatives. Targeted key informants were selected using a purposive sampling approach. Key informants include Chirumanzu District Medical Officer (DMO), Environmental Management Agency

(EMA) Officer, hospital Environmental Health Technician (EHT), hospital Head of Cleaning Department/Supervisor (HCD/S) and Hospital Matron (HM).

Table 1: Sample size for questionnaire survey

Hospital name	Number of health workers	Grouping of workers according to their occupation	Required sample size using Taro Yamane formula $n = \frac{N}{1 + N(e)^2}$	Sample size to represent each stratum $\frac{\text{Required Sample Size}}{\text{Population size}} \times \text{strata size}$	Total
ST Theresa	147	Nurses 118, Doctors 3, Laboratory technicians 4, Physiotherapist 2, Radiologic technologist 2, Anaesthetists 2, Eye optician 2, Cleaners 14.	105	Nurses 86, Doctors 2, Laboratory technicians 3, Physiotherapist 1, Radiologic technologist 1, anaesthetists 1, Eye optician 1, Cleaners 10.	105
Holy Cross	64	Nurses 41, Doctors 1, Laboratory technicians 3, Physiotherapist 2, Radiologic technologist 2, anaesthetists 2, Eye opticians 1, Cleaners 12	55	Nurses 35, Doctors 1, Laboratory technicians 2, Physiotherapist 2, Radiologic technologist 2, anaesthetists 2, Eye opticians 1, Cleaners 10.	55
Total questionnaire respondents					160

Source: Authors

3.2.2.3 Data collection methods

Questionnaires were used to solicit demographic data such as gender and level of education, since these can affect perceptions of an individual towards hospital solid waste management. Data regarding solid waste characteristics, management strategies and waste management challenges were collected through use of questionnaires. Interviews were conducted to collect data on the nature of hospital waste and management approaches. To validate data from questionnaires and interviews, observations were applied to collect data on hospital solid waste

characteristics and management approaches. Already existing data on hospital solid waste and management techniques were retrieved from secondary sources.

3.2.2.4 Solid waste characterisation and quantification

Characterisation of hospital solid waste in different categories was done using WHO and UNICEF (2015) approach. Therefore, hospital solid waste was grouped into infectious, pathological, chemical, sharps, cytotoxic, pharmaceutical, radioactive and general solid waste. Different hospital solid waste types were loaded in labelled plastic bags (bin liners) with support of research assistants. During loading of solid waste in plastic bags segregation was carried through a hand sorting approach, since it is regarded as the accurate strategy to collect reliable data [33, 58]. Types of hospital solid waste under each category were recorded on solid waste characterisation form. Collection of data regarding quantity of hospital solid waste generated per patient and solid waste generated during days of data collection at each hospital was done. In terms of selecting a patient to deal with during the study specifically to obtain an average quantity of waste per patient per day, random sampling was applied. This was easy since hospital beds were numbered, therefore, a computer-generated random table was used to select the patient. Plastic bags or bin liners were given to selected patient. Data on the quantity of hospital solid waste generated were collected from 7 March to 14 March 2023. Determination of solid waste quantity and composition after 7 days present to minimise ambiguity since Jerie (2014) adopted it to collect accurate data during solid waste research. A digital weighing scale was used to weigh plastic bags to determine the weight of solid waste. Quantity of solid waste obtained during the weighing process was recorded in a notebook. Ahmed (1997)'s formula: Waste Generation Rate = Average Waste Production /Patient/day X Total Number of Patients admitted ($WGR = AWP/P/D \times T \text{ No of } P$), was utilized to quantify solid waste generated by the hospital in relation to admitted patients per day.

3.2.2.5 Data analysis and presentation

Collected quantitative data were analysed using Statistical Package for Social Sciences version 25.0 at 95% confidence level. Descriptive statistics such as mean, frequencies and mode were used to show response rate particularly for questionnaires. Analysis of hospital solid waste quantity average was carried out through descriptive analysis. Non-parametric tests like Chi-

square were used to test association between association between number of admitted patients and quantity of hospital solid waste generated. Quantitative data were presented in the form of tables, charts and graphs. Qualitative data were analysed through content analysis and presented using expressive and persuasive narratives as well as direct and indirect quotations.

3.3 Results and discussion

3.3.1 Socio-demographic data of healthcare workers

Majority of questionnaire respondents at STT and HC hospitals were females consisting of 62.9% and 56.4% respectively. This implies that female health workers dominate at these rural hospitals compared to male workers. This explains that culturally and socially females are interested in offering health services including caring for the sick. Females are in the forefront of offering health services to people with various ailments (Drennan and Ross, 2019; Murat et al. 2021). At STT hospital 29.5% of health workers are between 27 and 35 years, 13.3% (18–26 years) and 10.5% are 54 years and above. This was different to HC hospital where 30.9% of the health workers' age ranges from 36 to 44 years while 10.9% were between 18 and 26 years (Table 2). The hospitals include employees with significant work experience and those who are new in the health workforce. This causes variation in terms of knowledge, awareness and perspectives towards hospital solid waste management. A view supported by Woromogo et al. [86] and Akkajit et al. [6] that knowledge related to hospital waste management is determined by work experience.

In terms of educational level, 60% of the health workers at STT hospital are holders of diplomas and those with secondary level comprises 10.5%, although 3.8% have masters (Table 2). HC hospital accommodates 52.7% health workers with diplomas and 18.2% who attained secondary level. Dominance of diploma holders is attributed to the fact that most of the general nurses in Zimbabwe are holders of 3-year diplomas [28, 43]. Differences in level of education entail that a solid waste management framework which considers the level of knowledge of all health workers is required. Sustainable solid waste management framework must consider everyone [74–76] and people with different levels of knowledge are included. Only 15.2% of health workers at STT hospital have work experience of 12 years and above in comparison to 20% at HC hospital. Most of STT hospital's health workers' work experience was 0 to 5 years, yet at HC hospital it was 6 to 11 years (Table 2). At STT 31.4% of health workers have work

experience of 6–11 years. This potentially affects hospital solid waste management, since generally workers with more work experience have better understanding owing to participation in various workshops and training. This concurs with [77, 78] that more experienced health workers have better knowledge about waste management and associated environmental health risks. At STT hospital 13.3% of the respondents were in the maternity department and 12.4% in the paediatric ward (Table 3). This was slightly different to Holy Cross where the paediatric ward was served by 10.9% of the health workers. More health workers were found in the maternity department because it consists of various sections and activities while caring for young children in the paediatric ward is demanding.

Table 2: Socio-demographic data of healthcare workers at ST Theresa and Holy Cross hospitals

Variable	Response category	Respondents at each hospital					
		ST Theresa Hospital			Holy Cross Hospital		
		Frequency	%	Cumulative %	Frequency	%	Cumulative %
Gender	Males	39	37.1	37.1	24	43.6	43.6
	Females	66	62.9	100.0	31	56.4	100
Age	18-26	14	13.3	13.3	6	10.9	10.9
	27-35	31	29.5	42.8	12	21.8	32.7
	36-44	23	21.9	64.7	17	30.9	63.6
	45-53	26	24.8	89.5	11	20.0	83.6
	54+	11	10.5	100.0	9	16.4	100.0
Educational level	Secondary	11	10.5	10.5	10	18.2	18.2
	Certificate	20	19.0	29.5	13	23.6	41.8
	Diploma	63	60.0	89.5	29	52.7	94.5
	Degree	7	6.7	96.2	3	5.5	100
	Masters	4	3.8	100.0	0	0	
Work experience (years)	0-5	56	53.3	53.3	13	23.6	23.6
	6-11	33	31.4	84.8	31	56.4	80.0
	12+	16	15.2	100.0	11	20.0	100.0

Source: Field data (2023)

Table 3: Categories of questionnaire respondents according to the department they were attached to during the survey

Department	Respondents at each hospital					
	ST Theresa Hospital			Holy Cross Hospital		
	Frequency	%	Cumulative %	Frequency	%	Cumulative %
Pediatric ward	13	12.4	12.4	6	10.9	10.9
Eye Unit	3	2.9	15.2	2	3.6	14.5
Family Health Clinic	6	5.7	21.0	4	7.3	21.8
Female Ward	9	8.6	29.5	4	7.3	29.1
Male Ward	9	8.6	38.1	4	7.3	36.4
Maternity Ward	14	13.3	51.4	5	9.1	45.5
Outpatient Department	11	10.5	61.9	4	7.3	52.8
Hospital Laboratory	4	3.8	65.7	2	3.6	56.4
X-ray Department	3	2.9	68.6	1	1.8	58.2
Theatre section	9	8.6	77.2	5	9.1	67.3
Rehabilitation Department	2	1.9	79.1	2	3.6	70.9
Isolation Wards	9	8.6	87.7	4	7.3	78.2
Doctors Rooms	2	1.9	89.6	1	1.8	80
Cleaning Department	10	9.5	99.1	10	18.2	98.2
Anesthetist Rooms	1	1.0	100	1	1.8	100

Source: Field data (2023)

3.3.2 Characteristics of hospital solid waste generated at ST Theresa and Holy Cross hospitals

In terms of the nature of hospital solid waste generated at these two hospitals, data collected from questionnaires and observations concur. Broad categories of hospital solid waste produced were pharmaceutical, sharps, infectious, pathological, cytotoxic, radioactive, chemical and general solid waste (Table 4). This indicated that solid waste generated at STT and HC hospitals consist of hazardous and non-hazardous waste. Similarly, rural healthcare

facilities in Vhembe district in Limpopo province, South Africa also produce hazardous and non-hazardous waste [62]. STT EHT further grouped hospital solid waste into combustible and non-combustible waste. Non-combustible solid waste highlighted include food leftovers, glass and metals while combustible solid waste encompasses papers, plastics, gloves, textiles, cotton wool, empty boxes. As a result, a certain proportion of hospital solid waste can go through the energy recovery process. Observations indicated that hospitals are sources of construction and demolition waste namely broken bricks and tiles. Renovation, maintenance and expansion of hospital structures generate construction and demolition waste [8, 32]. Electronic waste encompasses disposed cartridges, sphygmomanometer, printers, computers and pieces of electric cables. This implies that technological evolving was among drivers of solid waste increase at these rural hospitals. This suggests that Zimbabwean health institutions are sources of electronic waste (Jerie and Shabani, [95]. Cleaning supervisor at STT hospital highlighted that textile waste such as pieces of cloth are generated from the sewing and laundry department. At HC hospital, the EHT and Matron concur that solid waste produced encompass organic waste such as food and pathological waste and inorganic solid waste namely sharps, textiles, gloves, aprons, papers, plastics and theatre caps. As a result, solid waste from rural hospitals comprises biodegradable and non-degradable waste. A view upheld by Ghimire and Dhungana [30] that hospital solid waste consists of non-degradable and degradable waste.

Table 4: Hospital solid waste generated at ST Theresa and Holy Cross hospitals

Types of solid waste generated	Components of the solid waste
Pharmaceutical	Outdated/expired drugs, soiled drugs (tablets), remains of drugs, defective tablets, empty containers and sachets of drugs/medicine
Sharps	Iron/steel nails, surgical knives, hypodermic needles, syringes with needles, broken glasses, infusion tubes or sets, blades, slides, pipettes and metal scrap
Infectious	Culture/specimen containers, contaminated (cotton wool, gauze, mattresses, cotton swabs, plaster casters and bed linen), soiled

	gloves, towels, masks, gowns, bandages, diapers, pads and theatre caps
Pathological	Severed limbs, health and unhealthy tissues, body parts and organs
Cytotoxic	Remains of cytotoxic drugs, materials contaminated by materials used to suppress cell growth and cancer
Radioactive	Unsealed radionuclides, materials contaminated by radioactive materials and absorbent paper
Chemical	Containers of chemicals such as reagents, disinfectants
General	Food waste (sadza, vegetables, maize cobs and fruits), stationary (files, papers, book covers), water and drink bottles, package materials (empty boxes, plastics)

Source: Field data (2023)

3.3.3 Generation trend and quantity of hospital solid waste

Respondents at STT hospital (53.3%) agreed that solid waste was increasing while 17.1% strongly agree (Fig. 3). At HC hospital 50.9% agreed whilst 21.8 strongly agreed that solid waste was increasing. The DMO postulated that comparing the rate of hospital solid waste generation with the previous years, there was a slight increase. Hospital solid waste is increasing at both rural and urban hospitals in developing and developed countries [10, 41]. Although, respondents at STT (10.5%) and HC (10.9%) were not sure if hospitals are increasing or not (Fig. 3). This contradicts with the EMA Officer who noted that the solid waste increase at these rural hospitals was overwhelming the capacity of rural hospitals. Research findings demonstrated that 31.1% of health workers at STT and 32.5% at HC hospital pointed out that solid waste was increasing at a high rate. Therefore, it is clear that the quantity of hospital solid waste was exceeding the threshold of previous years. Increase of solid waste adds burden to already struggling rural hospitals [45, 70, 70].

In terms of drivers of solid waste increase, 42.5% of the respondents at STT hospital and 35.1% at HC hospital (Fig. 4), highlighted high use of disposable PPE/C. Questionnaire respondents, DMO and Matrons revealed high use of disposable gloves, masks, theatre caps and aprons to curb spread of infectious diseases. High utilization and compulsory use of PPE/C among health workers accelerates generation of solid waste [31, 81]. In total, 30% of health workers at HC, 29.7% at STT hospital and EHT pointed that increase of solid waste was attributed to the large number of patients offered services. Solid waste increase was owed to population proliferation in the catchment area since those people seek assistance from these hospitals, although people from other districts are among the patients. According to [77, 78] if the number of patients offered services at any hospital rises, solid waste also increases.

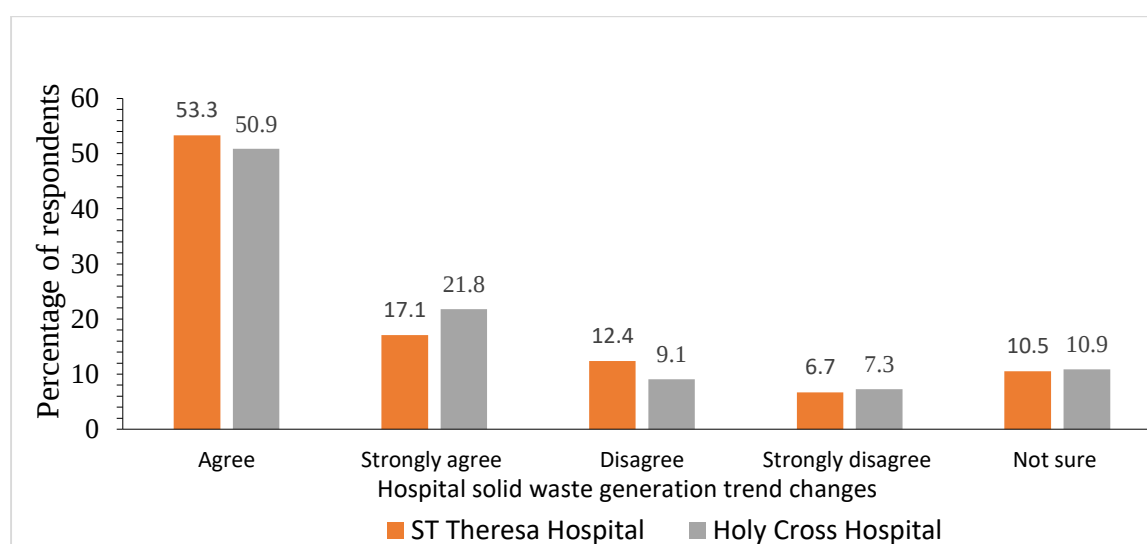


Fig. 3: Questionnaire respondents' perceptions on hospital solid waste generation trend changes

Source: Field data (2023)

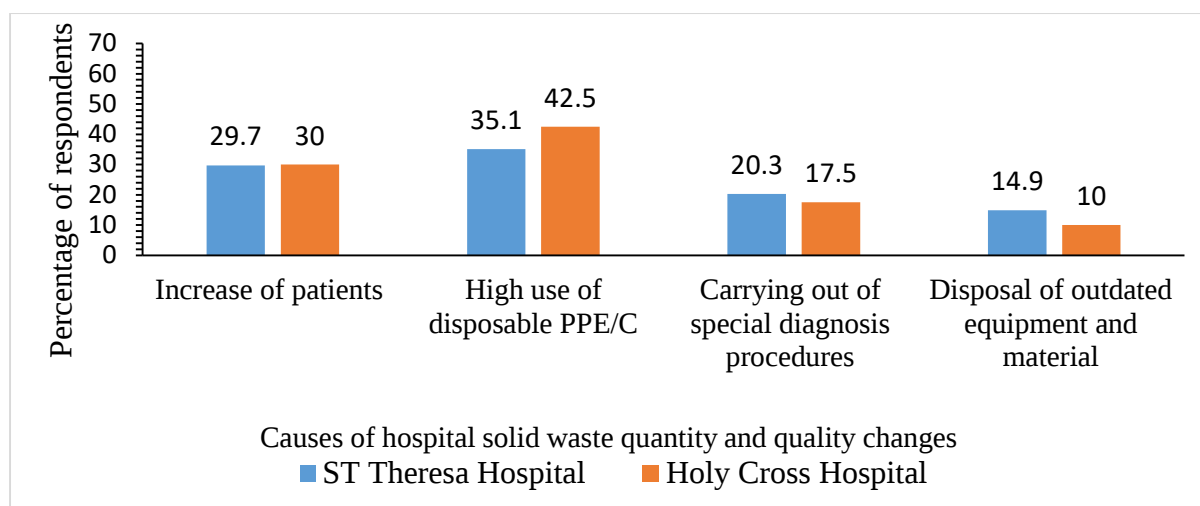


Fig. 4: Causes of hospital solid waste quantity and quality changes.

Source: Field data (2023)

Results suggest that 20.3% respondents at STT hospital expressed the issue of carrying out special diagnosis procedures among causes of hospital solid waste increase (Fig. 4). Health workers postulate that procedures such as Full Blood Count (FBC), minor and major operations produce various types of sharps and infectious waste since a number of items are utilized. The proportion of questionnaire respondents who mentioned disposal of outdated equipment and material as one of the key aspects causing solid waste increase was 10% at HC and 14.9% at STT (Fig. 4). Respondents articulated equipment such as non-functioning clinical thermometers, weighing scales, sphygmomanometer, electrical lamps, printers, cartridges, pharmaceuticals and computers. At HC hospital, average solid waste generated per patient per day was 0.83 kg. This was used to calculate solid waste generated at HC hospital per day (Table 5). Quantity of solid waste generated at Holy Cross depends on the number of inpatients (Table 5). Average quantity of solid waste generated per patient per day at HC is supported by Khudhair [44]'s in Iran which shows that 0.83 kg of waste was generated per patient per day. At STT hospital, the quantity of solid waste produced per patient per day was 0.87 kg and this was utilized to calculate the quantity of solid waste generated per day at the hospital (Table 5). Findings at each hospital revealed that the number of patients influenced the quantity of solid waste generated. This concurs with Ansari et al. [10] and Sangkham, (2020) that total number of patients served at a health facility affect the quantity of solid produced directly. Admission and discharge of patients explains the fluctuation of patient numbers and quantity of solid waste (Table 5). HC hospital generated a maximum of 38.18 kg, a minimum of 24.07 kg and an average of 31.54 kg of solid waste during data collection days. However, STT hospital

produced a maximum of 79.17 kg, 48.72 kg minimum and an average of 65.13 kg during the data collection period. This illustrates that although these hospitals are in the same district, but waste generation rate differs. A scenario which can be better explained by variation in terms of services offered and number of patients served at each hospital.

Table 5: Quantity of hospital solid waste produced in relation to number of admitted patients

Hospital Name	Days when data was collected	Number of admitted patients per day of data collection	Quantity of waste generated per day (Kg) per each day of data collection
Holy Cross	1	46	38.18
	2	41	34.03
	3	36	29.88
	4	43	35.69
	5	33	27.39
	6	38	31.54
	7	29	24.07
ST Theresa	1	91	79.17
	2	88	76.56
	3	68	59.16
	4	77	66.99
	5	83	72.21
	6	61	53.07
	7	54	48.72

Source: Field data (2023)

Pearson Chi-square test conducted on data collected from ST Theresa (Table 6) and Holy Cross (Table 7) hospitals, demonstrated a value of 0.000, which is less than the significance level of 0.05. Therefore, Pearson Chi-square tests demonstrated that there was association between the quantity of solid waste generated and number of patients at these hospitals. The results are in line with studies carried out in Zimbabwe by [77, 78].

Table 6: Chi-Square Tests of solid waste generated at ST Theresa hospital and number of patients

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	168.000 ^a	36	.000
Likelihood Ratio	101.311	36	.000
Linear-by-Linear Association	26.928	1	.000
N of Valid Cases	28		

Source: Field data (2023)

Table 7: Chi-Square Tests of solid waste generated at Holy Cross hospital and number of patients

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	168.000 ^a	42	.000
Likelihood Ratio	101.311	42	.000
Linear-by-Linear Association	26.984	1	.000
N of Valid Cases	28		

a. 56 cells (100.0%) have expected count less than 5. The minimum expected count is .04.

Source: Field data (2023)

Average composition of hospital solid waste generated at STT hospital was dominated by general waste (77.35%), 9% infectious, Chemical waste (2.3%), pharmaceutical (2.35%) and 3.88% sharp waste (Fig. 5). Composition of cytotoxic waste was 0.15% and radioactive waste (0.77%) and 4.2% pathological waste at STT hospital. Composition of waste produced at STT hospital shows existence of solid waste with similar characteristics to general domestic waste in large volumes. However, if waste is improperly segregated, the whole proportion of the waste becomes hazardous [77, 78], Shabani et al. [96]. A significant composition of general waste (79%) was generated at Holy Cross hospital with 7.59% infectious waste (Fig. 6). Average composition of chemical waste was 2%, 5% pathological waste and 3% pharmaceutical waste at Holy Cross hospital. A small percentage of solid waste consists of radioactive waste (0.71%) and cytotoxic waste (0.5%) and sharp waste (2.2%) at Holy Cross hospital. Considering the composition of solid waste (Figs. 5, 6), it is clear that the large quantity of generated waste was non-hazardous and a minor proportion was hazardous. Findings are almost similar to Behnam et al. (2020) and Agamuthu and Barasarathi, [105]'s

studies that approximately 75 to 80% of hospital solid waste is non-hazardous while 20 to 25% is hazardous.

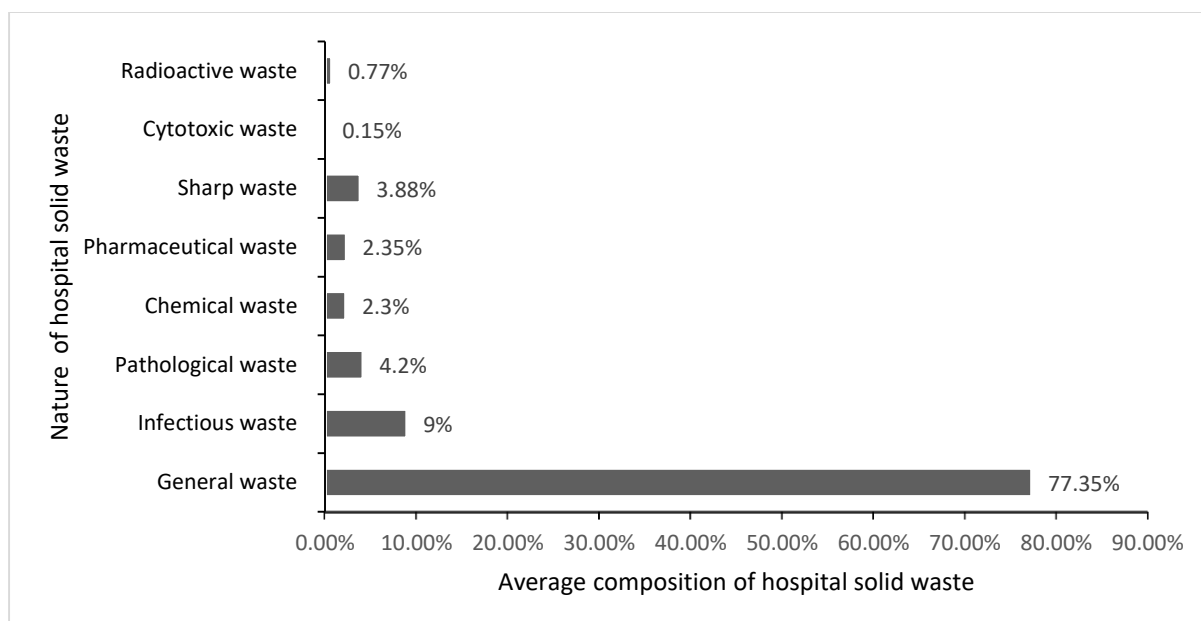


Fig. 5: Average composition of hospital solid waste generated at ST Theresa hospital per week (percentage by weight)

Source: Field data (2023)

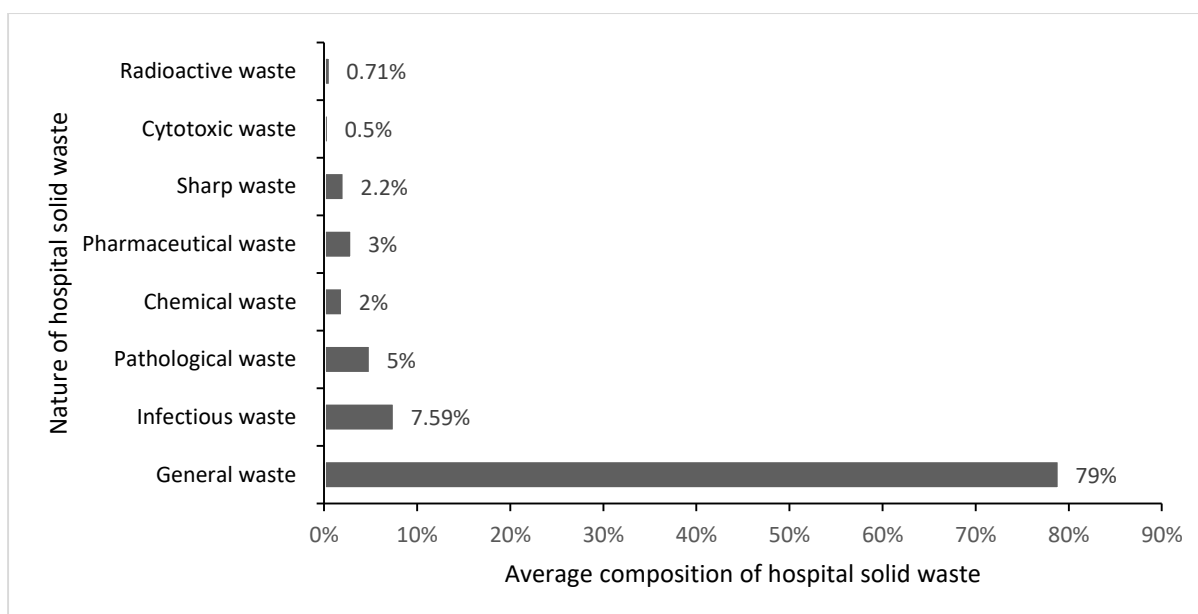


Fig. 6: Average composition of hospital solid waste generated at Holy Cross hospital per week (percentage by weight)

Source: Field data (2023)

3.3.4 Hospital solid waste management approaches at ST Theresa and Holy Cross hospitals

3.3.4.1 Types of hospital solid waste storage receptacles used at the two hospitals

Different hospital solid waste storage receptacles were identified among them include sharp containers, metal buckets and pedal operated bins (Fig. 7). This was supported by respondents at STT hospital (72.4%) (Fig. 8) and EHTs who mentioned sharp containers, foot operated bins and plastic bags. A total of 6.7%, 16.2% and 4.8% respondents at STT hospital indicated metal and plastic buckets, plastic bags and cardboard boxes, respectively, as storage containers. Different types of solid waste receptacles are also used at hospitals in India [80] and in Nigeria [4]. At HC hospital 16.2% highlighted plastic bags while 5.5% mentioned metal and plastic buckets whereas utilisation of sharp containers and pedal operated bins was confirmed by 69.1% (Fig. 8). The popularity of sharp containers was probably attributed to its characteristics among them include being made of puncture resistant materials. Sharp containers are mostly used at hospitals because they are leaking proof, puncture proof and are recommended by WHO

[60, 87]. Pedal operated bins are highly used as storage containers at the hospitals under study (Fig. 8). Dominance of pedal operated bins at hospitals is attributed to its hygienic nature since the bins are opened without using hands [77, 78]. Observations indicated that large waste containers with potential to accommodate 50 kgs of waste are placed at open spaces and inside building at STT hospital (Fig. 9).

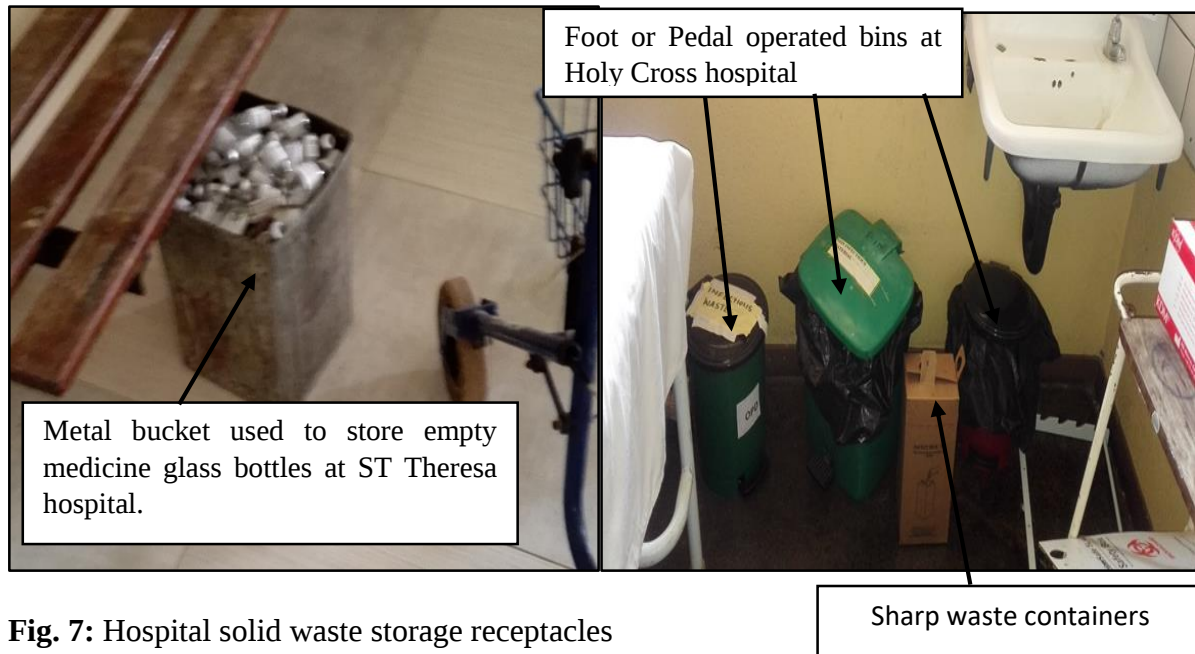


Fig. 7: Hospital solid waste storage receptacles

Source: Field data (2023)

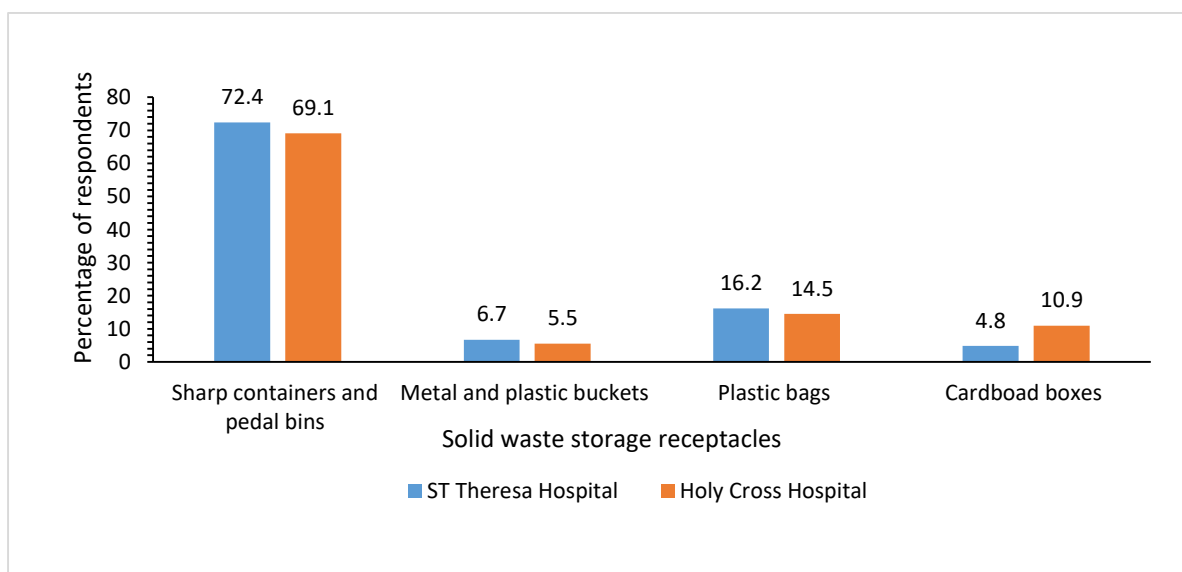


Fig. 8: Types of hospital solid waste storage receptacles used

Source: Field data (2023)

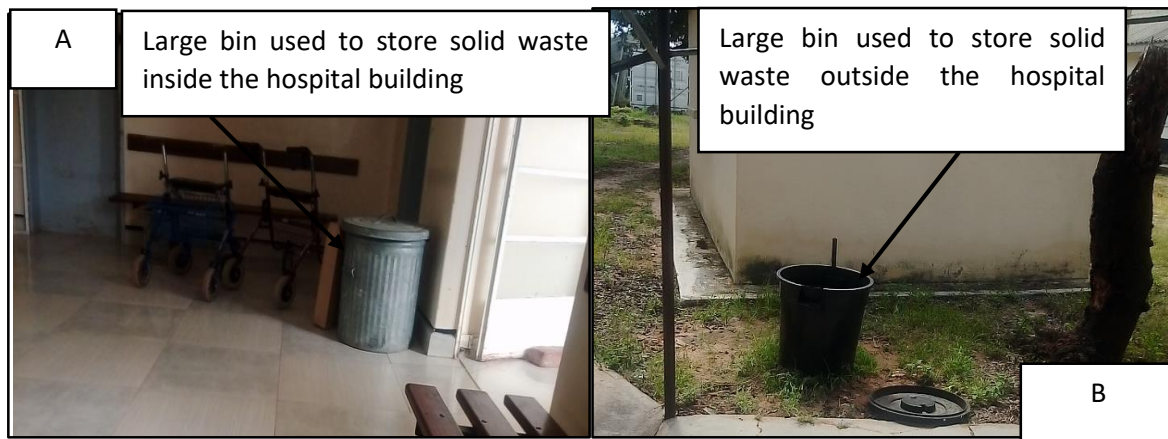


Fig. 9: Large metal A and plastic bins B used to store solid waste at ST Theresa hospital.
Source: Field data (plate 2023)

Regarding hospital solid waste segregation, observations suggest that storage containers were labelled as infectious and non-infectious waste bins (Fig. 10), while some were penciled plastics and papers (Fig. 11). Despite the existence of labelled bins, contaminated and non-contaminated materials were found in one container. This illustrates that conformity of health workers to labels on the bins was low, denoting lack of awareness as well as negative attitude to proper waste segregation. At STT and HC it was observed and supported by EHTs that solid waste was separated into sharps and non-sharps during storage. This was supported by questionnaire respondents at STT (41%) and HC (32.7%) hospitals (Fig. 12). A view upheld by Ansari et al. [10] that sharp waste and non-sharps must be stored in separate containers. However, at STT and HC existence of sharps including razor blades, needles and slides was observed in bins with soiled linen and disposable towels. However, respondents at HC hospital (67.3%) and STT (35.2%) argued that infectious and non-infectious waste was stored in different containers. Separation of hospital solid waste into infectious and non-infectious waste is common at various medical facilities across the globe [23, 34]. According to the STT hospital cleaning supervisor, contaminated and non-contaminated solid waste was stored in different receptacles. Observations revealed that food waste, empty plastics, papers and other contaminated materials were stored in the same receptacles in certain wards and rooms at these hospitals. This means indiscriminate storage of solid waste also exists at these rural hospitals, however, this increases difficulties in management of solid waste. Mismanagement of solid waste is worsened by co-storage waste at both urban and rural hospitals [74–76].



Fig. 10: Solid waste receptacles for infectious waste, non-infectious materials and sharps at Holy Cross hospital.

Source: Field data (2023)



Fig. 11: Receptacles for plastic and paper waste at ST Theresa hospital.

Source: Field data (2023)

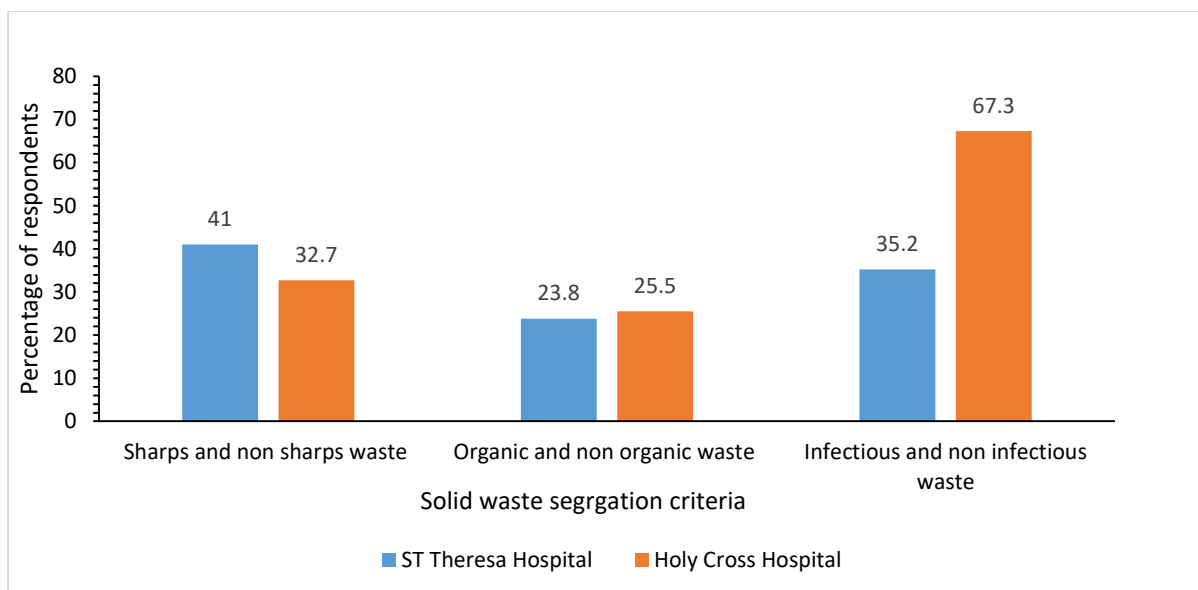


Fig. 12: Hospital solid waste segregation during storage.

Source: Field data (2023)

The EHTs at STT and HC hospitals denote that solid waste separation status at their hospitals was according to standards. The EHTs were highlighting their efforts to separate sharps and non-sharps and infectious and non-infectious waste. This concurs with respondents at STT (31.4%) and HC (32.7%) who claim that hospital solid waste segregation standard was good and a total of 39.0% respondents at STT hospital who indicated very good (Fig. 13). This contradicts observations since plastics, sharps and papers were noticed in the same bins in some hospital wards. Consequently, the solid waste segregation system at STT and HC fails to adequately address demands of WHO and Zimbabwe Ministry of Health and Child Care. This concurs with [20] that in developing nations the standard of hospital solid waste segregation is far-off from sustainability. A small proportion of health workers at HC (10.9%) and STT hospitals (7.6%) considered segregation at the storage stage as poor (Fig. 13). The EMA Officer argued that evidence of improper segregation at the storage stage was illustrated by mixed waste at disposal sites. This entails that the appearance of plastics, food waste, bottles and papers in the same spits was a tail end issue of improper segregation during storage. This is supported by Angmo and Shah [9] and Pujara et al. [66] that existence of non-segregated waste at disposal sites demonstrates evidence of indiscriminate storage of solid waste.

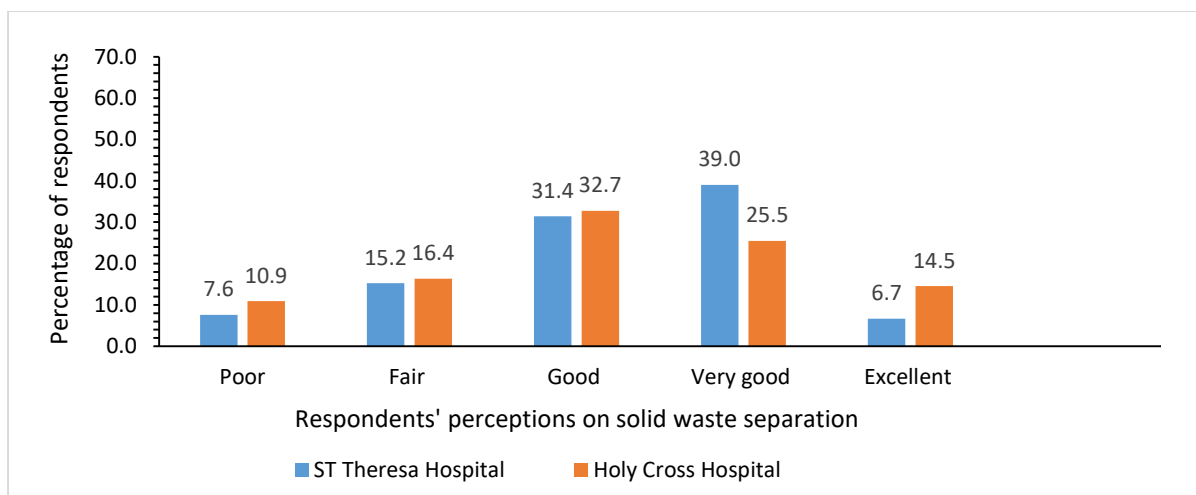


Fig. 13: Questionnaire respondents’ perceptions on standard of hospital solid waste separation.

Source: Field data (2023)

3.3.4.2 Treatment of solid waste at Holy Cross and ST Theresa hospitals

Highly infectious solid waste from various hospital departments was disinfected through chlorination and autoclaving. EHTs and the DMO indicated that to destroy bacteria, fungi and viruses, infectious materials are exposed to steaming, high temperature and pressure in an autoclave machine. Chlorination and autoclaving are usually used to treat solid waste expected to contain infectious organisms in less developed countries [10, 19] and Zimbabwe is not exempted. The DMO supported by EHTs from both hospitals revealed that an oxidizing agent named chlorine was used to eradicate microorganisms on contaminated materials. The DMO said, “*Chlorination is capable of destroying various microorganisms, although it is not suitable to treat hospital radioactive waste*”. This goes in line with Ahmad et al. [5] and Chisholm et al. [19]’s studies that chlorination has the potential to destroy pathogens. This entails that chlorination has the potential to destroy viruses and bacteria, thus suppressing spread of diseases associated with infectious waste. Adequate efficiency of chlorination was hindered by non-segregation of solid waste at various stages of management. However, results indicated that solid waste from these rural hospitals was usually transported to disposal sites without receiving proper treatment due to shortage of resources. Shortage of resources is also experienced at rural hospitals in Uganda [45].

3.3.4.3 Transportation of solid waste at Holy Cross and ST Theresa hospitals

Observations and EHTs revealed that health workers transported hospital solid waste to disposal sites manually. Manual handling of hospital solid waste receptacles facilitates removal of waste from the generation site, although it exposes health workers to back, hand and shoulder pain. Manual handling of solid waste receptacles results in musculoskeletal disorders [18]. Sharp containers and large bins were transported to the incineration site using wheelbarrows. Questionnaire respondents at hospitals under study indicated use of wheelbarrows and manual handling of waste receptacles. They argued that manual handling of solid waste receptacles to disposal sites was attributed to limited resources, specifically finance. Most rural hospitals in developing countries are operated without adequate resources (Manyisa and van-Aswegen, 2017 [19]). At STT and HC hospitals, multipurpose trolleys were used to deliver waste containers to rooms where waste was treated. This suggests that rural hospitals require support in form of finance to purchase trolleys which are specifically for waste transportation.

3.3.4.4 Frequency of emptying hospital solid waste receptacles

Results of the study at STT hospital (87%) and HC hospital (78%) depict that solid waste receptacles were emptied on a daily basis (Fig. 14). This coincides with views of hospital Matrons and cleaning supervisors at these hospitals. Daily conveyance of solid waste receptacles is significant since it reduces spread of waste related diseases among patients and health workers. In addition, emptying of waste containers on a daily basis is a requirement by WHO guidelines. Data gathered during observations highlighted that stored solid waste was generating noxious odours and moulds in storage receptacles. This means solid waste was allowed to remain in storage containers for more than two days as highlighted by respondents at STT (10%) and 15% at HC hospitals. This signifies that frequency of emptying waste receptacles sometimes contradicts WHO and ZMoHCC waste management guide lines. Solid waste management activities encompassing emptying of storage receptacles at health institutions is usually less sustainable [7]. A total of 3% and 7% participants at STT and HC hospitals, respectively, indicated that waste storage containers were emptied twice a day (Fig. 14). This small proportion points out that emptying of solid waste receptacles twice a day was rare. Hospitals' EHTs, cleaning supervisors and DMO concur that hospital sharp waste was disposed when the container was $\frac{3}{4}$ full. Disposal of containers with sharp waste was not

determined by number of days but quantity in the container. Similarly, sharp waste containers are disposed when they are $\frac{3}{4}$ full at hospitals in South Africa [55].

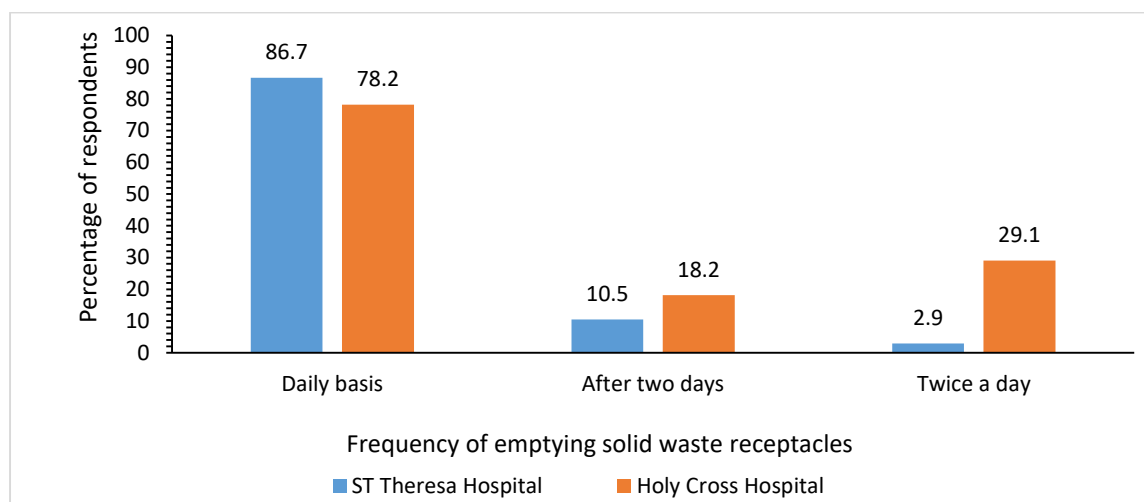


Fig. 14: Frequency of emptying solid waste receptacles at ST Theresa and Holy Cross hospitals.

Source: Field data (2023)

3.3.4.5 Disposal of solid waste at Holy Cross and ST Theresa hospitals

Disposal of hospital solid waste was carried out within hospital yards as observed at STT and HC hospitals. Field observations illustrated that hospital solid waste produced at STT and HC hospitals was disposed into open pits, incinerators, auto-way pits and open burning. The findings are similar to studies carried out in Niger state in Nigeria by [2]. A view also revealed by Awodele et al. [12] and Chisholm et al. [19] that a number of approaches are used to dispose waste at medical facilities in African nations including Zimbabwe. An incinerator was used to dispose various types of solid waste at HC (Fig. 15) and at STT hospital (Fig. 16). Incineration was highly used as alluded to by respondents at STT hospital (44.8%) and HC hospital (41.8%) (Fig. 17). Incineration was used to dispose various types of solid waste namely papers, plastics, infectious waste like soiled masks, gloves, bandages, cotton wool and textiles as well as pharmaceutical waste. Issues of sharp waste incineration was supported by cleaning supervisors and EHTs at the hospitals under study. Results of the study concur with findings obtained at Mwananyamala and Temeke regional referral hospitals in Tanzania [35, 71].

Incineration is highly utilized to dispose hospital solid waste because it reduces volume and toxicity of hazardous waste from hospitals [7, 10].

Moreover, observations revealed that auto-way pits were used to dispose hospital solid waste at HC hospital (Fig. 18) and STT hospital (Fig. 19). Pathological waste namely body parts and organs are discarded in auto-way pits as alluded by respondents at STT (27.6%) and HC (29.1%) hospitals (Fig. 17). This is in line with [77, 78] that pathological waste from health institutions is disposed in auto way pits. Hospital solid waste was disposed through open burning as demonstrated by health workers at HC hospital (12.7%) and STT (11.4%) (Fig. 17). Respondents noted that a certain fraction of solid waste namely papers, plastics, sachets of pharmaceuticals and contaminated materials like swabs, cotton wool and textiles were disposed through open burning. Open combustion of solid waste is also common at rural hospitals in Pakistan [70, 70]. However, open burning of solid waste generates various pollutants with potential to cause air pollution. Gases like nitrous oxide, carbon dioxide and carbon monoxide generated from waste combustion cause air pollution translating to respiratory ailments [64, 88]. Respondents at STT (16.2%), HC (16.4%) supported by hospital EHTs stipulated that solid waste such as food waste like rice, sadza, vegetable and fruits were disposed in open pits. This entails that open pits were highly meant for organic waste at these rural hospitals. Findings concur with Kwikiriza et al. [45]'s studies which illustrate that open pits are among disposal strategies used at rural hospitals in Uganda. Nevertheless, due to inappropriate monitoring and indiscriminate disposal of waste at STT and HC, the pits are acting as breeding sites for vectors. This is in line with Jerie [38] that poorly managed dump sites offer fertile breeding sites for flies with potential to transmit pathogens which cause diseases to people. To worsen the scenario, observations indicated that non organic and organic waste was disposed together in an open pit (Fig. 20). Indiscriminate disposal of solid waste at HC and STT hospitals was postulated by EMA Officer. Discarding non-degradable hospital waste into organic pits shortens the lifespan of organic pits, thus worsening solid waste management challenges at STT and HC. The study results coincide with findings at rural health institutions in KwaZulu Natal, South Africa [55].

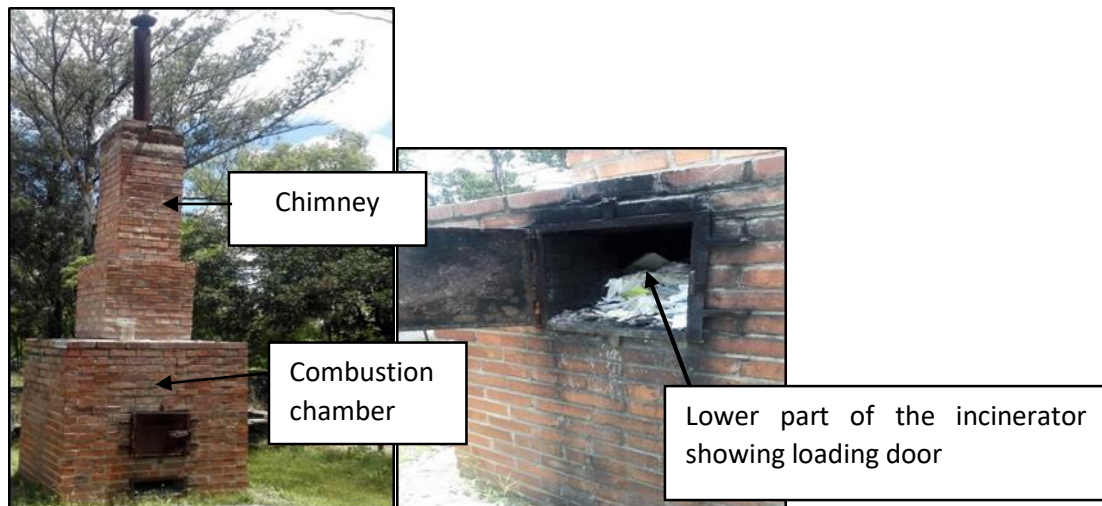


Fig. 15: Incinerator used to dispose medical waste at Holy Cross hospital.

Source: Field data (2023)

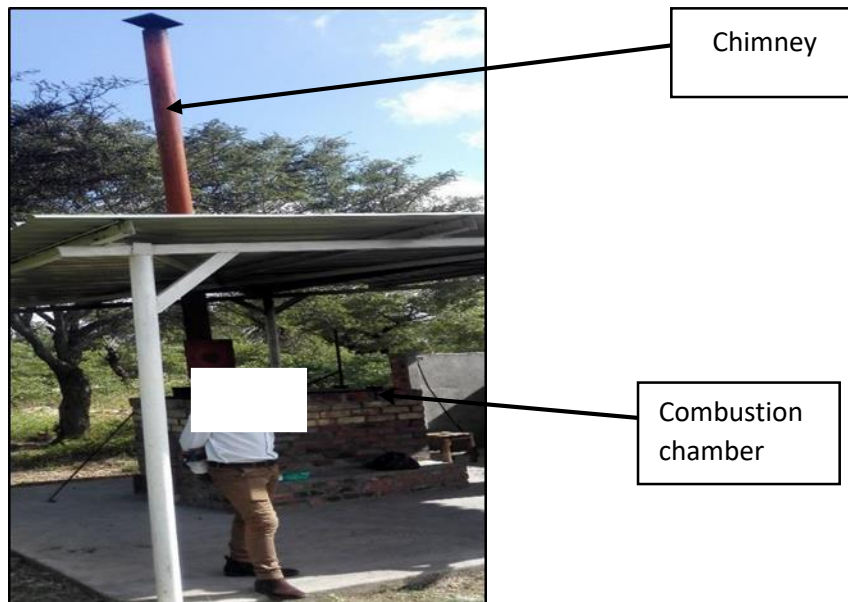


Fig. 16: Incinerator used to dispose solid waste at ST Theresa hospital.

Source: Field data (2023)

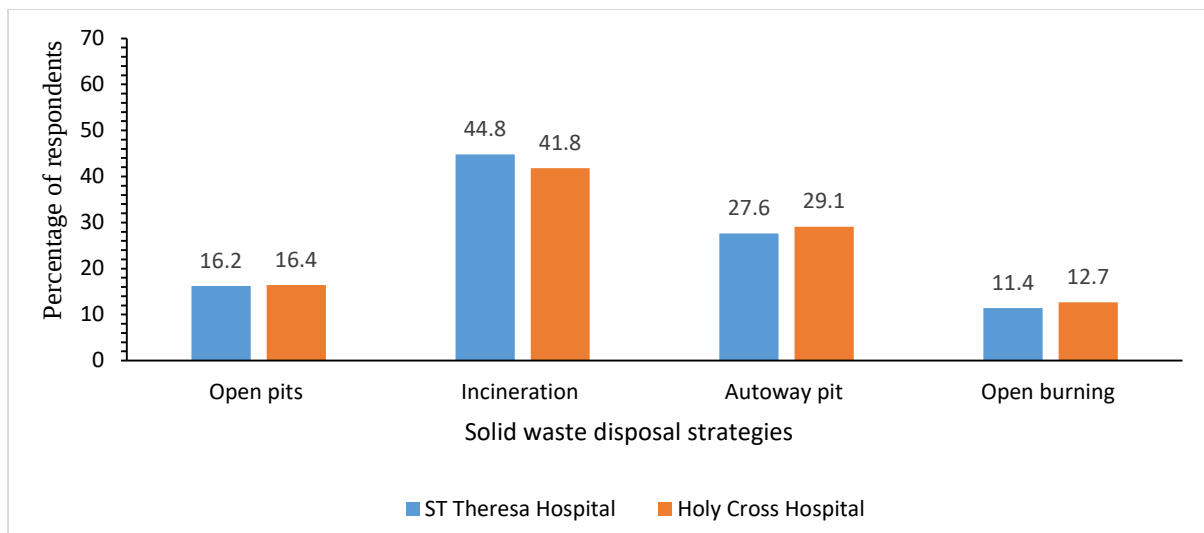


Fig. 17: Hospital solid waste disposal strategies

Source: Field data (2023)



Fig. 18: Auto-way pit (located in a minor orchard) used to dispose pathological waste at Holy Cross hospital.

Source: Field data (2023)

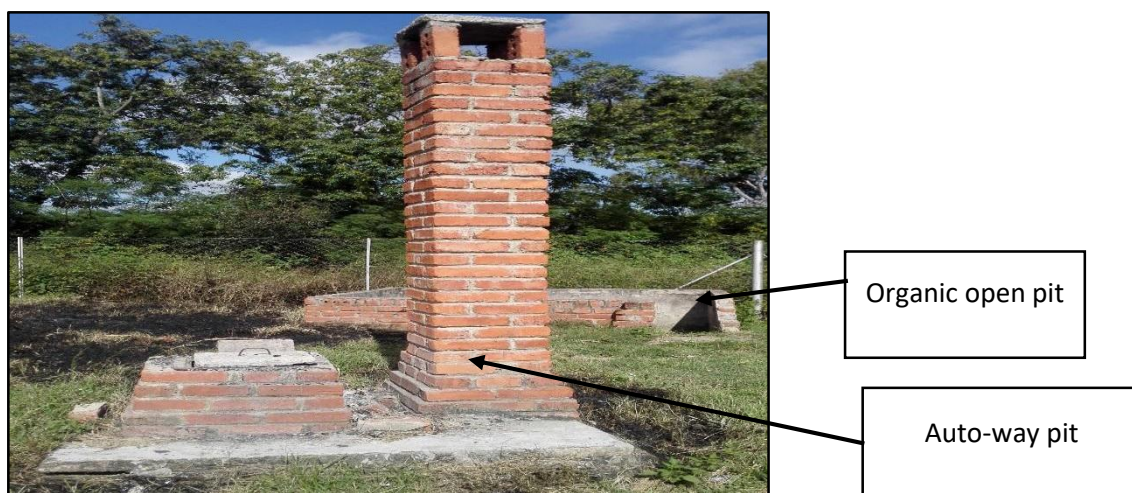


Fig. 19: Auto-way pit and organic open pit used to dispose pathological waste and organic waste respectively at ST Theresa hospital.

Source: Field data (2023)

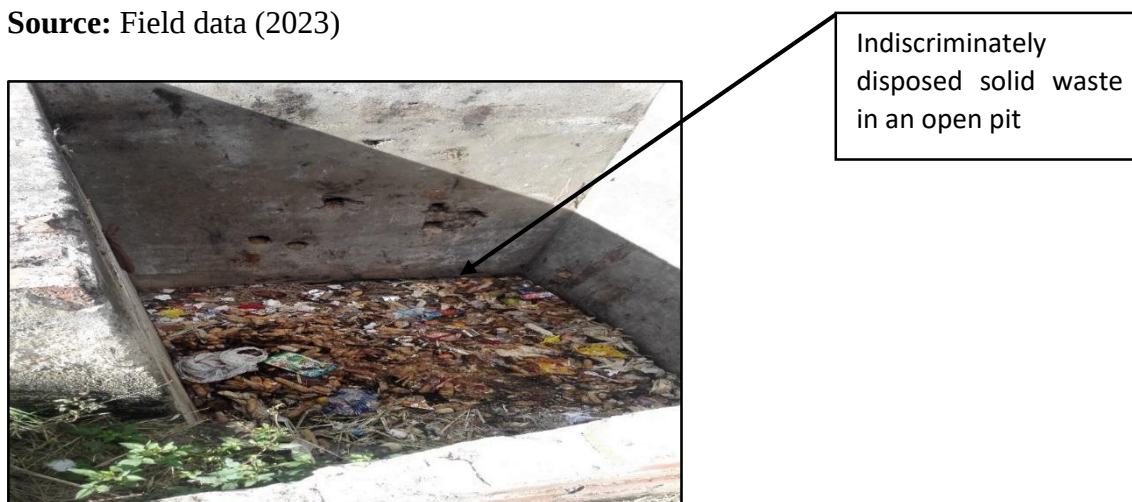


Fig. 20: Disposed solid waste consisting of organic waste and inorganic waste (plastics and papers) in organic pit at ST Theresa hospital.

Source: Field survey (2023)

3.3.5 Awareness of solid waste management legislation and policies among health workers at ST Theresa and Holy Cross hospitals

Majority of the respondents at HC (58.2%) and 54.3% at STT have little knowledge regarding legislation and policies governing hospital solid waste management (Fig. 21). The EMA officer asserted that most health workers' legal frameworks awareness is low. Inadequate knowledge related hospital waste management among health workers worsens problems in waste management at these rural hospitals. Results tallies with Doylo et al.'s studies [22] where rural health workers in Eastern Ethiopia demonstrate less awareness of solid waste legislation and policies. Interview results indicated that negative attitudes among health workers also hinder appropriate solid waste management at STT and HC hospitals. Lack of knowledge regarding legal framework exacerbate challenges in management of waste [15, 40] not excluding management of solid waste from rural hospitals. A total of 45.7% at STT and 41.8% at HC had good knowledge on legislation and policies linked to hospital solid waste management. This concurs with EHTs who indicated that aspects related to hospital solid waste legislation are covered during workshops and training. This congruence with Mmereki's research [53] that in Botswana information related to solid waste including medical waste is disseminated through workshops and training.

Respondents who were aware of legislations and policies at STT hospital (41.7%) and HC hospital (47.8%) noted the Environmental Management Act (Fig. 21). However, 22.9% and 21.7% at STT and HC hospitals, respectively, were aware of the Public Health Act. The EHT alluded that disposal of hospital solid waste utilising approaches which affect human health negatively was prohibited by Public Health Act. MoHCC waste management guidelines were stipulated by 35.4% and 30.4% respondents at STT and HC, respectively. Therefore, like other developing countries, management of solid waste from rural hospitals of Zimbabwe should conform to guidelines. However, existing legislations and policies are lacking clear issues directed to the responsibility of local authorities when it comes to management of waste from rural health institutions. In terms of legislation linked to hospital solid waste management, the EMA officer mentioned EMA Act Chapter 20:27 which upheld protection of the environment from all forms of pollution. According to the EMA officer, Atmospheric Pollution Prevention Act Chapter 20:03 and Hazardous Substances and Articles Act Chapter 15:05 are applied. Applicability of these Acts was attributed to the fact that some disposal strategies used at these rural hospitals cause air pollution while hazardous solid waste is generated. Results are upheld

by studies which indicated that EMA is accountable for monitoring various environmental issues including solid waste management in Zimbabwe (Jerie, [98]; [48]). This signifies that EMA has an upper hand in management of solid waste including waste from rural hospitals. However, achievement of proper solid waste management at rural hospitals requires participation and co-operation of various stakeholders.

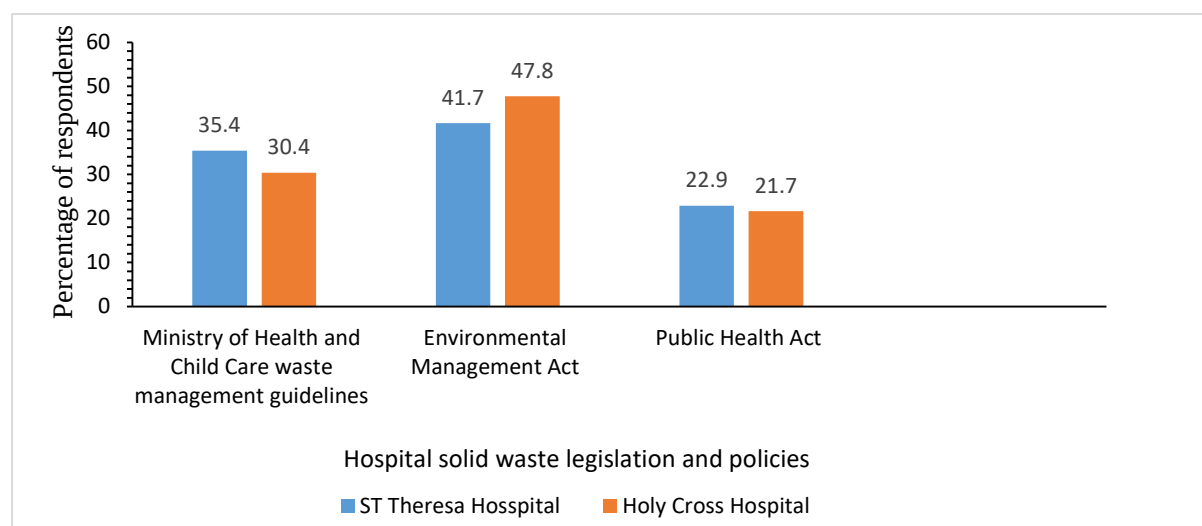


Fig. 21: Hospital solid waste management legislations and policies indicated by health workers.

Source: Field data (2023)

In terms of conformity to solid waste legislation and policies, 25.0% respondents at STT and 21.7% at HC consider it as moderate (Fig. 22). This was supported by HC EHT that although they experienced shortage of resources, they tried to maintain recommended standards. Similarly, adequate conformity to solid waste management legislations is limited by lack of resources at rural hospitals in Uganda [45] and Nigeria (Abubakar et al. [104]). Participants at STT (16.7%) and 13.0% at HC hospitals argued that solid waste management strategies conform to a larger extent (Fig. 22). A small percentage of these respondents indicated that these rural hospitals give less priority to solid waste management. This was supported by respondents at HC (47.8%) and STT (45.8%) who noted that they conform but to a lesser extent. Hence, approaches utilized to manage solid waste at hospitals conform to existing legislation and policies but to a limited degree compared to recommended standards. This concurs with Khan et al. [102] and [62] that owing to various challenges including giving less attention to legislations, solid waste management at rural hospitals is far from sustainability.

The EMA officer argued that hospitals focus much on delivering health services while neglecting sustainable solid waste management. For these rural hospitals to direct enough resources to waste issues, health workers must be informed that waste-related diseases add burden to health institutions. Inadequate conformity was also indicated by chimneys of the incinerators which were far from recommended standards. This suggests that incinerators used at these rural hospitals have potential to cause air contamination translating to occurrence of respiratory diseases. This concurs with Khudhair [44] and Kwikiriza et al. [45] that improperly constructed incinerators generate dioxins, furans and gases which cause detrimental impacts to human well-being.

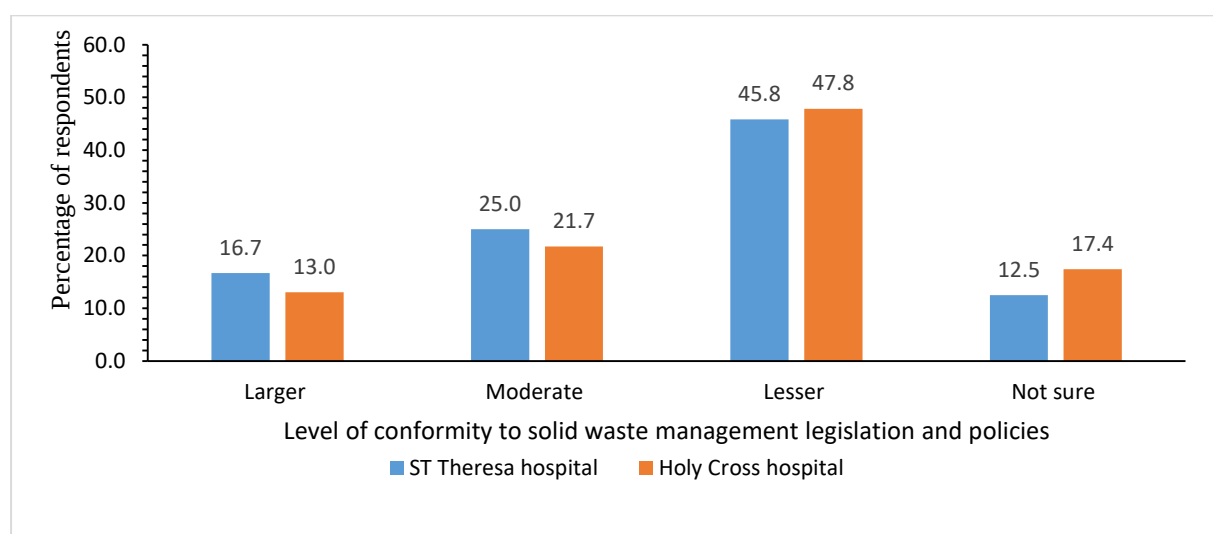


Fig. 22: Adherence or conformity of hospitals to solid waste management policies and legislations.

Source: Field data (2023)

3.3.6 Nature of existing solid waste management frameworks at ST Theresa and Holy Cross hospital

Results of the study demonstrated that STT hospital and HC hospitals have an already existing solid waste management system as shown by 100% of the respondents. This demonstrated that these hospitals have their way of managing solid waste. A scenario noted at rural hospitals in South West, Uganda (Kwikiriza et al. [45]). Although from an environmental perspective and sustainability the framework was surrounded by various questions. Respondents at STT

(73.3%) and HC (69.1%) hospitals and EMA officer described the system highlighting generation, storage, collection and disposal. It is clear that these rural hospitals put much emphasis on traditional linear solid waste management approaches. Traditional waste management system is an approach that lacks coordination among stakeholders, while giving less attention to waste minimisation techniques [77, 78]. Interview results revealed that existing management systems consider reuse as a peripheral aspect, therefore, a large quantity of solid waste is disposed. This means pinning the circular economy concept in solid waste management at rural hospitals is at an embryonic stage and needs sufficient attention. Mandevere and Jerie [94] asserted that in Zimbabwe about 90% of solid waste is disposed, not excluding waste from health institutions. EHTs expressed the aspect of composting organic waste which was later used as organic manure in the hospital garden. However, observations indicated that proper application of composting was difficult due to indiscriminate management of solid waste in these hospitals. This congruence with other studies that appropriate management of solid waste from hospitals is impeded by co-storage of solid waste [73]. A total of 26.7% and 30.9% of respondents at STT and HC hospital, respectively, asserted that reuse was also applied. Respondents mentioned reuse of soft drink and cooking oil containers to store water, giving food waste to those who want to feed their domestic animals namely dogs and chicken. Similarly, in Tanzania food waste from Mwananyamala Regional Referral hospitals was collected and used as animal feeds [35].

The HC Cleaning supervisor indicated that some papers and plastics are collected by health workers and used as fuel when making fire, specifically in this era where load shedding is high. This contradicts with the EMA Officer's view that almost all the waste generated at STT and HC hospitals was disposed. Furthermore, STT hospital EHTs and the Cleaning supervisor's views coincide that the existing solid waste management system has been implemented since 1957 when the hospital was constructed. Hence, most of the waste management approaches used at these institutions are failing to meet demands of the twenty-first century, specifically the SDGs and Zimbabwe NDS 1. The prevailing management techniques may fail to handle current quality and quantity of solid waste at these rural hospitals. Therefore, management approaches which meet sustainable goals as well as EMA objectives are essential. Nevertheless, HC Matrons argued that their EHT was capable of leading implementation of recommended management approaches but shortage of resources was a barrier. Moreover, a large number of respondents at STT (40.0%) and 41.8% HC hospitals illustrated that short age

of resources drives utilisation of existing systems (Fig. 23). This goes in line with studies conducted in Malawi which indicated that rural hospitals are affected by shortage of resources [29]. However, health workers at STT (20.0%) and HC (25.5%) hospitals revealed that adoption of the existing management strategies was ascribed to lack of awareness concerning negative impacts of the existing system. Although, respondents at STT (25.7%) and HC (20%) hospitals argued that existing strategies were accredited to lack of knowledge about other strategies. This entails that disseminating adequate knowledge to health workers is one of the solutions to deal with solid waste from rural hospitals. Equally, limited knowledge impedes application of proper solid waste management at rural hospitals in Limpopo province in South Africa [62]. Participants at HC (12.7%) and STT (14.3%) (Fig. 23) asserted that responsible authority was less willing to change the system, since they are almost conservative. This signifies that management of solid waste at these rural hospitals is a top-down approach where involvement of most health workers is low. Correspondingly, equal participation of all health workers in solid waste management issues is rare at rural health institutions in Egypt (Muhammed et al. 2019). Therefore, to achieve sustainability a framework which calls for all stakeholder inclusion in waste management is significant at hospitals under study.

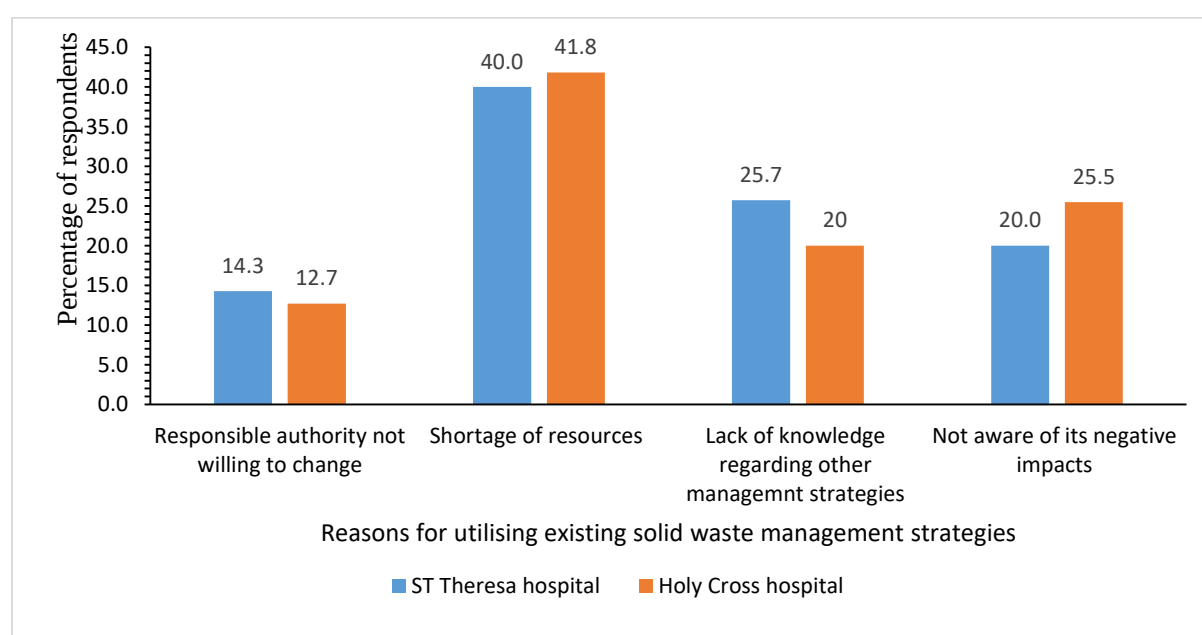


Fig. 23: Reasons for adopting and utilising existing solid waste management strategies.
Source: Field data (2023)

Results indicated that frameworks utilised at HC and STT hospitals consider involvement and participation of all stakeholders as less important. There was limited room for all health workers to participate in solid waste management aspects at STT (79.0%) and HC (76.4%)

(Fig. 24). Inclusion of all stakeholders in management of solid waste is still at a miniature stage at these rural hospitals. Results concur with findings at rural district hospitals in KwaZulu Natal, South Africa [61]. STT hospital's EHT argued that planning for solid waste management issues was the responsibility of the "Infection Control Team" and the EHT. Although the DMO suggested that every health worker was expected to participate and contribute towards proper management of hospital solid waste. Taking this into account, solid waste management approaches used at STT and HC sometimes contradict MoHCC as well as WHO requirements. Integrated approach can facilitate networking of various stakeholders and techniques which narrow the route to sustainability.

Health workers receive solid waste management training at STT (83.8%) and at HC (83.6%) hospitals. STT and HC hospitals EHT articulated that health workers are offered training linked to solid waste management. Findings are similar to studies carried out by Hossain et al. [36] in Gopalganj Sadar in Bangladesh. Considering these verdicts, hospital solid waste was supposed to be managed appropriately although the existing scenario was almost opposite. STT hospital EHT posits that solid waste management training was offered on a monthly basis although new staff members receive training as per request from hospital authority. Respondents at STT (16%) and HC (16%) stipulated that waste management training was done on a monthly basis. This goes in line with [77, 78] that health workers at rural hospitals receive waste management training on a monthly basis. However, most of the health workers at HC hospital (37%) and STT hospital (42%) suggested after a month and above. Considering this, it was clear that frequency of training intervals could not be sufficient to raise awareness of health workers. People involved in managing waste from medical institutions should receive training frequently to increase their awareness (Oyekale and Oyekale, [103], Khan et al. [102]). Participants at STT (35%) and HC (26%) revealed that frequency and intervals of training were not known, hence unclear (Fig. 25). Therefore, training activities can be described as erratic, inadequate and inconsistent resulting in continuous unawareness of health workers. Unawareness of health workers on aspects related to management of solid waste is mostly owed to inadequate training and educational workshops [7, 36].

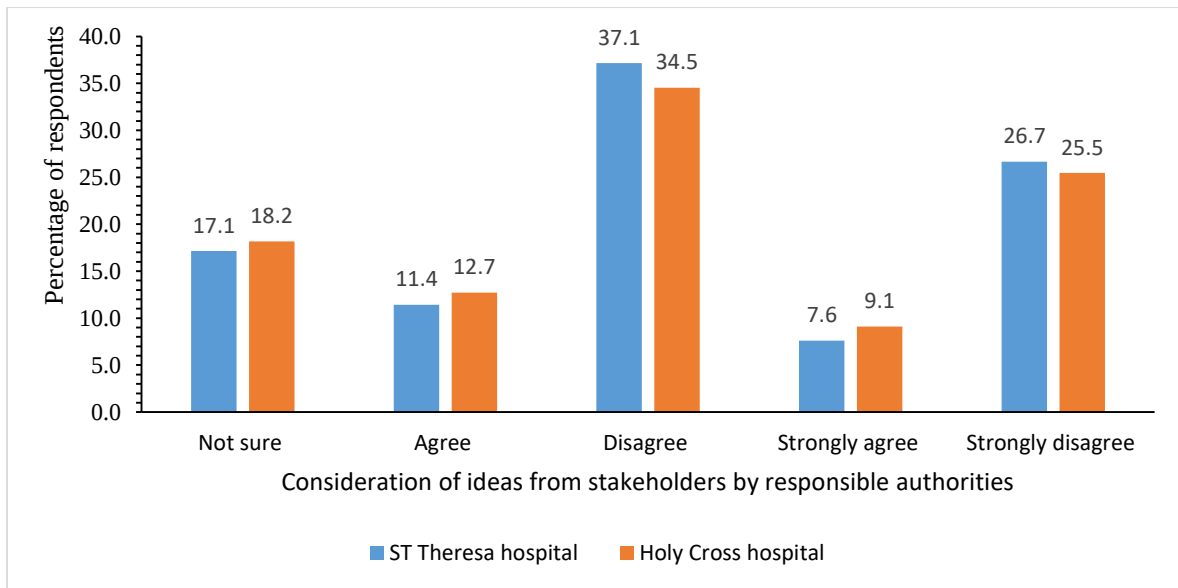


Fig. 24: Perceptions of respondents on consideration of ideas from various stakeholders during hospital solid waste management planning.

Source: Field data (2023)

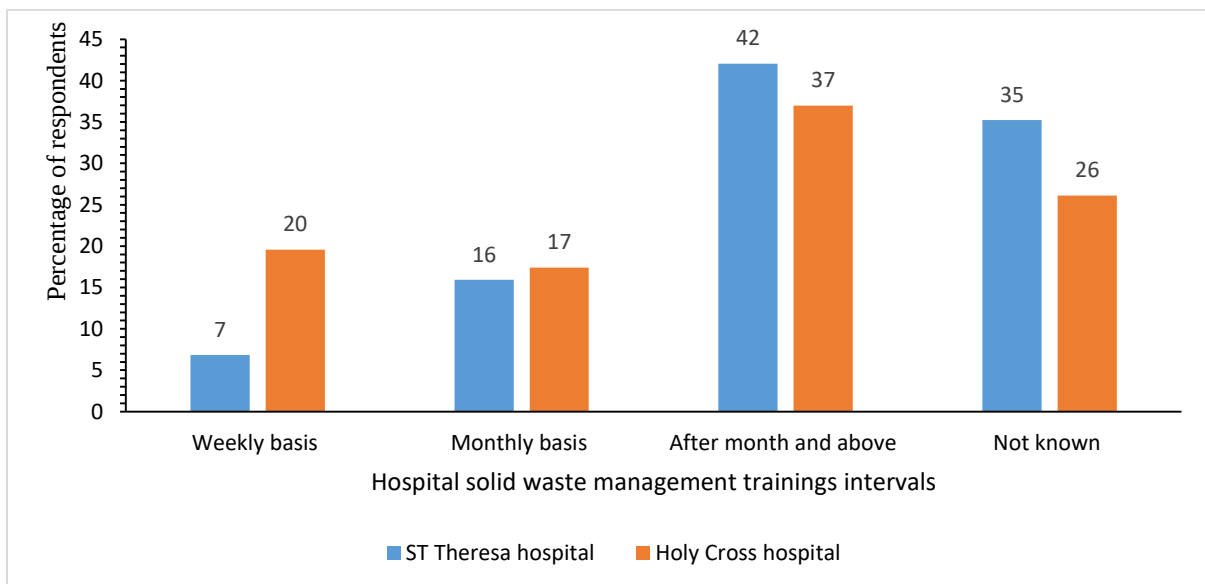


Fig. 25: Solid waste management training intervals ST Theresa and Holy Cross hospitals.

Source: Field data (2023)

3.3.7 Effectiveness of existing solid waste management approaches at ST Theresa and Holy Cross hospitals

Rating the effectiveness of hospital solid waste management strategies was carried out utilizing phrases such as low, average, high, very high and very low. A significant quantity of participants at STT hospital (31.4%) and HC hospital (30.9%) show that the effectiveness was on average (Fig. 26). This asserted that effectiveness of the management techniques was regarded as close to standard. This contradicts with participants at STT hospital (26.7%) and HC (23.6%) who suggested that the effectiveness was low. This suggests that solid waste management strategies at HC and STT hospitals are far from sustainability, hence is termed less effective. Findings congruence with research carried out at health institutions in African countries [19] and those in rural areas are encompassed. Most of the disposal approaches utilized occupy the lower base of the waste management hierarchy hence have potential to cause environmental health problems. This signifies that achievement of sustainable goals namely life below water, life on land, clean water and sanitation among others remain difficult if less attention is given to solid waste from rural hospitals.

In Zimbabwe, disposal of solid waste from medical facilities is highly centered on strategies which are least recommended by waste management hierarchy [74–78]. EMA Officer highlighted that effectiveness of solid waste management strategies at HC and STT was almost below the expected standards, particularly ZMoHCC and WHO guidelines. A view supported by [20] and Chisholm et al. [19] that management of solid waste from hospitals in developing nations usually contradicts with required standards. This was also confirmed by participants at Holy Cross hospital (18.2%) and ST Theresa hospital (18.1%) who pointed the level of effectiveness as very low (Fig. 26). This entails that solid waste management methods at STT and HC hospitals are surrounded by loopholes. Hence, from an environmental and socio-economic perspective efficiency of existing solid waste management is insufficient. Approaches to enhance efficiency of management techniques used at rural hospitals are paramount to attain the goal which calls for sustainable cities and communities. This presents the need for an integrated sustainable solid waste management framework at these hospitals. An issue also raised by [75, 76] that to achieve proper management of solid waste from hospitals an integrated framework is essential.

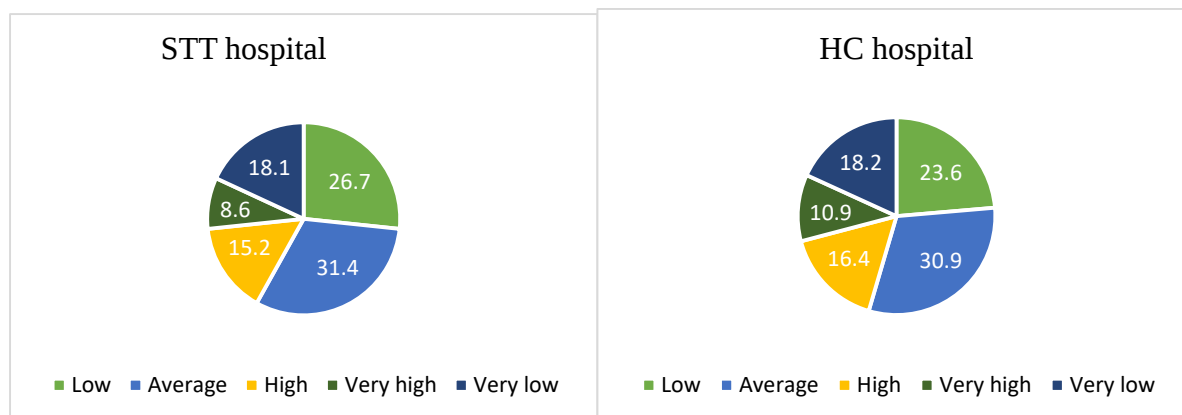


Fig. 26: Effectiveness of hospital solid waste management strategies used at ST Theresa and Holy Cross hospitals.

Source: Field data (2023)

3.3.8 Challenges in management of solid waste at Holy Cross and ST Theresa hospitals

Solid waste was increasing as noted by health workers at HC (23.6%) and STT (22.9%) hospitals (Fig. 18). The EMA Officer and hospital EHTs postulated that increase of solid waste at HC and STT hospital was a major challenge. Consequently, methods to insight health workers on how to minimize the quantity of solid waste generated at these rural hospitals are essential. According to EHTs, the management of solid waste is exacerbated by a sharp increase of waste, particularly infectious waste. To worsen the situation, the quantity of solid waste over whelmed capacity of available resources translating to improper management at rural hospitals under study. Solid waste quantity which overstrained existing resources was also noted at rural hospitals in South Africa [26]. Inappropriate management of solid waste was attributed to inadequate finance as upheld by respondents at STT (38.1%) and 30.9% at HC hospitals (Fig. 27). Financial shortages hinder availability of waste storage receptacles, construction of proper disposal sites, and provision of enough PPE/C to involved people as well as hiring of enough workers responsible for waste management at rural hospitals. Questionnaire and interview results concur that limited finance was a major barrier to achieve proper management of solid waste at STT and HC. Financial problems are also experienced at

rural health institutions in African countries like Botswana [57]. Participants at HC (20.0%), STT (15.2%) and the EMA Officer asserted that difficulties in management of solid waste was a result of unawareness among health workers. This implies that strategies to enlighten health workers about hospital solid waste issues are essential to reach sustainability. The reason being lack of awareness is among major challenges in hospital solid waste management in developing nations (Behnam et al. 2020; [80]).

In addition, respondents at HC (9.1%) and STT (10.5%) blamed responsible authorities for giving less attention to solid waste management (Fig. 27). This blame game increased fragmentation of the prevailing solid waste management system while exacerbating non-participation of other health workers in waste management issues. Results demonstrated that participants at HC (16.4%) and STT (13.3%) hospitals argued that shortage of skilled labour was among barriers faced during solid waste management. Limited availability of skilled labour increases difficulties faced during implementation of strategies which calls for appropriate solid waste management. This suggests that adoption of techniques like recycle, reuse and energy recovery methods is difficult owing to limited skills among responsible people. This is among reasons why STT and HC rural hospitals put much emphasis on management strategies which give less attention to the circular economy. Verdicts are supported by Zhang et al. [91] and Aycin and Kayapinar [13] that in the con text of solid waste management, adoption of management techniques which uphold circular economy require co-operation and involving people with required skills.

HC hospital EHT pointed out that improper separation at generation source causes various problems during solid waste management. Considering hazardous and non-hazardous characteristics of solid waste from STT and HC rural hospitals, management of mixed waste was problematic, particularly disposal. Disposal was difficult since different types of hospital solid waste needs its unique discarding technique. Inappropriate segregation intensifies problems in management of waste at rural hospitals in Darjeeling district, India [14] and at rural hospitals in Pakistan [70]. Hospital EHTs indicated use of substandard disposal infrastructure as the root cause of solid waste management complications. Utilisation of incinerators with cracked combustion chambers (Fig. 28), facilitates incomplete combustion, resulting in air pollution. Incinerator operator argued that cracking of the incinerator was attributed to use of general cement and bricks instead of fire-resistant bricks and cement. Hence, failure to include other health workers during planning was one of the challenges which fueled inappropriate disposal of solid waste at STT and HC. Findings are supported by Serge-

Kubanza and Simatele [72] and Batista et al. [15]'s studies that failure to include all stakeholders is among the root causes of waste mismanagement. To achieve sustainable management of solid waste at rural hospitals under study, hospital authorities are recommended not to overlook the need for all-stakeholder participation.

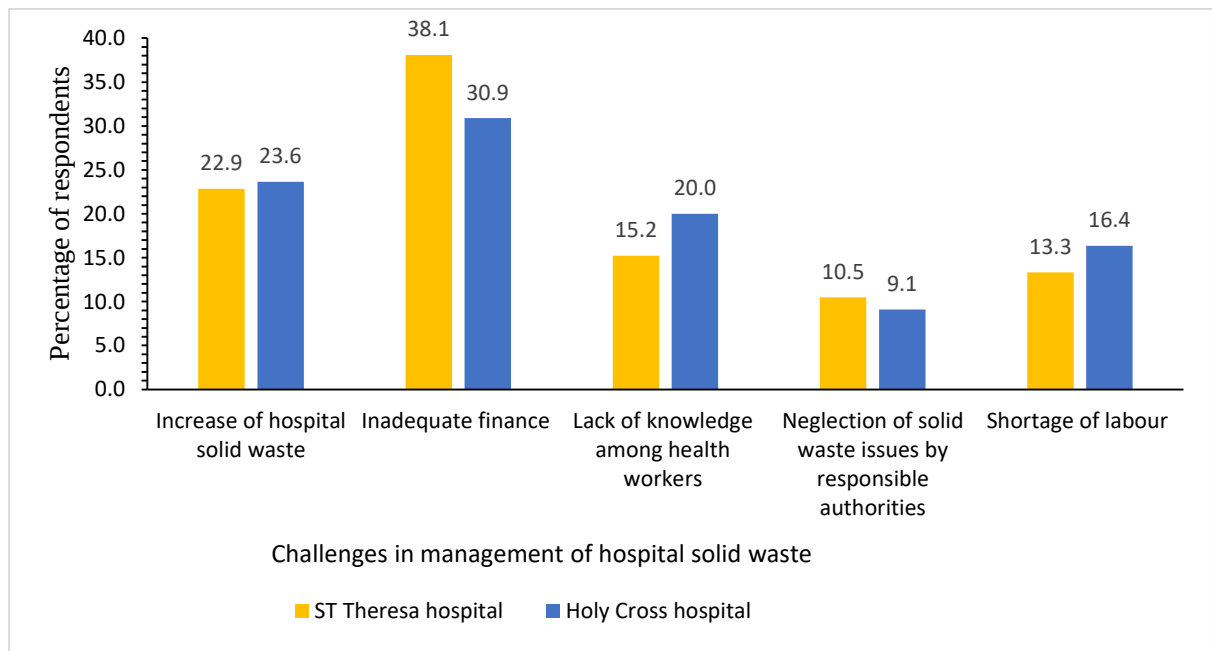


Fig. 27: Challenges faced by STT and HC hospitals in management of solid waste.

Source: Field data (2023)



Fig. 28: Cracked incinerator used to dispose solid waste at ST Theresa hospital.

Source: Field data (2023)

3.4 Conclusion and recommendations

Solid waste generated at rural hospitals in Chirumanzu district is a replica of waste from urban hospitals. STT and HC hospitals generate both hazardous and non-hazardous solid waste. Hazardous solid waste produced comprises pharmaceuticals, toxic chemicals, pathological, hospital radioactive waste, sharps and cytotoxic waste. Non-hazardous waste includes general solid waste in the form of uncontaminated papers, plastics, food remains, textiles and soft drink bottles. At STT and HC hospitals, solid waste was produced from hospital wards, kitchen, out-patient departments, emergency rooms, x-ray department, laboratory, hospital pharmacy, offices and laundry. Pharmaceutical solid waste generated encompasses contaminated and outdated drugs while pathological waste includes placentas, still foetuses and detached body parts. Sharp waste in the form of syringes, infusion sets, broken glasses, needles, razor blades, scalpels, nails, pipettes and knives were produced. Toxic chemicals like disinfectants, reagents and film developers whereas radioactive waste such as materials contaminated by radionuclides during cancer and tumour growth treatment. Infectious waste produced comprises soiled and used plaster casters, cotton wools, gloves, swabs, masks, aprons, hospital caps, beddings, dressings, goggles, and specimen containers. Infectious waste produced at the hospitals was suspected to contain pathogens.

Treatment and disinfection of infectious waste was done through chlorination and autoclaving, although the strategies were rarely applied due to indiscriminate storage of waste. Storage of non-segregated waste was observed in waste receptacles namely pedal operated bins, metal and plastic buckets and cardboard boxes. However, sharps were stored in sharp containers. Solid waste storage containers were transported to the hospital disposal site using wheelbarrows and manual handling of containers. Solid waste was disposed through open burning, dumping, incineration, and into open pits as well as auto-way pits, although solid waste was observed at illegal sites at these rural hospitals. Chirumanzu district rural hospitals are focusing much on disposal approaches which occupy the base of the waste management hierarchy. Hence disposal techniques have potential to cause air, soil, water contamination while exposing people to respiratory, skin and intestinal health problems. Relying on these disposal strategies at rural hospitals is attributed to various challenges namely inadequate finance, skilled labour, lack of commitment among responsible authority and insufficient awareness among health workers. Although the scenario is worsened by limited participation of all health workers in waste management issues. As a result, from an environmental perspective, existing management strategies are far from sustainability demands. To narrow the gap to achieve

sustainable solid waste management at these rural hospitals, an integrated approach is significant. There is a need for Environmental Management Agency Officers, Hospitals Environmental Health Department staff, all health workers to collaborate and deal with the existing situation. ZMoHCC and the Zimbabwe Ministry of Finance must work together to channel enough resources to solid waste management at rural hospitals, particularly STT and HC. Enough resources enable hospitals to invest in waste management approaches which support a circular economy, thus propelling economic growth while limiting the quantity of disposed waste.

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Chapter 4

Environmental Health Risks Associated with Solid Waste Management at Rural Hospitals in Chirumanzu District, Zimbabwe

Takunda Shabani¹ · Vurayayi Timothy Mutekwa¹ and Tapiwa Shabani¹

¹Midlands State University, Department of Geography, Environmental Sustainability and Resilience Building, P. Bag 9055 Gweru, Zimbabwe.

Corresponding Author: Shabani Takunda, Email: shabstaku@gmail.com

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Abstract

Management of hospital solid is currently a critical and challenging issue worldwide, particularly in developing nations due to population growth, disease outbreak and hospital solid waste increase. The issue is more complex at rural hospitals in Zimbabwe owing to limited resources. This paper focuses on understanding environmental health risks associated with solid waste management strategies utilised at rural hospitals in Zimbabwe. Descriptive cross-sectional design that employs qualitative and quantitative paradigms was used for data collection, analysis and presentation. Questionnaires, observations, interviews and secondary data sources were utilised to solicit data. Water and soil samples were collected and tested for heavy metals presents. Statistical Package for Social Sciences and content analysis were used to analyse quantitative and qualitative data respectively. HC and STT hospitals generate pharmaceutical, chemical, radioactive, cytotoxic, sharps, infectious, pathological, general waste, construction, demolition and electronic waste. Management of hospital solid waste was based on traditional linear approach following storage, collection and disposal, although reuse and composting were applied. Open pits, open burning, incinerators, open burning and auto-way pits were used as disposal strategies. Disposal strategies used pose soil, water and air contamination while exposing people to injuries, diseases and musculoskeletal disorders. Enhancement of solid waste management at these rural hospitals require adequate resources, raising awareness of health workers, use of current technology, collaboration of responsible stakeholders and provision of proper Personal Protective Equipment/Clothing to health workers.

Keywords: ST Theresa (STT) · Holy cross (HC) · Rural hospitals · Hospital solid waste · Management strategies · Environmental health risks · Management challenges

4.1 Introduction

Solid waste management refers to elements such as waste segregation, storage, collection, transportation, recovery and disposal as well as monitoring of disposal sites (Jerie and Tevera 2014; Yadav and Karmakar 2020). This implies that solid waste management comprises a series of activities that require adequate attention to avert cropping up of environmental health risks. However, solid waste management is emerging as a critical and threatening problem globally due to its increase, attributed to rapid urbanisation, industrialisation and population increase (Meena et al. 2023; Yadav and Karmakar 2020). A condition fuelled by outbreak of diseases (Yousefi et al. 2021). Considering this, hospital solid waste increase is not spared since diseases are among critical drivers of solid waste volume upsurge. A view upheld by Kalantary et al. (2021) and Das et al. (2021) that outbreak of diseases increases hospitalisation of people, translating to high generation of hospital solid waste. Increase of hospital waste is particularly inevitable in the twenty-first century since pandemics and epidemics are common. Currently, COVID-19 pandemic is among major drivers of hospital solid waste quantity escalation and quality changes in developed and developing countries (Yousefi et al. 2021; Daset al. 2021). Nevertheless, due to its communicable nature COVID-19 accelerate generation of infectious waste.

Ansari et al. (2019) and Shabani and Jerie (2023) coincide that hospitals generate different types of solid waste namely pathological, sharps, infectious, pharmaceutical, radioactive and general waste. Therefore, since hospital solid waste types differs, environmental health impacts associated with each type of waste varies. Additionally, in light of the indicated waste categories, it is clear that hospitals generate perilous and non-perilous solid waste. This goes in line with Kalogiannidou et al. (2018) and Rahman et al. (2020) that hospital solid waste consists of 15% hazardous and 85% non-hazardous waste. Owing to its characteristics, hospital solid waste has potential to affect various environmental components while human health is not spared. Inappropriate management of hospital solid waste specifically disposal cause air, water, soil pollution (Ansari et al. 2019; Nzediegwu and Chang 2020) while diminishing land's aesthetic value (Shabani and Jerie 2023). This entails that poorly monitored hospital solid waste poses detrimental effects to atmospheric, aquatic and terrestrial ecosystems. Ansari et al (2019) and Basak et al., (2019) coincide that hospital solid waste particularly sharps expose human beings to pricks and piercing. These percutaneous sharp injuries facilitate progression of

diseases since sharps are part of infectious waste. Improperly handled sharp waste increase the spread of some deadly diseases namely HIV and AIDS, Hepatitis B and C and tuberculosis (Edrees 2022; Janik-Karpinska et al. 2023).

Management of hospital solid waste require adequate attention to minimise environmental health risks associated with hospital waste. Recognising this, developed countries such as Canada and United State implemented strategies that support sustainable management of solid waste (Nzediegwu and Chang 2020). This congruence with Adelodun et al. (2021) and Ganguly and Chakraborty (2021) that in developed nations management of hospital solid waste is close to recommended standards since policies, strategies and legislations which support integrated management of waste exist. As a result, management of hospital solid waste meet demands of Agenda 21 and Sustainable Development Goals (SDGs), thus averting unnecessary cropping of environmental health risks. In developed nations such as Austria, Sweden, United Kingdom solid waste including hospital solid waste is managed through processes like pyrolysis and gasification (Kumar and Samadder 2017; Munir et al. 2021). Application of pyrolysis and gasification present to be feasible options compared to conventional approaches, since these processes facilitates conversion of solid waste to energy. Additionally, their policies and legislations support clear medical solid waste categorisation during storage as well as conveyance (Nzediegwu and Chang 2020; Munir et al. 2021). Segregation of hospital solid waste facilitates proper disposal of waste according to their characteristics translating to minimised environmental health problems. However, due to improper management of hospital solid waste, reduction of associated environmental health risks is difficult in developing nations like Pakistan (Ahmad et al. 2019) and Bangladesh (Basak et al. 2019).

Improper management of hospital solid waste in low-income countries is attributed to fragmented weakly enforced policies, shortage of resources and waste increase (Adelodun et al. 2021; Das et al. 2021). Increase of solid waste overwhelm available budget and resources set aside for hospital solid waste management. Nevertheless, Ahmad et al. (2019) and Adelodun et al. (2021) concur that this scenario is fuelled by application of traditional closed system in management of hospital solid waste. This management system gives less attention to integrated approach and participation of various stakeholders in management of hospital solid waste. Mismanagement of hospital solid waste in developing countries is generally a result of

economic, political and social problems (Ansari et al. 2019; Basak et al. 2019; Chisholm et al. 2021). Nonetheless, rural hospitals are highly affected by challenges in management of hospital solid waste due to lack of resources, expertise and solid waste increase (Ahmad et al. 2019; Yousefi et al. 2021). A situation noted by Ahmad et al. (2019) at rural hospitals located in remote regions of Pakistan such as Swat District. As a result of limited resources solid waste from rural hospitals is managed following some of the strategies with potential to cause detrimental impacts to the environment.

According to Thakur (2021) management of hospital solid waste in rural areas can be termed unorganised when compared to strategies applied in semi urban and urban areas. Considering this assertion, hospital solid waste management techniques used in rural areas is far from sustainability, hence can pose air, water and soil contamination. In African nations such as South Africa and Botswana co storage and indiscriminate disposal of hospital solid waste is common (Chisholm et al. 2021). This implies that disposal of non-segregated waste is also norm of the twenty-first century at rural hospitals, since they are not spared by regional and national situations. Rural hospitals usually dispose non segregated or treated solid waste using substandard incinerators and through open burning, burying and open pits in countries like Uganda (Kwikiriza et al. 2019) and Malawi (Mmanga et al. 2019). This entails that rural hospitals are mostly utilising disposing strategies which occupy the base of waste management hierarchy and those in Zimbabwe are not excluded. In Zimbabwe hospital solid waste management is far from acceptable standards as exhibited by haphazard collection and disposal by municipalities (Jerie 2006; Mangizvo and Chinamasa 2008; Shabani and Jerie 2023). The scenario tends to be worse in rural areas including rural hospitals since they are not covered by solid waste legislation such as Urban Council Act (Chapter 15:09) (Shabani and Jerie 2023).

According to Jerie (2013) Zimbabwe Urban Council Act (Chapter 15:09) stipulate that urban local authorities are responsible for offering services such as waste management services to areas under their authority. Municipalities or urban local authorities also give concern to institutions like hospitals in zones under their juris diction in urban areas. Henceforth, solid waste management services in Zimbabwe are skewed in favour of urban hospitals, giving less attention to rural hospitals. Therefore, nearly incapacitated rural hospitals in Zimbabwe shoulder the burden of managing their own solid waste. This cause improper management of

solid since according to Mangwanya (2019) and Roets et al., (2020) Zimbabwean rural hospitals are experiencing challenges including shortage of labour, finance and resources. Consequently, little available resources and finance is directed to department which deals with treatment of patients while neglecting management of solid waste. As a result, management of solid waste is overlooked at rural hospitals, resulting in treatment and disposal of solid waste using some of the rudimentary approaches with potential to affect the natural environment and human health. Therefore, solid waste generated by rural hospitals in Zimbabwe yawns for attention in order to understand environmental and health risks associated with utilised management approaches. In light of this, the research's objectives were to characterise hospital solid waste generated by rural hospitals, to examine hospital solid waste management strategies and analyse environmental health risks associated with hospital solid waste management in rural hospitals of Zimbabwe.

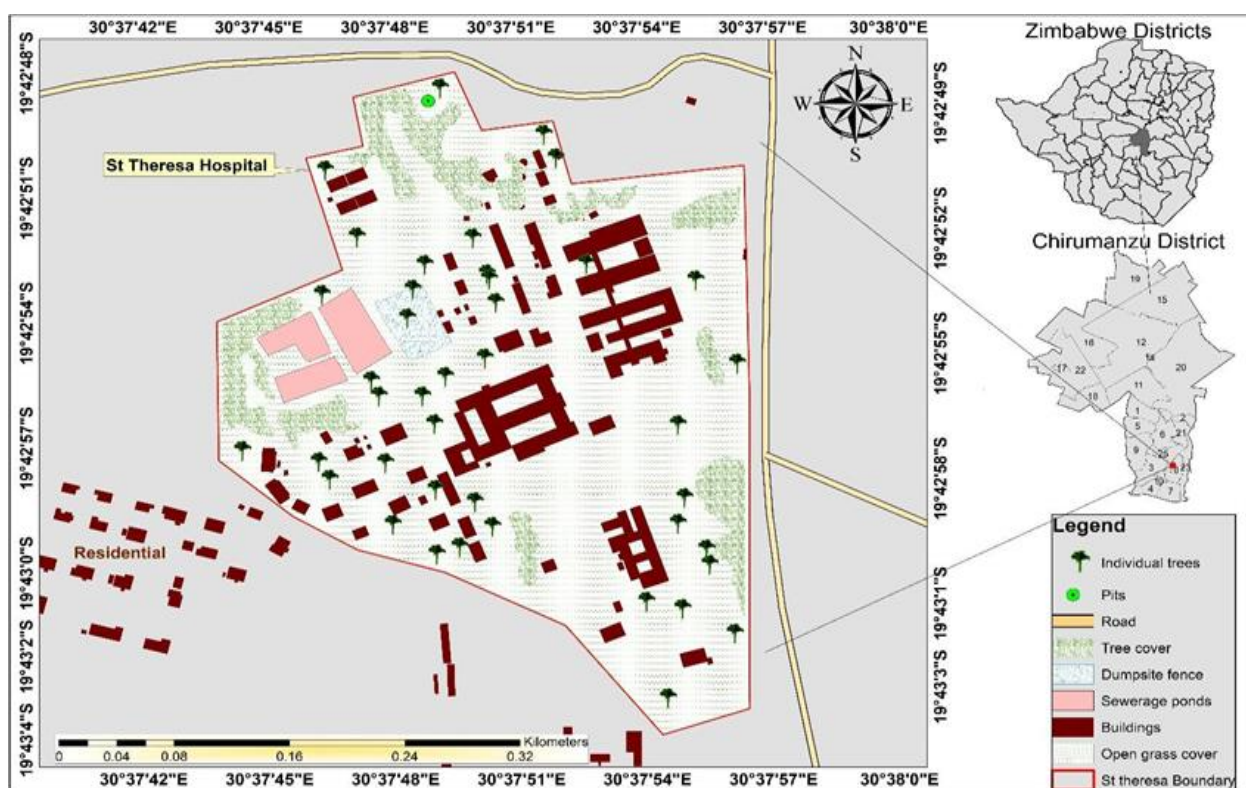
4.2 Materials and methods

4.2.1 Description of the study area

The research was carried out in Chirumanzu rural district located in the Midlands province, Zimbabwe. The district occupies 4.737 square kilometres of Midlands's province (Kori et al. 2013). The district is in agro-ecological zone 3, receiving average rainfall of 650 mm annually with an average temperature between 24 and 30 °C (Mugandani et al. 2012). The district is mainly covered by sandy loam soil which supports vegetation species such as *Brachystegia* specieforms like *Musasa* (Mar ambanyika et al. 2021), *Julbernadia globiflora* like Mutondo, and *Colospermum* (mopane) (Matsa and Dzawanda 2014) and patches of grass (Fakarayi et al. 2015). Moreover, population in the district grows at 1.2% per annum and its population is around 95,272 with 45,589 males, 49,683 females and 24,556 households (ZIMSTAT, 2022). Continuous growth of population and their need for health services add burden to hospitals leading to generation of large volumes of solid waste. The Chirumanzu population is served by clinics namely Nyautonge, Chizhou, Siyahokwe, Mhende, Doroguru, Hwata, Hama, Chimbindi and Chengwena. Rural hospitals in Chirumanzu district include ST Theresa, Holy Cross, Muvonde and Sanatorium. Nevertheless, the study focuses on ST Theresa (Map 1) and Holy Cross (Map 2) hospitals which are in ward 8 and 6 respectively.

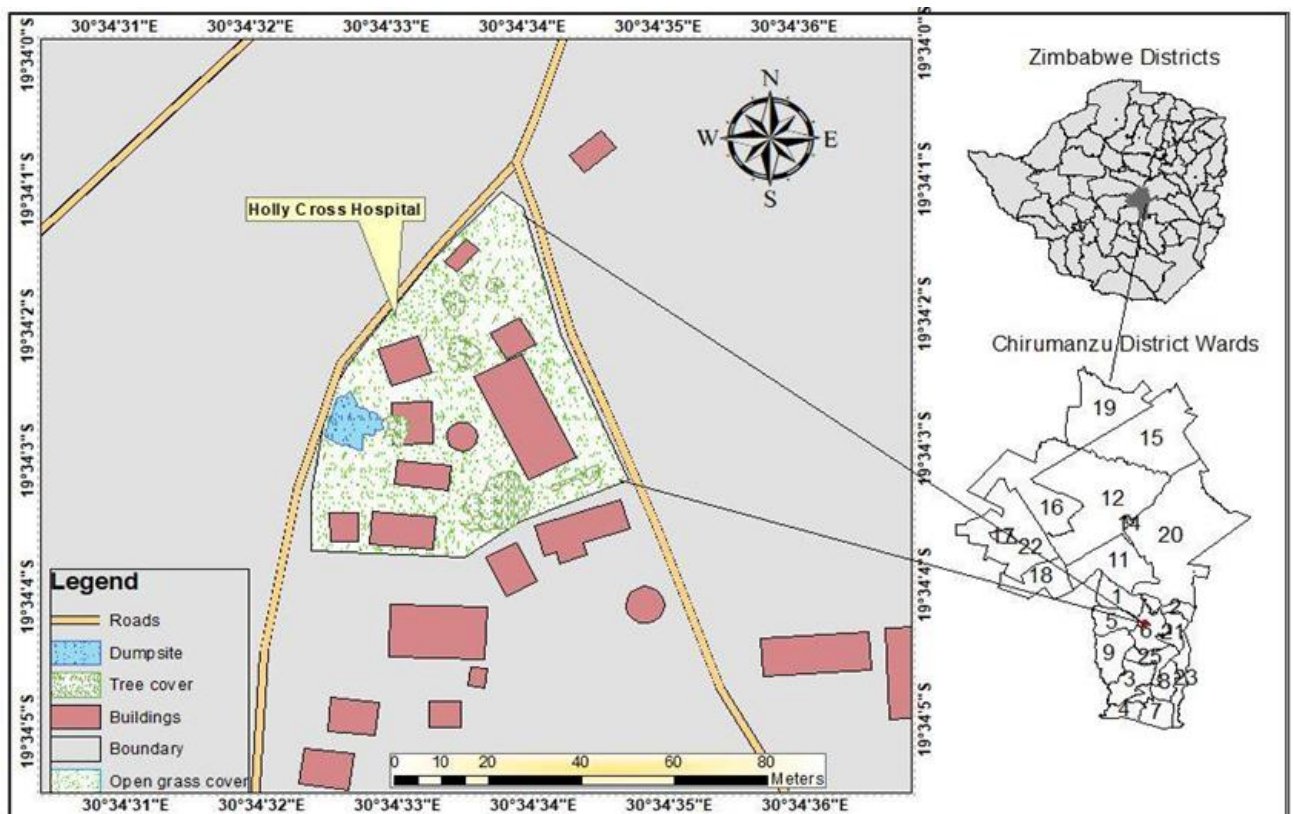
According to ZIMSTAT (2022) total population of ward 8 is approximately 3156 while ward 6 houses 3478 people. ST Theresa hospital was constructed in 1958 with a bed capacity of 80 while Holy Cross hospital was constructed in 1960 with a bed capacity of 50. The two hospitals

consist of different wards notably female, male, paediatric, maternity, isolation wards and departments such as administration, outpatient, family health clinic, laboratory, pharmacy, physiotherapy, doctors' offices and emergence rooms. This implies that a large number of people can be served at the hospital, therefore generation of high quantity of diverse hospital waste is inevitable. Holy Cross and ST Theresa hospitals were purposively selected since the hospitals also receive patients from health institutions in the primary level within the district and beyond. The hospitals are located in communal areas with high population density hence serve large number of people translating to hospital solid waste increase.



Map 1: Map showing location and characteristics of ST Theresa hospital in Chirumanzu district.

Source: Geographic Information System map derived from Google Earth image by the Author



Map 2: Map showing location and characteristics of Holy Cross hospital in Chirumanzu district.

Source: Geographic Information System map derived from Go ogle Earth image by the Author

4.2.2 Methods of data collection and analysis

Descriptive cross sectional research design that employs qualitative and quantitative paradigms in data collection, analysis and presentation was adopted. Health workers namely nurses, doctors, physiotherapists, laboratory technicians, radiologic technologists, eye-opticians, cleaners and anaesthetist were targeted as questionnaire respondents. Targeted health workers were 147 and 64 at STT and HC respectively. Sample size for questionnaire survey was determined using Taro Yamane (1967) formula, translating to 105 at STT and 55 at HC hospitals. Utilisation of stratified sampling procedure facilitates division of health workers into groups according to their occupation at hospitals. Representatives of each stratum was proportionally determined basing on strata size using Bowley (1926)'s formula:

$$\frac{\text{Required Sample Size}}{\text{Population size}} \times \text{stratum size}$$

Individuals for each stratum were numbered and computer-generated random table was used to select strata representatives. District Medical Officer (DMO), Environmental Management Agency (EMA) Officer, Hospital Environmental Health Technician (EHT), Hospital Head of Cleaning Department/ Supervisor and Hospital Matron were purposively selected as key informants.

Questionnaires and interviews were used to collect data regarding types of hospital solid waste, management systems and challenges, environmental problems associated with solid waste and strategies to minimise the problems. Questionnaires were administered from 07 March to 14 March 2023. Observations were used to collect data on hospital solid waste characteristics, management approaches, potential environmental health risks and fauna with access to disposal sites. Data regarding type of fauna and waste they consume necessitate predicting of health risks that may affect fauna and how pollutants accumulate in the food chain. A digital camera was utilised to capture photographs during observations. Data on flora was collected through the use of transect lines and quadrants. Data on flora facilitates understanding potential effects of dumpsite pollutants on vegetation. According to the US EPA (2020) pollutants have the potential to spread up to 500 meters from the dumpsites. Therefore, water samples were collected in March and May 2023 from groundwater sources within a radius of 500 meters from the dumpsite centre. A focus on groundwater was driven by Burri *et al.*, (2019)'s view that the current anthropocene era is witnessing ground water quality deterioration. However, water source with least distance from the Holy Cross and ST Theresa hospital waste site and the one with highest distance were purposively selected, translating to 2 water samples at each hospital under study. The purpose for selecting these water sources is to enable determination of the spatial distribution of pollutants in ground water around the dumpsites used by each hospital under study. Soil and water samples were collected and submitted to the laboratory for analysis to understand impacts of disposal sites pollutants to soil and proximity water sources.

Quantitative data was analysed using SPSS version 25.0 at 95% confidence level. Descriptive statistics such as mean, frequencies and mode were used to show response rate for questionnaires. Chi-square was used to test association between quantity of solid waste and number of patients. Quantitative data was presented in the form of tables, charts and graphs. Geometric and attribute data was collected using GPS and analysed using GIS by overlaying proximity to dumpsite, landuse/cover and slope to determine vulnerability of attributes to

dumpsite pollutants. Water samples were subjected to laboratory analysis to test P.H, electrical conductivity, chemical dissolved demand and total dissolved solids. Similarly, soil and water samples collected was submitted to the laboratory to be tested for lead (Pb), Arsenic (Ad), mercury (Hg) and cadmium (Cd) levels. T-test was carried out at T-test was carried out at $p < 0.05$ and 95% confidence level to compare pollutants concentrations in soil and water samples collected from various distances from the waste site. Results from water and soil sample analysis was analysed by comparing them with WHO water and soil quality standards. Qualitative data was analysed through content analysis and presented using expressive and persuasive narratives as well as direct and indirect quotations.

4.2.3 Research Ethics

Ethics were highly observed through obtaining detailed clearance documents from Midlands State University Department of Geography, Environmental Sustainability and Resilience Building. Permission to carry out investigation at the rural hospitals was granted by Chirumanzu District Medical Officer (DMO), since the DMO is a governor of all health institutions in the district. However, the researcher sought permission from the hospital matron at each hospital, so that the researcher was introduced to everyone at the hospital to reduce conflicts during data collection. Participants were verbally informed about the motive and importance of the research so that they voluntarily participate or reject. Informed consent is crucial so that participants are free to opt in or out of the study at any point of time (American Psychological Association, 2017). This can enable research participants to gain confidence since clear explanations reduce psychological risks. Individuals who participated in the research were respected and guaranteed that the collected information was solely for academic purposes, not meant to exploit them. This creates a merit to the researcher since the respondents provided adequate data which suits research objectives. Respondents were named by numbers to observe the issue of confidentiality and anonymity. Authorisation to record audios during interviews was requested from the interviewee to comply with data protection policy. In order to curb piracy secondary data sources were accredited to their specific authors through in-text and end-text citation.

4.3 Results and discussion

4.3.1 Socio-demographic characteristics of respondents

Majority of questionnaire respondents at HC and STT hospitals were females than males (Table 1). Gender disparity can be explained by that culturally and socially females are interested in offering health services compared to males. Females are perceived as caregivers in societies, which might be the reason for their dominance during questionnaire survey at these hospitals. Females are in the forefront of offering health services to people with various ailments (Drennan and Ross 2019; Murat et al. 2021). Respondents at both hospitals consist health workers of different age groups (Table 1) for instance 18–26 years and 45 to 53 years. Thus, including those with significant work experience and new workforce. This translates to variation in terms of knowledge, awareness and perspectives towards hospital solid waste management among health workers. Educational level of HC and STT hospital health workers varies since it includes people with certificates, diplomas, degrees, masters and those who reach secondary level (Table 1). This explains differences in awareness of health workers towards hospital solid waste management. Differences in level of education entails that a comprehensive solid waste management framework which consider level of knowledge of all health workers is required. Work experience of health workers at hospitals under study was different, some with 0 to 5, 6 to 11 and 12 + years of work experience (Table 1). This could potentially affect hospital solid waste management, since generally health workers with more work experience have better understanding of solid waste issues. Their knowledge is probably enhanced by having attending more trainings and workshops related to hospital solid waste management than those with less experience.

Table 1: Socio-demographic data of healthcare workers at STT and HC hospitals.

Variable	Response category	Respondents at each hospital			
		STT Hospital		HC Hospital	
		Frequency	%	Frequency	%
Gender	Males	39	37.1	24	43.6
	Females	66	62.9	31	56.4
Age	18-26	14	13.3	6	10.9
	27-35	31	29.5	12	21.8

	36-44	23	21.9	17	30.9
	45-53	26	24.8	11	20.0
	54 ⁺	11	10.5	9	6.4
Educational level	Secondary	9	8.6	10	18.2
	Certificate	20	19.0	13	23.6
	Diploma	63	60.0	29	52.7
	Degree	7	8.6	3	5.5
	Masters	4	3.8	0	0
Work experience (years)	0-5	56	53.3	13	23.6
	6-11	33	31.4	31	56.4
	12 ⁺	16	15.2	11	20.0

Source: Field data (2023)

4.3.2 Characteristics of generated hospital solid waste

Broad categories of solid waste produced at STT and HC hospitals was pharmaceutical, sharps, infectious, pathological, cytotoxic, radioactive, chemical and general solid waste (Table 2). Results are similar to other rural hospitals in Uganda (Kwikiriza et al. 2019) and India (Vitthal et al. 2015). Interviews, observations and questionnaire results indicated that each category of hospital solid waste was represented by various components (Table 2). Considering Table 2, these two hospitals produce non-hazardous and hazardous waste which require proper segregation to enable sustainable management. General solid waste produced include food waste, stationary, boxes, water and drink bottles. These hospitals produce a certain proportion of solid waste which can be reused, recycled or composted. This can be achieved if hospital solid waste is properly segregated. Existence of various waste categories (Table 2) entails that integrated management approach is required to achieve sustainability. The two institutions produced electronic waste and waste in form of builder's debris, broken bricks and tiles. Hospitals are also sources construction and demolition (Shabani and Jerie 2023).

Table 2: Hospital solid waste generated at STT and HC hospitals.

Major types of solid waste generated	Components of the solid waste
Pharmaceutical	Outdated/expired drugs, soiled drugs (tablets), remains of drugs, defective tablets, empty containers and sachets of drugs/medicine
Sharps	Iron/steel nails, surgical knives, hypodermic needles, syringes with needles, broken glasses, infusion tubes or sets, blades, slides, pipettes and metal scrap
Infectious	Culture/specimen containers, contaminated (cotton wool, gauze, mattresses, cotton swabs, plaster casters and bed linen), soiled gloves, towels, masks, gowns, bandages, diapers, pads and theatre caps
Pathological	Severed limbs, health and unhealthy tissues, body parts and organs
Cytotoxic	Remains of cytotoxic drugs, materials contaminated by materials used to suppress cells growth and cancer
Radioactive	Unsealed radio nuclides, materials contaminated by radioactive materials and absorbent paper
Chemical	Containers of chemicals such as reagents, disinfectants
General	Food waste (sadza, vegetables, maize cobs and fruits), stationary (files, papers, book covers), water and drink bottles, package materials (empty boxes, plastics)

Source: Field data (2023)

4.3.3 Generation trend and quantity of solid waste

Figure 1 shows respondents' perceptions on hospital solid waste generation trends. Approximately more than half of the respondents 53.3% at STT and 50.9% at HC hospitals agree that solid waste was increasing. A scenario indicated by the DMO and hospital Matrons during interviews. Hospital solid waste increase was ascribed to increase of patients, special diagnosis procedures and disposal of outdated materials (Fig. 2). High use of disposable PPE/C was highlighted by a significant number of respondents at HC (42.5%) and 35.1% at STT hospital. This means, utilisation of non-reusable materials to curb spread of infectious diseases was accelerating generation of solid waste at these two hospitals. Adoption of single use approach when using hospital PPE/C contributed to increase of hospital solid waste (Kalantary et al. 2021). Increase of patients was pointed as one of the driving forces since besides generating solid waste during diagnosing those patients, their visitors produced solid waste particularly food waste, paper and plastics.

Hospital solid waste generated was dominated by general solid waste accounted for 77.35% at STT hospital and 79% at HC hospital (Fig. 3). Large volumes of solid waste were similar to household general waste, hence the materials can be recycled and reused. Infectious, cytotoxic, sharps, radioactive, pharmaceutical, pathological and chemical waste's total accounted for 22.65% at STT hospital and 21% at HC hospital (Fig. 3). Therefore, a small proportion of solid waste generated at these hospitals was hazardous. Existence of hazardous and non-hazardous solid waste at STT and HC hospitals emphasises the significance of effective solid waste segregation during storage, treatment and disposal. Results were slightly similar to other studies that about 75 to 90% of hospital solid waste is non-hazardous while 10 to 25% is hazardous (WHO 2014; Behnam et al. 2020; Agamuthu and Barasarathi 2021). Disparity of hospital solid waste composition at these health facilities means sustainable integrated management approach is required to manage different types of solid waste effectively.

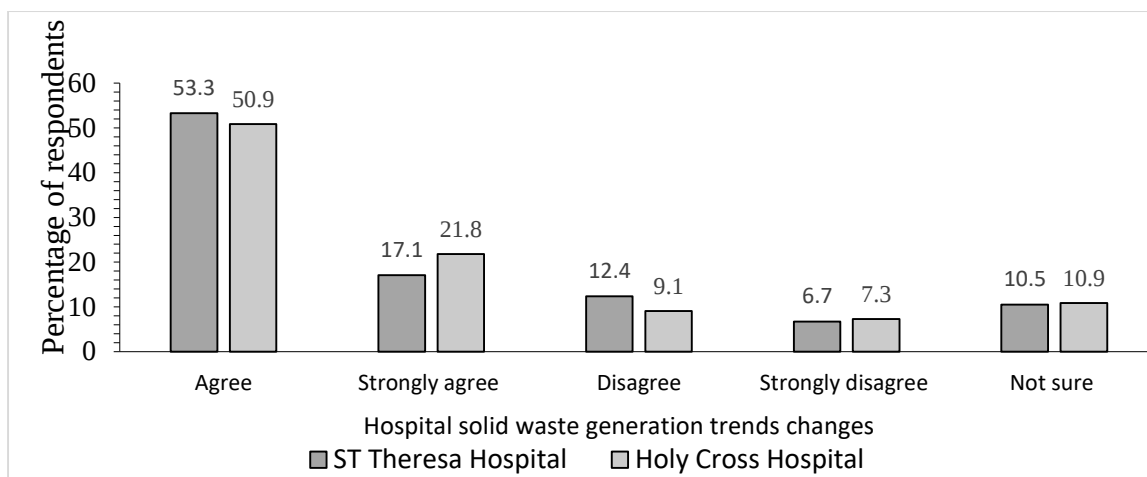


Fig. 1: Respondents' perceptions on hospital solid waste generation trends changes.

Source: Field data (2023)

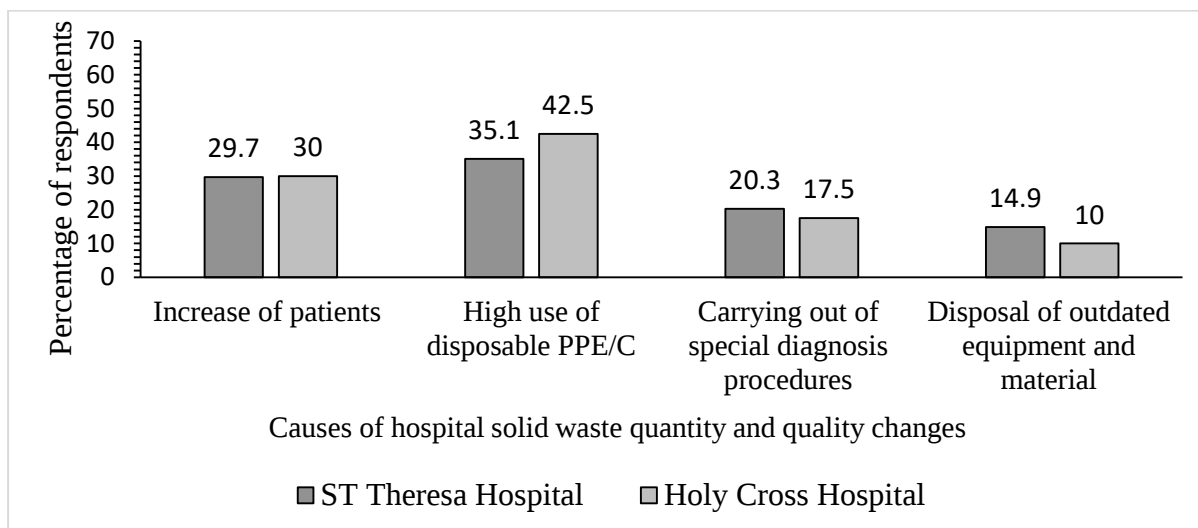


Fig. 2: Causes of hospital solid waste quantity and quality changes.

Source: Field data (2023)

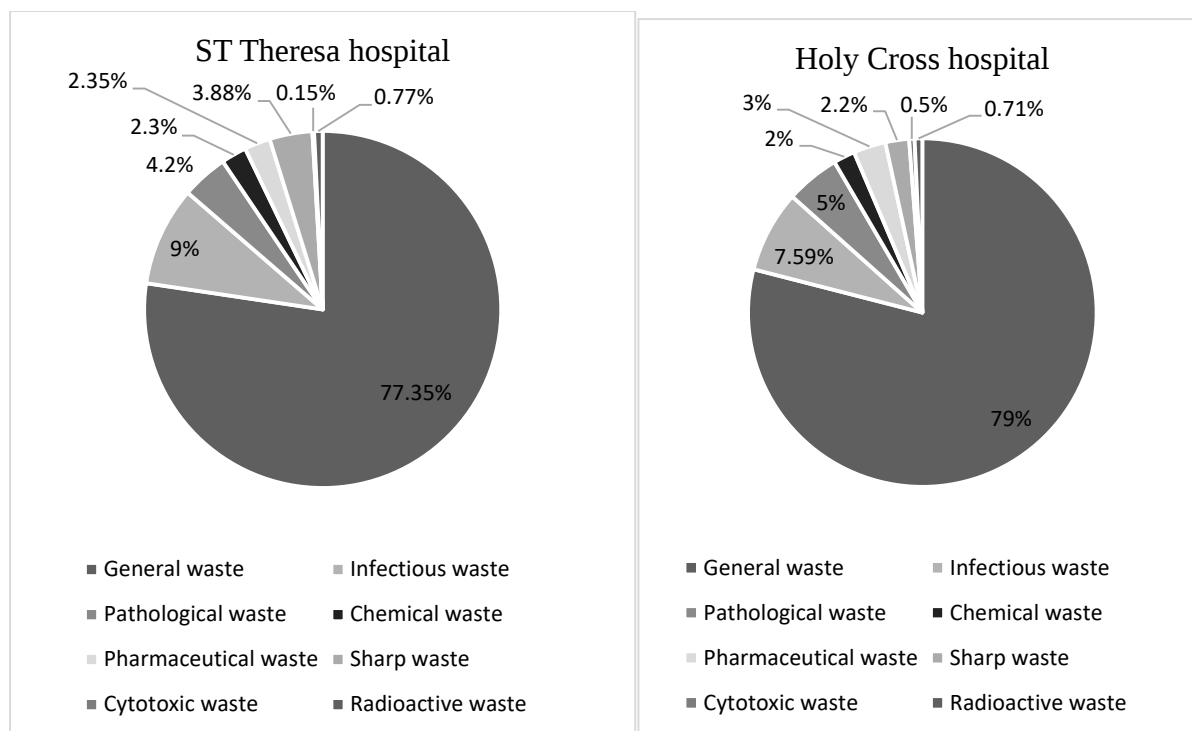


Fig. 3: Average composition of hospital solid waste generated per week (% by weight).

Source: Field data (2023)

4.3.4 Relationship of hospital solid waste generated and number of patients

Verdicts in Table 3 demonstrated quantity of hospital solid waste generated. The table indicated that when the number of patients was high, the quantity of waste was also high. Similarly, when low quantity of solid waste was produced when number of patients was low. This presents an undeniable relationship between number of patients and hospital solid waste increase. This was supported by Pearson Chi-square test results which indicated that there was association between quantity of hospital solid waste generated and number of patients. Pearson Chi-square test of data collected at STT hospital and HC hospital indicated that χ^2 cal was 0.000, which is less than 0.05. Quantity of solid waste from health facilities is usually directly proportional to number of patients (Ansari et al. 2019; Das et al. 2021; Sangkham, 2020).

Table 3: Quantity of hospital solid waste produced in relation to number of patients.

Hospital Name	Days when data was collected	Number of admitted patients per day of data collection	Quantity of waste generated per day (Kg) per each day of data collection
HC	1	46	38.18
	2	41	34.03
	3	36	29.88
	4	43	35.69
	5	33	27.39
	6	38	31.54
	7	29	24.07
STT	1	91	79.17
	2	88	76.56
	3	68	59.16
	4	77	66.99
	5	83	72.21
	6	61	53.07
	7	54	48.72

Source: Field data (2023)

4.3.5 Hospital solid waste management approaches

4.3.5.1 Types of hospital solid waste storage receptacles used

Solid waste storage receptacles used at HC and STT hospitals include cardboard boxes, plastic bags, metal and plastic buckets, sharp containers and pedal operated bins (Fig. 4). Findings coincide with research carried out by (Theodore and Theodore, 2021) and (Lemma et al. 2021). A considerable number of respondents at STT (72.4%) and HC (69.1%) highlighted use of sharp containers and pedal operated bins. Popularity of sharp containers was probably attributed to its characteristics namely puncture resistant materials which facilitate storage of sharps. Dominance of pedal operated bins was ascribed to its hygienic nature where bins are opened without using hands, thus minimising potential risk of cross infection. In terms of hospital solid waste segregation at storage level, majority of respondents at STT (35.2%) and 67.3% at HC hospital indicated infectious and non-infectious (Fig. 5). This suggest that hospital

contaminated materials and non contaminated materials were stored in distinct waste receptacles. Although, other health workers asserted that solid waste was separated into sharps and non sharps during storage (Fig. 5). In most hospitals, solid waste is separated into infectious and non-infectious as well as sharps and non sharps (WHO 2014; Theodore and Theodore 2021). Hospital solid waste was also separated into organic and non organic waste as noted by 23.8% respondents at STT hospital and 25.5% at HC hospital. This entails that non degradable and degradable useless materials were stored in separate receptacles. Nevertheless, at STT and HC hospitals core storage of solid waste was observed, where food waste, plastics and papers were stored together. Solid waste is indiscriminately stored at most medical institutions in Zimbabwe (Shabani and Jerie 2023).

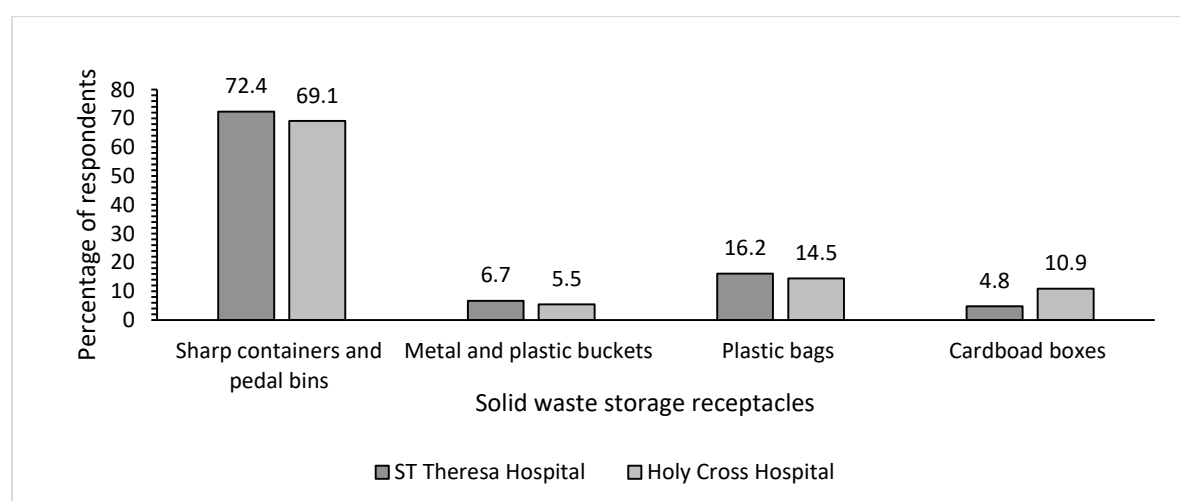


Fig. 4: Types of hospital solid waste storage receptacles used.

Source: Field data (2023)

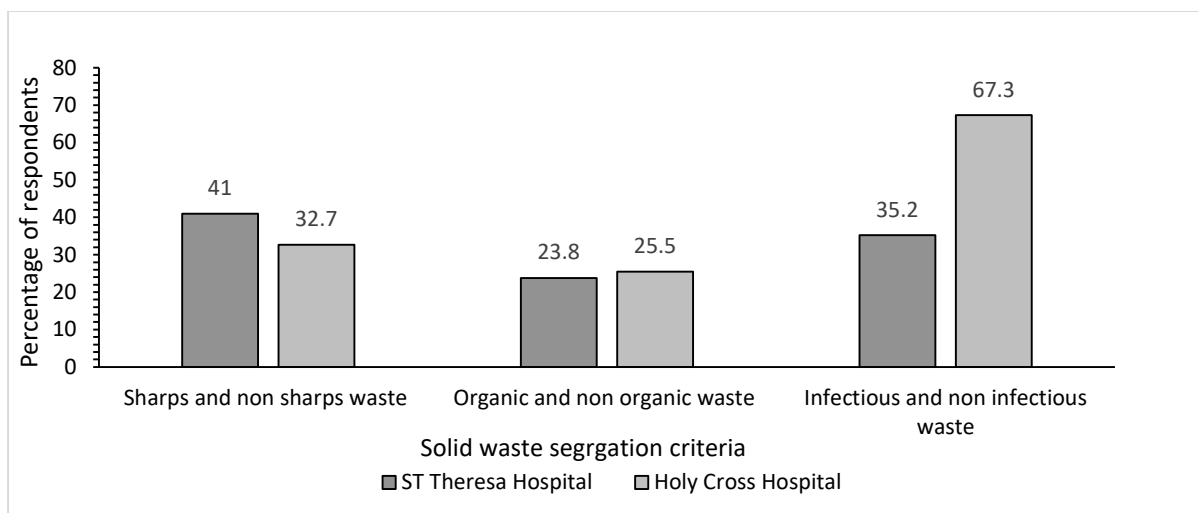


Fig. 5: Hospital solid waste segregation during storage.

Source: Field data (2023)

4.3.5.2 Treatment of hospital solid waste

Highly infectious hospital solid waste particularly from isolation wards was disinfected through autoclaving and chlorination. This asserts that these hospitals are applying other approaches which destroys pathogens, thus minimising impacts of infectious waste on human well beings. Treatment of medical solid waste through chlorination and autoclaving is necessary to destroy micro-organisms on infectious solid waste (Gupta 2022). In countries with limited resources chlorination and autoclaving are usually used to treat solid waste expected to contain bacteria, fungi and virus (Ansari et al. 2019; Chisholm et al. 2021). This might be the reason behind high utilisation of chlorination and autoclaving at STT and HC rural hospitals. Although, results from interviews indicated that use of autoclaving machine was hampered by power shortages owing to load shedding experienced in the country, hence chlorination remains the chief treatment method. In developing nations, chlorination is mostly preferred under conditions where autoclaving is not feasible (Ansari et al. 2019; Chisholm et al. 2021; Gupta 2022).

4.3.5.3 Transportation of hospital solid waste

In terms of conveying hospital solid waste, observations, interviews and questionnaire results correspond that utilisation of wheelbarrows and manual handing by workers was common at HC and STT hospitals. Manual transportation of hospital solid waste to disposal sites was possibly due to minimal cost experienced when purchasing wheel barrows. Therefore, rural

hospitals affected by shortage of finance consider it feasible to use wheelbarrows. Manual handling of hospital solid waste receptacles to disposal sites is also attributed to limited resources specifically finance at STT and HC hospitals. Most rural hospitals in various developing countries are operated devoid of enough resources (Smith et al. 2019; Roets et al. 2020). Improvising shortage of resources by manual handling of waste receptacles avert continuous accumulation of solid waste at generation source at these hospitals. Health workers involved in manual handling of waste receptacles and pushing wheelbarrows at these hospitals are vulnerable to hand pain, shoulder pain and wrist pain. Manual handling of solid waste receptacles, solid waste loading and offloading results in occurrence of musculoskeletal disorders among involved workers (Jerie 2016; Shabani et al. 2023a, b). In addition, handling of receptacles with infectious solid expose health workers to various pathogens. Manual handling of waste containers is less expensive and convenient but have potential to increase sharp waste injuries and pricks among health workers, particularly if sharp waste is handled in plastic bags. As a result, better alternatives to transport hospital solid waste to disposal sites are required at HC and STT rural hospitals.

4.3.5.4 Frequency of conveying and emptying hospital solid waste receptacles

According to verdicts of the research conducted at STT and HC hospitals, solid waste receptacles were conveyed and emptied on daily basis. This was postulated by a significant at STT hospital (87%) and 78% at HC hospital (Fig. 6). Daily emptying of hospital solid waste receptacles is crucial to reduce spread of infections and odours within hospital premises. Emptying and conveying of solid waste receptacles on daily basis is recommended by WHO standards. Considering physical appearance of stored hospital solid waste, it was clear that solid waste was conveyed to disposal sites after two or more days. A situation noted by respondents at STT hospital (10%) and HC (15%) (Fig. 6). This entails that, sometimes frequency of emptying waste storage receptacles at STT and HC hospitals fail to conform to WHO and Zimbabwe Ministry of Health and Child Care standards. Delaying emptying of solid waste containers at these hospitals cause continuous accumulation of solid waste in already overwhelmed containers, resulting in spilling of solid waste on hospital floors. This poses significant health risks to human beings including patients, visitors and health workers. Frequent and regular emptying of hospital solid waste is necessary to upheld safety of the public. Interview results of study conducted at STT and HC hospitals illustrated that sharp containers are disposed when they are $\frac{3}{4}$ full, a standard also recommended by WHO. Disposal

of sharp waste containers when they are $\frac{3}{4}$ full minimize risks of sharp injuries experienced when the containers are filled to capacity. Considering results related to sharps, disposal of sharp waste containers at STT and HC hospitals was determined by quantity in the container rather than days.

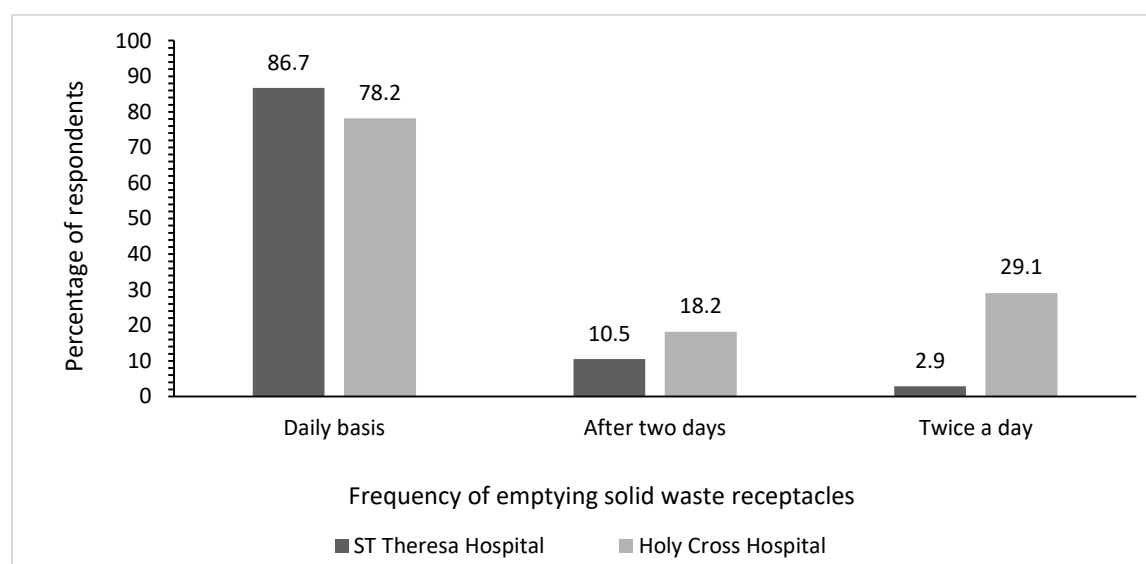


Fig. 6: Frequency of emptying solid waste receptacles.

Source: Field data (2023)

4.3.5.5 Disposal of hospital solid waste

Results in Fig. 7, interviews and observations illustrated that at HC and STT hospitals, various solid waste disposal strategies are used namely incinerators (Plate 1), autoway pits (Plate 2), open pits (Plate 2) and open burning. Observations indicated that solid waste exist on non designated sites on hospitals corners and under trees where visitors reside. This illustrates that solid waste was disposed following both recommended and non recommended approaches at these rural hospitals. Respondents at STT (44.8%) and HC hospital (41.8%) (Fig. 7) postulated that incineration was used to dispose solid waste for instance sharps, papers, plastics, infectious waste like soiled masks, gloves, bandages, cotton wool and textiles. Majority of questionnaire respondents and interviewees, indicated that incineration was regarded as the most effective strategy compared to other disposal approaches. Popularity of incineration at rural hospitals was attributed to its ability to destroy pathogens and turning bulk waste into ashes. Incineration is considered as golden approach used to dispose solid waste at urban and rural hospitals

(Kwikiriza et al. 2019; Ansari et al. 2019; Sangkham et al. 2020). It was observed that at HC and STT hospitals both combustibles and non combustibles materials were loaded together in incinerators. Thus, reducing efficiency of incinerators resulting in generation of partially burnt incinerator residues, translating to difficulties in disposing partially incinerated waste. At STT hospital, inefficiency of the incinerator was exacerbated by utilization of an incinerator with cracked combustion chamber. As a result, maintenance of the incinerator is required to propel its efficiency.

Questionnaire respondents (16.2%) and HC (16.4%) (Fig. 7) and STT hospital EHT stipulated that hospital organic solid waste like food remains was disposed in open pits. Nevertheless, non organic products such as plastics and papers were observed in the pit. Existence of inorganic and organic waste in similar pit was a result indiscriminate storage of hospital solid waste at generation source. Indiscriminate storage and disposal of hospital solid waste is common among various hospitals (Das et al. 2021; Shabani and Jerie 2023). At these two hospitals, open burning was also used to dispose hospital solid waste. However uncontrolled open burning is associated with incomplete burning which generate toxic gases leading to various respiratory problems. Most of the approaches used to dispose hospital solid waste at these two hospitals are least prioritized by waste management hierarchy. In Zimbabwe a number of approaches used to dispose solid waste of medical nature occupy base of solid waste management hierarchy (Shabani and Jerie 2023). HCD/S at STT hospital denotes that soft drink bottles are reused to store water while food left overs are given to those who want to feed dogs and chicken, although large fraction of hospital waste was discarded. Hence, robust approaches to enhance solid waste minimisation strategies are required at these hospitals.

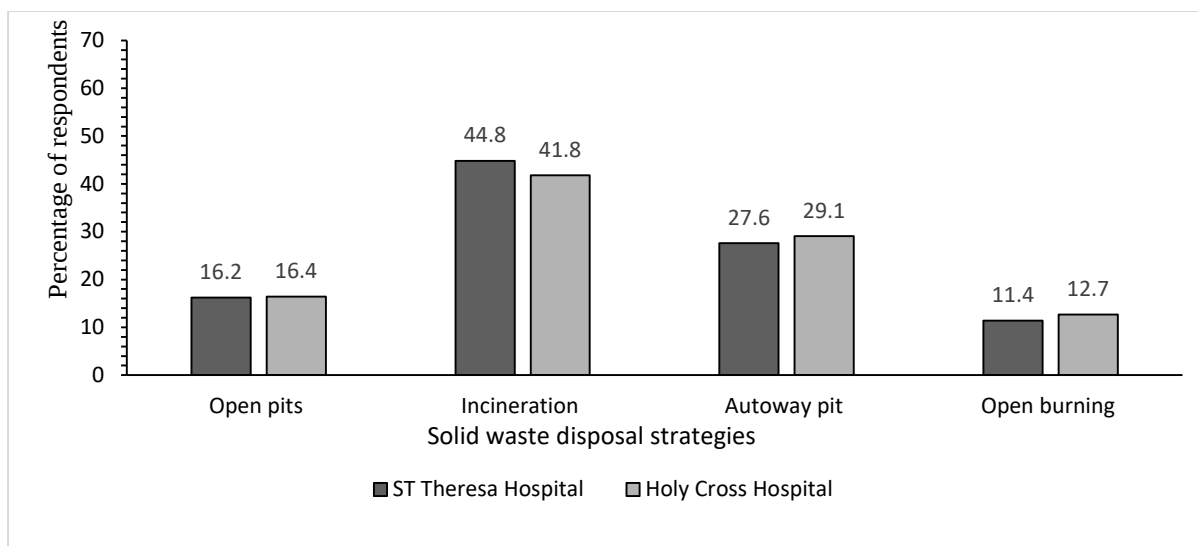


Fig. 7: Hospital solid waste disposal strategies.

Source: Field data (2023)

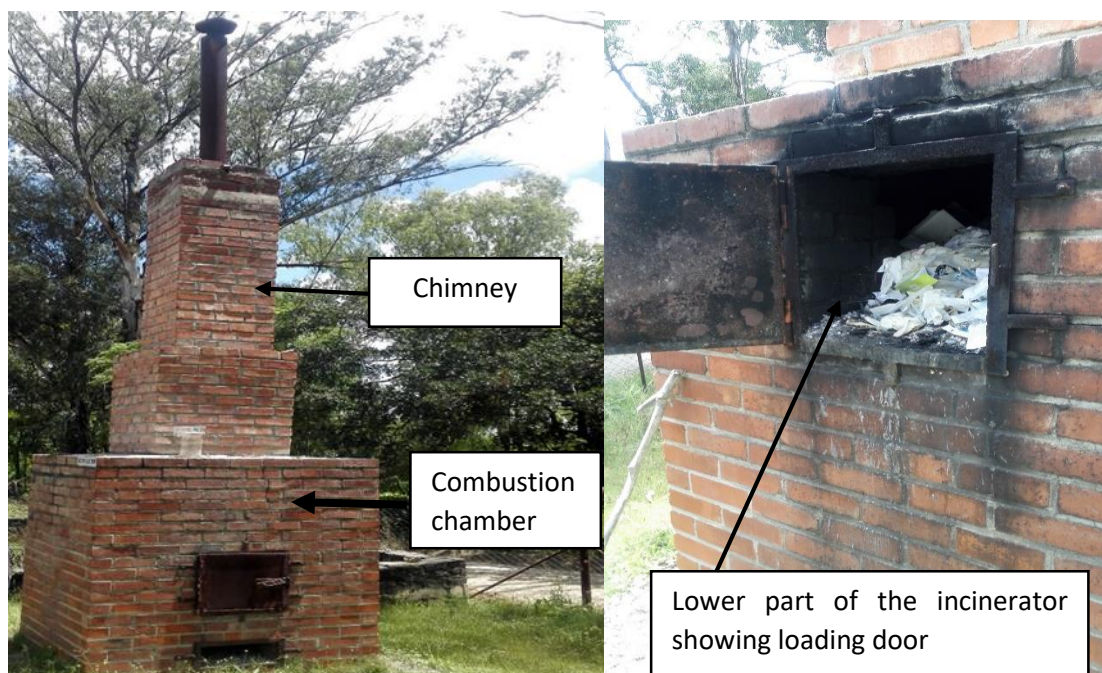


Plate 1: Incinerator used to dispose medical waste at HC hospital.

Source: Field data (2023)



Plate 2: Auto-way pit and organic open pit used to dispose pathological waste and organic waste respectively at STT hospital.

Source: Field data (2023)

4.3.6 Environmental risks associated with hospital solid waste management strategies

Environmental problems associated with various hospital solid waste disposal strategies used at STT and HC hospitals include air, water, soil contamination as well as visual pollution and fire outbreaks (Fig. 8). Respondents at STT hospital (59%) and 56.4% at HC hospital articulated that incineration result in air pollution. Majority of respondents at HC hospital (58.2%) and at STT hospital (73.3%) highlighted that open burning pose air contamination. Similarly, interviews revealed that open burning and incineration processes cause air pollution. Results suggest that incineration and uncontrolled open burning are major contributors of air contamination (Fig. 8). This is because they generate toxic gases namely carbon dioxide, nitrous oxide, carbon monoxide as well as dioxins, furans, fumes and smoke which deform air quality. Incineration and open combustion of hospital solid waste release various pollutants and particulate matter which alter natural concentration of gases in the atmosphere (Ansari et al. 2019; Theodore and Theodore 2021). Decomposition of solid waste in open pits and auto-way pits was noted among causes of air pollution by EMA Officer and respondents at STT (22.9%) and HC (27.3%). Decomposing organic and pathological waste generate methane into the atmosphere, thus increasing global warming since methane is a greenhouse gas.

Additionally, 20% of STT and HC hospitals respondents coincide that pollutants from open pits cause ground water pollution (Fig. 8). The EMA Officer and 49.5% respondents at STT

hospital and 40% at HC hospital concurs that auto-way pits pose ground water contamination. This was ascribed to the fact that pollutants from unlined auto-way pits and open pits infiltrate and percolate to reach ground water. Non-lined solid waste disposal structures produce pollutants which reach ground water (Han et al.2016; Mor et al.2018). Hospital dumpsites were indicated as contributors of ground water pollution since inorganic and organic compounds from degrading solid waste and incineration residues reach ground water. Impacts of hospital solid waste dumpsite to ground water was shown by existence of high heavy metals concentration in ground water sources near hospital solid waste disposal sites. At STT hospital, water sample from water source A contain 0.009 mg/L of arsenic in wet season, 0.006 mg/L in dry season (Table 4). However, it was not detected in water samples of water source B. At HC hospital level of cadmium in water source A was 0.003 mg/L in wet season and 0.001 mg/L although cadmium was not detected in samples of water source B. This situation was due variation in distance from the dumpsite, since A was a label for water source in proximity to hospital dumpsite as compared to water source labelled B.

At STT hospital concentration of lead in samples from water source A was 0.006 mg/L in wet season and 0.0013 mg/L in water samples from water source B. This entails that there is association as well as correlation between concentration of pollutants (heavy metals) in water samples and distance from the dumpsite, since water source A was closer to dumpsite than B. Concentration of heavy metals in water sources that are in vicinity to dumpsites is high (Sankoh et al. 2023; Omeiza et al. 2023). Additionally, concentration of Mercury in water samples collected from water source A at STT hospital was 0.008 mg/L in wet season and 0.006 mg/L. At HC hospital concentration of lead was 0.007 mg/L in wet season and 0.005 mg/L in dry season (Table 5). High concentration of heavy metals in water sources during wet season was possibly due to rainfall which facilitate easy movement of heavy metals from dumpsites to ground water. Concentration of heavy metals in water samples was below WHO limits. However, attention is needed to avert continuous accumulation of heavy metals in water sources, particularly water sources labelled as A.

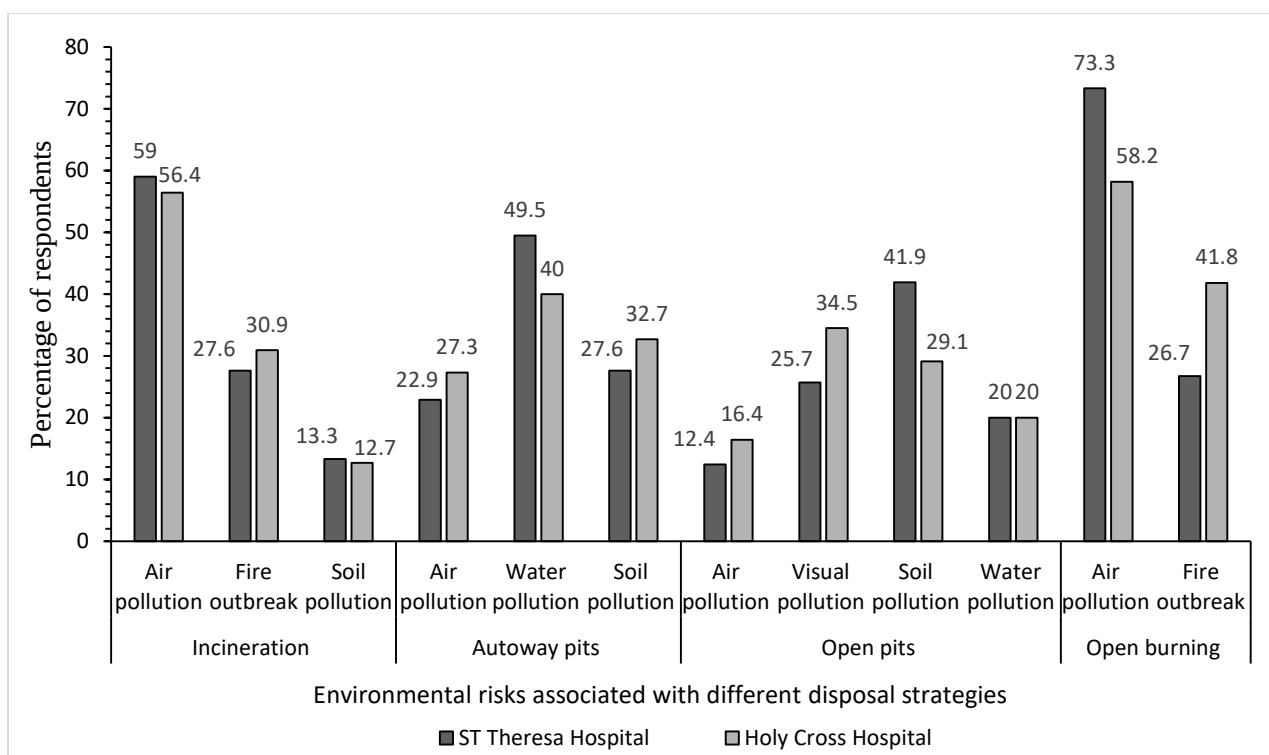


Fig. 8: Environmental risks associated with various hospital solid waste disposal strategies.

Source: Field data (2023)

Table 4: Metal concentration in ground water sources in proximity to STT hospital dumpsite, during dry and wet seasons.

Metal	Water Source A		Water Source B	
	Wet season	Dry season	Wet Season	Dry season
Arsenic	0.009mg/L	0.006mg/L	<i>ND*</i>	<i>ND*</i>
Lead	0.006mg/L	0.004mg/L	0.0013mg/L	0.0012mg/L
Cadmium	0.004mg/L	0.003mg/L	0.001mg/L	0.001mg/L
Mercury	0.008mg/L	0.006mg/L	<i>ND*</i>	<i>ND*</i>

Key: *ND**-Not Detected

Source: Field data (2023)

Table 5: Metal concentration in ground water sources in proximity to HC hospital dumpsite, during dry and wet seasons.

Metal	Water Source A		Water Source B	
	Wet season	Dry season	Wet Season	Dry season
Arsenic	0.005mg/L	0.003mg/L	<i>ND*</i>	<i>ND*</i>
Lead	0.007mg/L	0.005mg/L	0.002	0.0012
Cadmium	0.003mg/L	0.001mg/L	<i>ND*</i>	<i>ND*</i>
Mercury	0.006mg/L	0.004mg/L	<i>ND*</i>	<i>ND*</i>

Key: *ND**-Not Detected

Source: Field data (2023)

At HC hospital P.H was 7.18 in wet season and 7.21 in dry season in water source A, however in water source B, P.H was 6.21 in wet season and 6.28 in dry season (Table 6). This signifies slight differences in water samples P.H in dry and wet sea son, although range of the P.H was within WHO acceptable limits of 6.5 to 8.5. P.H of water samples collected during the wet season present to be slightly acidic as compared to dry season samples which are slightly alkaline. Slight acidic during wet season was probably attributed to influx of pollutants from dumpsites into ground water sources. EC was 395 and 389 in wet and dry season respectively in water source A and in water source B it was 229 in wet season and 221 in dry season at STT hospital (Table 6). This was possibly due to high infiltration and percolation of pollutants specifically inorganic contaminants namely ions during the rain season. In water source A at HC hospital TDS was 128 in wet season and 123 in dry season but in water source B, TDS was 118 and 115 in wet and dry seasons respectively. TDS present to be high in water sources during wet maybe due to availability of rainfall which drives both organic and inorganic solids to reach underground water through infiltration and percolation. TDS was 128 in water source A in wet season and 118 in water source B at HC hospital. Water source A is highly affected by dissolved solid since it was close to dumpsites in comparison to water source B, therefore distance is triggering the variation. Henceforth, STT and HC dumpsites pollutants are causing detrimental impacts to underground water sources particularly those in close proximity to hospital dumpsites.

Table 6: Characteristics of water samples in terms of P.H, electrical conductivity, chemical oxygen demand and total dissolved solids.

STT hospital				
	Water Source A		Water Source B	
	Wet season	Dry season	Wet Season	Dry season
P.H	6.88	7.73	6.16	6.23
Electrical Conductivity (EC)	395	389	229	221
Chemical Oxygen Demand (COD)	7.38	7.28	5.42	5.36
Total Dissolved Solids (TDS)	123	117	115	113
HC hospital				
	Water Source A		Water Source B	
	Wet season	Dry season	Wet Season	Dry season
P.H	7.18	7.21	6.21	6.28
Electrical Conductivity	426	420	301	294
Chemical Oxygen Demand	6.53	6.48	3.86	3.77
Total Dissolved Solids	128	123	118	115

Source: Field data (2023)

Results from questionnaire respondents (Fig. 8) and EMA officer alluded that auto-way pits, open pits and incineration residues generates pollutants which affect soil particles and characteristics negatively. Respondents at HC hospital (29.1%) and STT hospital (41.9%) noted that open pits generate pollutants which cause soil contamination. Pollutants from auto-way pits were among drivers of soil pollution as highlighted by 27.6% and 32.7% respondents at STT and HC hospitals respectively. Hence, there is need to curb negatives caused by open and auto-way pits through lining the bottom and sides of the structures with concrete. Laboratory analysis of soil samples collected from various distances from STT dumpsites and HC dumpsites revealed that the soil samples contain lead, mercury, arsenic and cadmium (Table 7). Soil samples collected at 0 m from STT hospital dumpsite contain 52.4 mg/kg of lead and samples collected at 0 m from HC hospital contain 56.3 mg/kg of lead. Concentration of lead in soil samples collected at a distance 0 m from the dumpsites was above WHO limits of 50 mg/ kg. This entails that hospital solid waste dumpsites are sources of heavy metals with potential to increase soil acidity, hence affecting soil fertility and micro-organisms. Dumpsites generate heavy metals which affect soil quality (Rouhani et al. 2023). Concentration of lead in soil samples collected at 30 m from HC and STT dumpsites was 30.2 mg/kg and 33.2 mg/kg respectively. Concentration of lead was below WHO limits at 30 m from dumpsites. As a result, concentration of heavy metals in soils decreased as distance from the hospital dumpsite increased, since lead concentration was higher in soils at 0 m than at 30 m. This was supported T-test which was used to compare concentration of lead at 0 m, 10 m, 30 m and 60 m. T-test results indicated P value at 0.000 and 0.001 which is less 0.05, therefore it is statistically significant. This translates to mean there is difference in concentration of lead as distance increase from the dumpsites. These verdicts correspond with that concentration of heavy metals such as lead, mercury, cadmium and arsenic in soil commonly depend on distance from dumpsites (Rouhani et al. 2023; Ozoko and Amadi 2022).

Table 7: Concentrations of heavy metal pollutants in soil samples.

Distance from the dumpsite	Name of metal	ST Theresa	HC
		Metal content (mg/kg)	Metal content (mg/kg)
0m	Lead	52.4	56.3
	Cadmium	3.16	3.9
	Mercury	1.09	1.04
	Arsenic	0.2	0.4
10m	Lead	46.7	42.8
	Cadmium	3.11	3.3
	Mercury	1.073	1.077
	Arsenic	0.06	0.09
30m	Lead	33.2	30.2
	Cadmium	1.2	1.4
	Mercury	0.88	0.63
	Arsenic	0.001	0.004
60m	Lead	19.6	21.3
	Cadmium	0.7	0.10
	Mercury	0.023	0.029
	Arsenic	Not Detected	Not detected

Source: Field data (2023)

Moreover, scavenging animals that visit STT and HC hospitals dumpsites include cats (*Felis catus*), dogs (*Canis lupus familiars*), Chicken (*Gallus gallus domesticus*) and wild foxes (*Vulpes vulpes*). Domestic and wild animals consider hospital dump sites as dietary sources since they consume edible items on the dumpsites. Different types of animals visit dumpsites looking for food (Katlani et al. 2018; Shabani and Jerie2023). Interviews revealed that other animals consume plastics which are attached to food scraps. Hence, the animals are vulnerable to intestinal blockage, throat choking leading to death and internal bleeding due to laceration caused by plastics. To worsen the scenario, plastics including those used in hospitals are sources of bisphenol and phthalates chemicals that can impact animals' endocrine systems negatively. Birds such as crows (*Corvus spp.*), vultures (*Cathartes aura*), eagles

(*Accipitridae*) and red-whiskered bulbul (*Pycnonotus jocosus*) (Table 8). Wild birds visiting the dumpsites were dominated by *Corvus spp.* at both hospital dumpsites representing 37% at STT dumpsite and 32% at HC hospital. Dominance of *corvus spp.* was a result of its high availability in the areas where the two hospitals are located. Composition of Vultures (*Cathartus aura*) at STT hospital was 29% and 25% at HC hospital dumpsite. Large number of Vultures (*Cathartus aura*) scavenging for food on dumpsites was observed researches conducted by McGrady et al. (2018) and Tauler-Ametller et al. (2018). These birds are affected negatively by hospitals solid waste since they consume pathogens and can be trapped within the dumpsites translating to death.

Table 8: Average % of different birds visiting hospital dumpsites.

Name of the bird			STTdumpsite	HC dumpsite
Shona	English	Scientific		
Makunguwo	crows	<i>Corvus spp</i>	36	32
Magora	vultures	<i>Cathartus aura</i>	29	25
Makondo	eagles	<i>Accipitridae</i>	12	17
Makwenhure	red-whiskered bulbul	<i>Pycnonotus jocosus</i>	23	26

Source: Field data (2023)

Vegetation survey indicated that characteristics of vegetation species namely grass, trees and shrubs vary with distance from HC and STT dumpsites (Table 9). Composition of grass in quadrant at 0 m from HC hospital dumpsite was 73% invasive species and 27% native species, 61% invasive species and 39% native species at 160 m and 9% invasive species and 91% native species. At STT hospital quadrants located at 0 m, 160 m and 320 m composed of 81%, 61% and 23% invasive shrubs respectively while native shrubs were 19%, 39% and 77% in quadrants located at 0 m, 160 m and 320 m respectively. Quadrants in proximity to dumpsites were found to accommodate higher prevalence of invasive vegetation species than native species. This suggest that hospital solid waste dumpsites generate pollutants which support growth of invasive grass and shrubs which are aggressive and have potential to out compete native plants. Dumpsites contaminants have potential to alter vegetation composition (Vaverkova et al. 2019).

Table 9: Composition (%) of invasive and native vegetation species at different locations from dumpsites.

Distance from dumpsite	Grass				Shrubs				Trees			
	HC		ST Theresa		HC		STT		HC		STT	
	I	N	I	N	I	N	I	N	I	N	I	N
0 m	73	27	78	22	79	21	81	19	0	0	0	0
160 m	61	39	56	44	55	45	61	39	57	43	51	49
320 m	9	91	16	84	36	64	23	77	3	97	7	93

Source: Field data (2023)

4.3.6.1 Perceptions of respondents on rate of occurrence and impacts of environmental risks associated with hospital solid waste

Interviews with EMA Officer disclosed that hospital solid waste disposal strategies like incineration and open burning cause severe air pollution. The EMA officer explained that the severity of air pollution was exhibited by its potential to impact human health. Responses showed that 45.7% at ST Theresa hospital and 23.6% at Holy Cross hospital concur that air pollution was severe (Fig. 9). However, 13.3% of health workers at ST Theresa and 10.9% at Holy Cross hospital correspond that air pollution was very severe. Respondents were arguing that incineration and open burning of hospital solid waste occur almost every day, therefore release of air pollutants was common. Results revealed that air pollution was at moderate level as advocated by 20% participants at ST Theresa hospital and 34.5% at Holy Cross hospital. The DMO also expressed that level of air contamination cannot be termed serious but was at moderate level. Considering the occurrence of water pollution, it was at moderate level according to 48.6% questionnaire respondents at ST Theresa hospital and 27.3% participants at Holy Cross hospital. The same opinion was raised by the EHT at ST Theresa who opined that impacts of their open pits and auto-way pits to underground water could be termed moderate since they are lined by cement. Nevertheless, health workers at ST Theresa (20%) and 16.4% at Holy Cross hospital present the aspect of water pollution as severe. Their perceptions were supported by Holy Cross hospital EHT that groundwater pollution was difficult to avert since pollutants percolate to ground water. The EHT specified that the state was severe during the rain season, since rainfall facilitates movement of leachates. Observations signifies that impacts of dumpsites pollutants and incineration ashes cause severe

impacts to soil since pollutants manage to modify physical characteristics of soil namely colour.

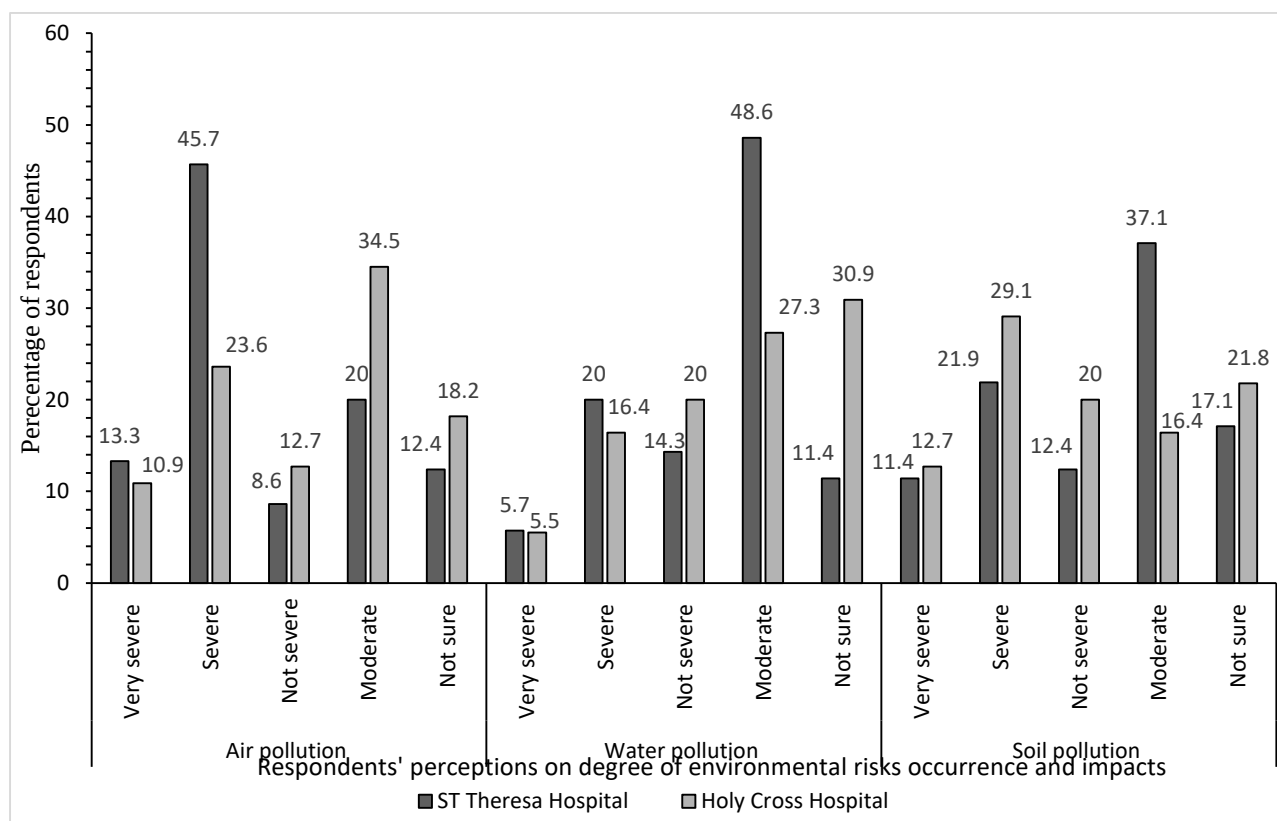


Fig. 9: Respondents' perceptions on degree of environmental risks occurrence and impacts associated with hospital solid waste.

Source: Field data (2023)

Moreover, Holy Cross (29.1%) and ST Theresa (21.9%) participants suggest that the rate of soil pollution as a result of various discarding techniques is severe. Nonetheless, in terms of rating effects of hospital solid waste pollutants to soil, 21.8% of Holy Cross health workers and 17.1% of ST Theresa health workers (Fig. 9) were not sure about the prevailing conditions. At Holy Cross hospital, the Cleaning Supervisor demonstrated inadequate knowledge on soil pollution. The Cleaning Supervisor posits that although the cadre was a leader of the cleaning team, information linked to rating of soil pollution occurrence is insufficient. However, contamination of soil was very severe as noted by 12.7% respondents at Holy Cross hospital and 11.4% at ST Theresa hospital. The EMA officer highlighted that severity of soil pollution owing to hospital solid waste pollutants can be termed high since incinerator ashes are destined on soil. Questionnaire respondents at ST Theresa hospital (13.3%) and 10.9% at Holy Cross hospital established that air pollution was very severe. Participants at ST Theresa hospital

(5.7%) and Holy Cross hospital (5.5%) (Fig. 9), agreed that water pollution owing to hospital solid waste pollutants was very severe. This was disputed by ST Theresa hospital Matron that existence of underground water contamination due to hospital solid waste pollutants was questionable. The hospital Matron argued that there were no records of health problems related to the use of ground water sources in proximity.

4.3.6.2 Assessment of vulnerability of environmental attributes using geographic information systems

This was determined through overlaying of proximity to dumpsite (Fig. 10), landuse/cover (Fig. 11) and slope (Fig. 12) at ST Theresa hospital (Fig. 13). Similarly, overlaying areas proximity to dumpsite (Fig. 14), landuse/cover (Fig. 15), and slope Fig. 16 at Holy Cross. Overlaying proximity, slope and land use/cover illustrated that areas in red colour are regarded as high-risk areas at ST Theresa (Fig. 13) and Holy Cross (Fig. 17). These areas include areas which are close to the dumpsites, however areas located at 50 m, 50 m–150 m, 150 m–350 m were at high risk compared to those at 350 m–500 and 500 m–1000 m. These findings were similar to those at Holy Cross where areas at 50 m and below, 50 to 100 were at high risk compared to those at 150 m to 200 m. Red colour demonstrated that, areas on steep slopes of 15–34 degrees are highly affected by pollutants from ST Theresa dumpsites as compared to areas at a slope of 7–15 degrees which are affected at moderate rate (blue colour) as shown by (Fig. 13). At Holy Cross hospital, areas on steep slopes of 19–35 degrees are at high risk (red colour) while areas at a slope of 8–19 degrees are affected at moderate level (Fig. 17). On landuse, overlaying indicated that built-up areas (Fig. 15) are at high risk as indicated by red colour (Fig. 13). However, areas used for cultivation are moderately affected as shown by blue colour (Fig. 13). Moreover, areas with built-up areas are at high risk (red colour) (Fig. 17) particularly built-up areas of close proximity of 50 m and less from Holy Cross dumpsite (Fig. 15). Figure 13 illustrates that the water source in Fig. 12 is highly affected since it is in the red zone (high risk areas). This may be attributed to the steepness of the area where the water source is located. On Fig. 13 and Fig. 17, low risk areas are indicated by black colour, indicating areas with gentle terrain, and areas which are not close to the dumpsite in terms of proximity.

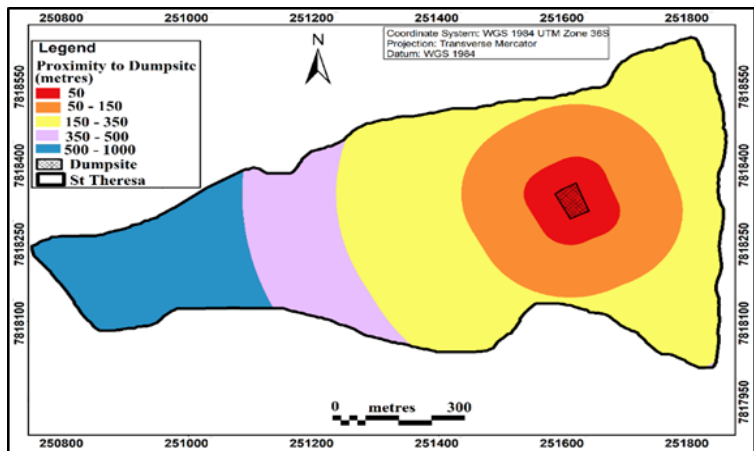


Figure 10: Distance from ST Theresa hospital dumpsite

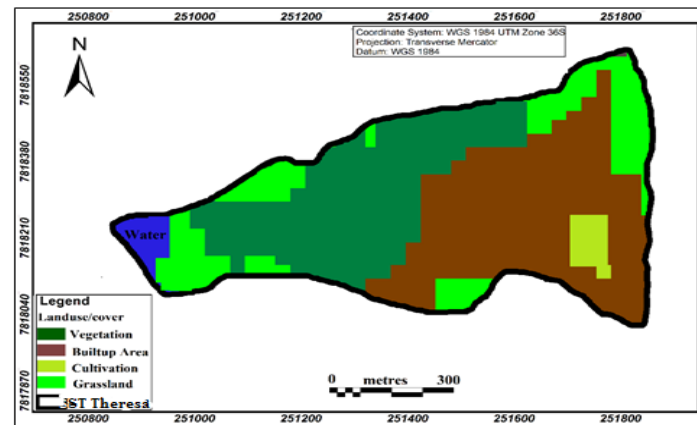


Figure 11: Landuse/cover map of ST Theresa hospital

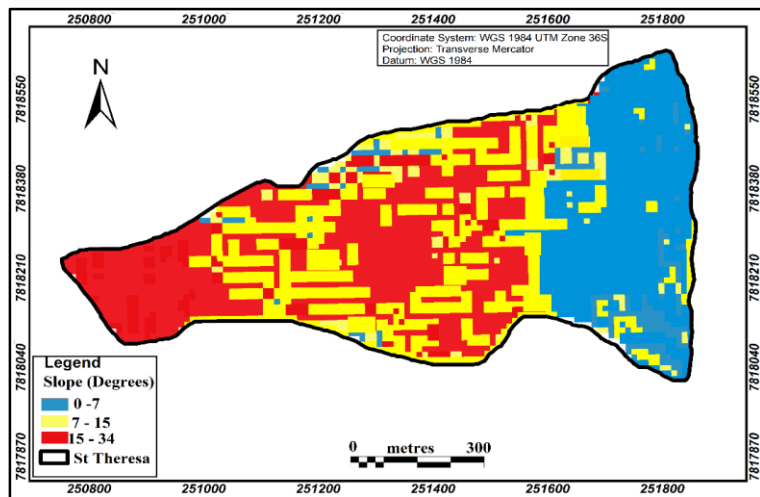


Figure 12: Map showing slope of ST Theresa hospital area

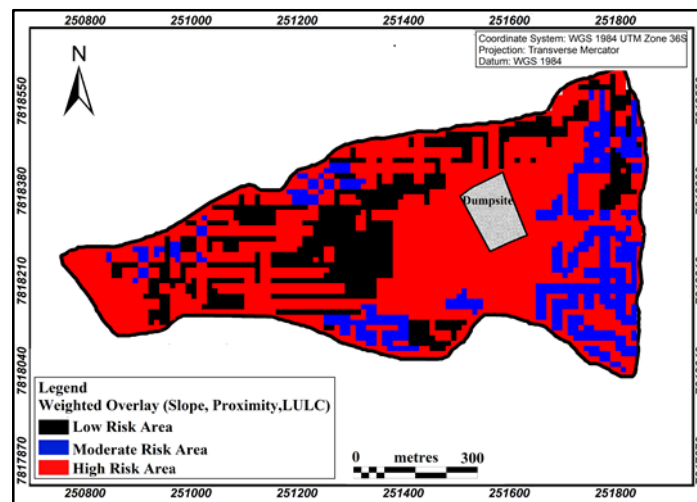


Figure 13: Vulnerability of environmental attributes demonstrated by overlaying of proximity, slope and landuse/cover maps (ST Theresa)

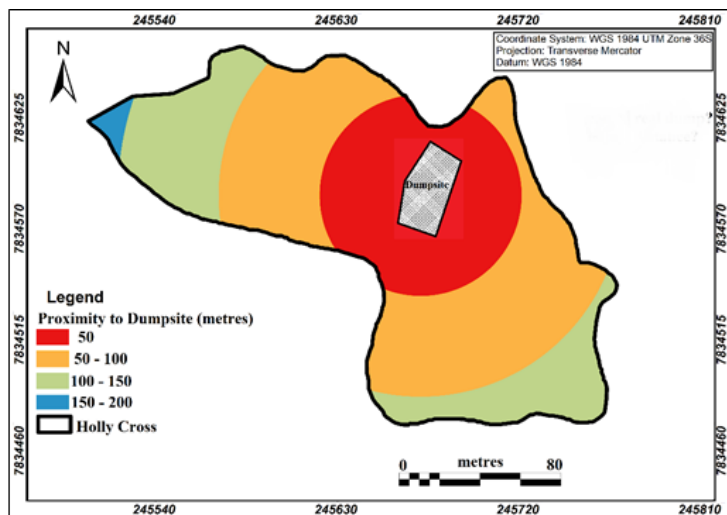


Figure 14: Distance from Holy Cross hospital dumpsite



Figure 15: Landuse/cover map of Holy Cross hospital

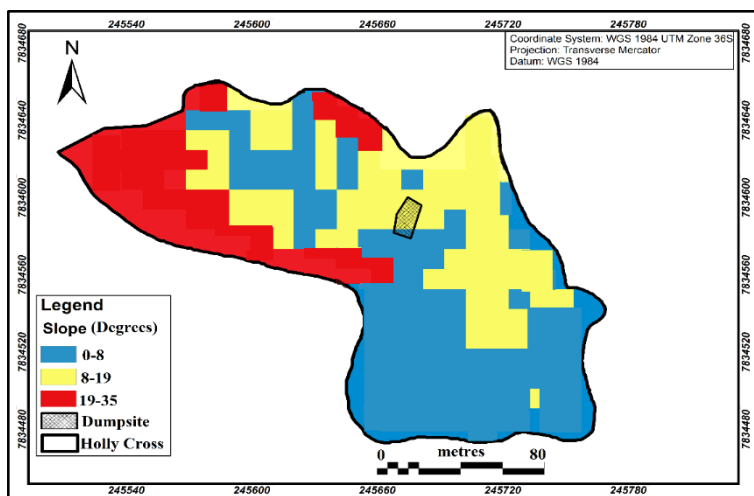


Figure 16: Map showing slope of Holy Cross hospital area

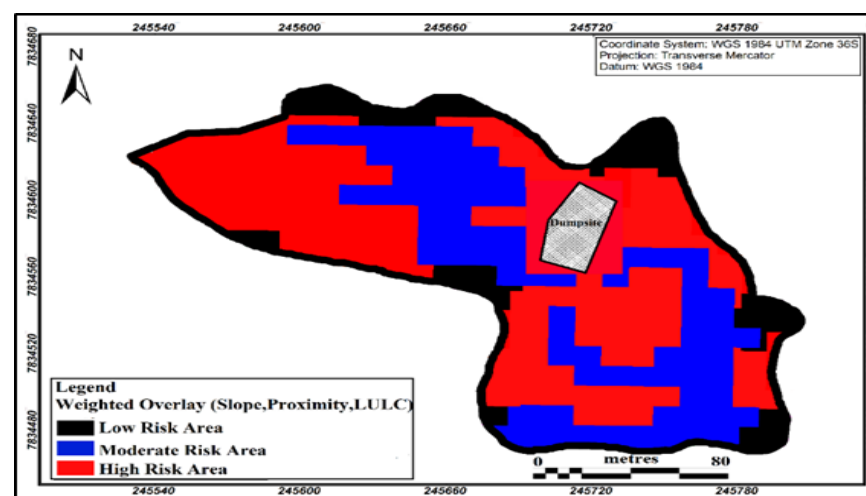


Figure 17: Vulnerability of environmental attributes demonstrated by overlaying of

proximity, slope and landuse/cover maps (Holy Cross hospital)

4.3.7 Occupational health risks associated with hospital solid waste management strategies

Results indicated that health workers are aware of occupational health risks associated hospital solid waste management as demonstrated by 89.5% at STT and 83.6% at HC hospitals. High level of awareness can be attributed to their work which deals with health issues and active participation in awareness programs. Existence of knowledgeable health workers is crucial since awareness is essential in minimising occupational health risks associated with handling hospital solid waste. Occupational health risks highlighted by respondents include pricks, cuts, contacting infectious waste, inhaling noxious odours, hand pain, back pain and being exposed to heat or radiation from combustion of hospital solid waste (Fig. 18). Majority of health workers 28.7% at STT and 23.9% at HC indicated that pricks occur at solid waste storage stage. Similarly, 19.1% at STT hospital and 15.2% at HC hospital highlighted cuts at storage stage. Therefore, most sharp injuries experienced by health workers occurred during handling of sharps at storage stage. This is an issue of concern since injuries caused by hospital sharp waste puts health workers at risk of contracting diseases namely hepatitis, HIV and AIDS, tetanus, tuberculosis and COVID-19.

Individuals who are vulnerable to hospital sharp waste are at high risk of affected by sharp injuries translating to occurrence of infectious ailments (Ansari et al. 2019; Adelodun et al. 2021). However, health workers contact infectious materials during storage, transportation and disposal of hospital solid waste, hence are vulnerable to various pathogens. In order to safeguard themselves, hospital workers should prioritise use of PPE/C such as gloves, masks and aprons. Incinerator operators highlighted that they are threatened by back and hand pain due to manual lifting of solid waste receptacles when loading incinerators. Owing to repetitive nature of the work coupled by weight of receptacles waste, waste workers are affected by musculoskeletal disorders namely muscle pain alongside joint injuries. Musculoskeletal disorders occupational hazard is common among workers involved in manual waste management tasks (Jerie 2016; Shabani et al. 2023a, b). At ST Theresa, hospital incinerator operator was observed performing daily duties without enough safety gear (Plate 3). Hence, they are susceptible to excessive radiation translating to dehydration, heat stress, skin irritation, rash, neurological problems and high blood pressure. Findings illustrated that health workers inhale noxious odours during storage, collection, treatment and disposal of hospital solid waste. Exposure to noxious odours result in respiratory problems like coughing, nausea, throat

irritation, dizziness, throat and eye irritation and headache. Therefore, provision of adequate PPE/C to hospital incinerator operators is crucial to uphold their health.

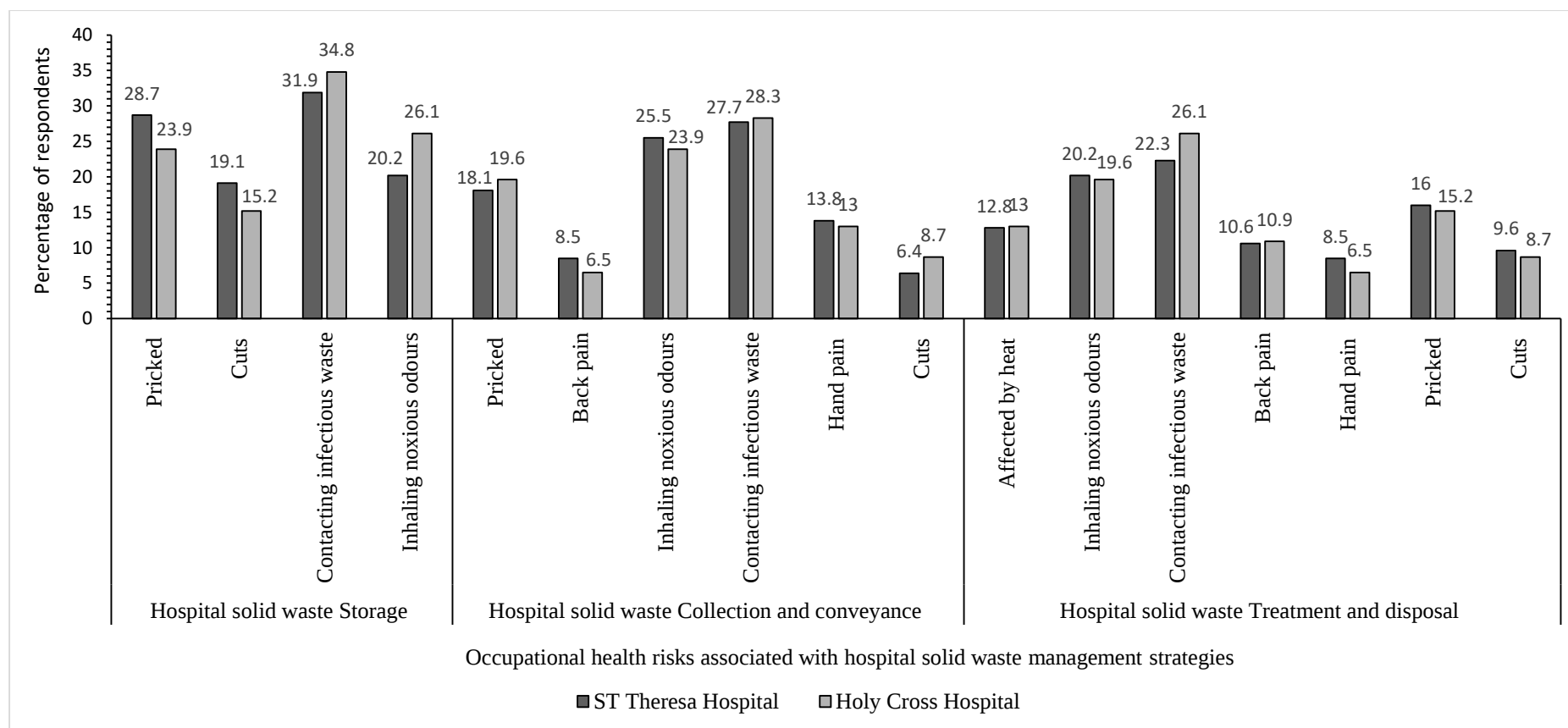


Fig. 18: Occupational health risks associated with hospital solid waste management strategies.

Source: Field data (2023)



Plate 3: Incinerator operator wearing inadequate safety gear at STT hospital.

Source: Field data (2023)

4.3.8 Challenges in management of hospital solid waste

EMA officer asserted that most health workers are unaware of legal framework that address hospital solid waste. Unawareness of legislation was articulated by majority of respondents at HC 58.2% and 54.3% at ST Theresa. Lack of understanding of legal framework guiding solid waste management cause improper hospital solid waste management. Knowledgeable health workers noted that hospital solid waste management was guided by Ministry of Health and Child Care waste management guidelines, Environmental Management Act Chapter 20:27 and

Public Health Act Chapter 15:09. Failure to mention Zimbabwe Integrated Solid Waste Management Plan means involvement of stakeholders and different approaches in management of hospital solid waste is still at infancy stage. Additionally, problems are fueled by lack of awareness towards WHO hospital solid waste guidelines. Conformity to hospital solid waste management legal framework was considered less by 45.8% respondents at STT hospital and 47.8% at HC. This asserts that solid waste management approaches at these two hospitals are far from recommended legislation and policies, hence can be termed unsustainable. Limited conformity to legislations at rural hospitals can be attributed to unawareness coupled by inadequate law and policy enforcement and follow-ups. Without appropriate enforcement, compliance to solid waste legislations, standards and policies remain low (Oyebode, 2018; Muheirwe et al. 2022). Respondents (Fig. 19) and interview results illustrated that hospital solid waste management challenges involves waste increase, inadequate finance, unawareness among health workers, and shortage of labour as well as neglecting of solid waste issues by responsible authority.

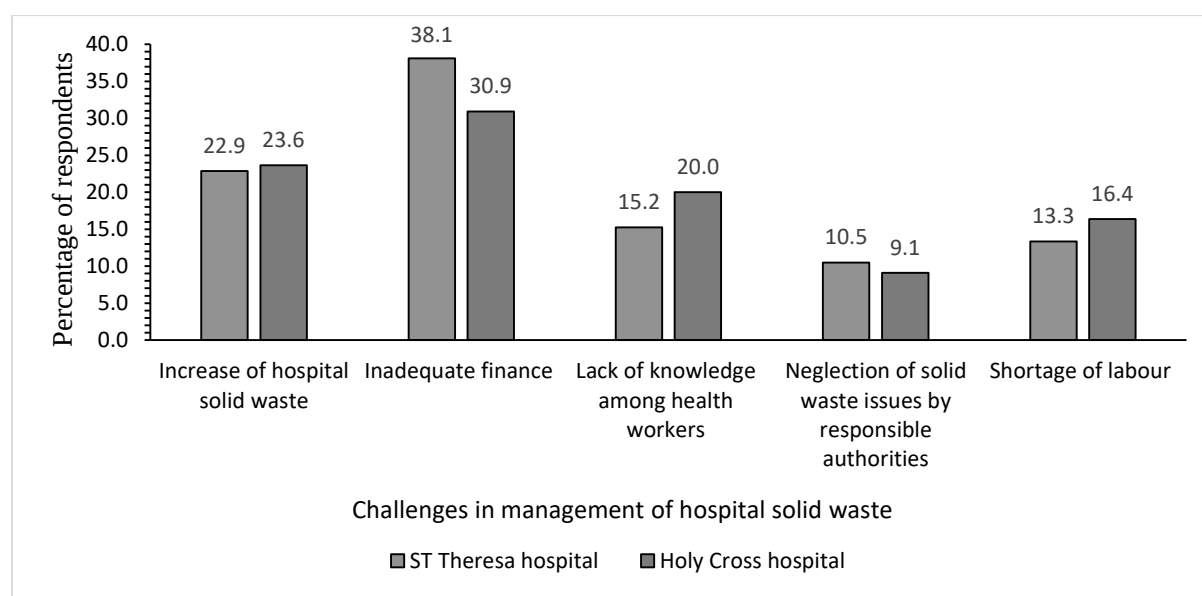


Fig. 19: Challenges faced by STT and HC hospitals in management of solid waste.

Source: Field survey (2023)

A significant number of health workers at STT (79.0%) and HC (76.4%) noted that there was no room for all stakeholders to provide ideas in solid waste management issues. Participation and inclusion of all health workers in management planning for management of solid waste is limited at these hospitals, resulting in difficulties in achieving sustainable hospital solid waste management. Inclusion of various relevant stakeholders in management of solid waste is an essential ingredient to achieve apt solid waste management (Sinthumule and Mkumbuzi 2019; Nhuhu et al. 2021). Challenges posing problems in management of hospital solid waste include shortage of labour, lack knowledge among health workers and neglect of hospital solid waste issues by hospital authority. Consequently, irresponsible hospital authorities are among contributors of problems experienced in management of hospital solid waste. Large proportion of health workers at STT hospital (38.1%) and 30.9% at HC hospital revealed inadequate finance as a challenge. Shortage of finance limit purchasing enough resources namely hospital waste receptacles, hinder construction of standard waste disposal infrastructure and impede recruiting of enough labour. EMA officer, 22.9% respondents at STT and 23.6% HC hospitals coincide that increase of solid waste cause obstacles in management of solid waste. Solid waste increase overwhelms capacity of available solid waste receptacles, disposal structures and available workforce at rural hospitals, resulting in improper management of hospital solid waste. Medical waste mismanagement in Zimbabwe is largely ascribed to inadequate enforcement of legal frameworks, insufficient finance and non-involvement of all stakeholders and health workers' unawareness (Shabani and Jerie 2023).

Moreover, respondents at STT (73.3%) and HC (69.1%) hospitals indicated that existing solid waste management framework follows collection to disposal approach. Therefore, the implemented frameworks at these hospitals give minor attention to CE and upper part of waste management hierarchy. Low utilisation of solid waste minimisation strategies was indicated by participants at STT (26.7%) and HC (30.9%). This may be attributed to the fact that practicing reuse of hospital materials is controversial due to nature of hospital materials which may pose health risks. Application of waste minimisation techniques namely reuse and recycling is still at infancy stage in Zimbabwe (Jerie and Mandevera 2018). Observations illustrates that indiscriminate storage of solid waste was practiced at these hospitals translating to difficulties in management of solid waste. In terms of trainings intervals, respondents noted weekly basis, monthly basis, after month and above as well as not known (Fig. 20). Variation of respondents' views denotes that the framework's training system can be described as inconsistent and erratic.

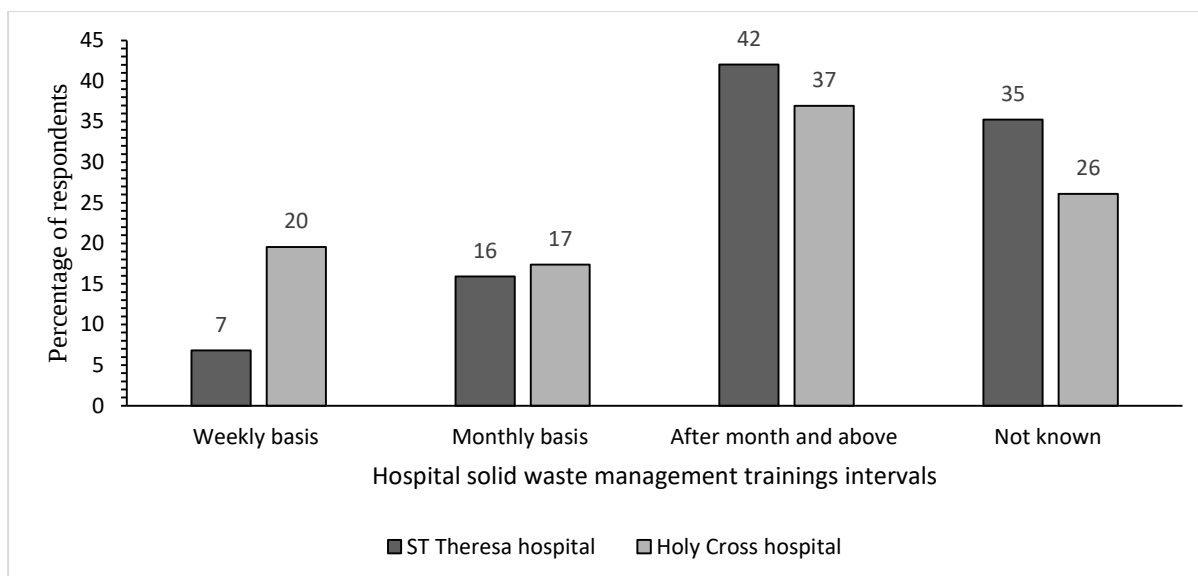


Fig. 20: Hospital solid waste management trainings intervals STT and HC hospital.

Source: Field survey (2023)

4.4 Conclusions and recommendations

Hospital solid waste management is among pressing issues impacting Zimbabwe rural hospitals due to population increase and diseases outbreak. Chemical, pathological, cytotoxic, radioactive, pharmaceutical, infectious, sharps and general waste as well as electronic and construction and demolition solid waste are generated at STT and HC hospitals. Waste increase was ascribed to outbreak of diseases, high use of disposable PPE/C, discarding of outdated materials and equipment. Solid waste generated at these hospitals is stored in plastic and metal buckets, pedal operated bins, sharp containers, plastic bags and cardboard boxes. Hospital solid waste was separated into organic and inorganic waste, sharps and non sharps as well as infectious and non-infectious waste during storage. Although, indiscriminate storage plastics and food waste was common. Infectious waste was disinfected through chlorination or autoclaving at HC and STT hospitals. Solid waste was transported to disposal sites through manual handling and use of wheelbarrows. Solid waste was disposed through incineration, open pits, auto-way pits and open burning. However, waste was disposed under trees and building corners while composting and reuse was also applied. Disposal approaches mostly utilised at these hospitals occupy bottom part of waste management hierarchy. As a result, they cause air, soil, water contamination, visual pollution, outbreak of veldfires and affecting flora and fauna negatively. Occupational health risks associated with management of hospital solid

waste encompass pricks, cuts, contacting infectious waste, inhaling noxious odours, musculoskeletal disorders and being exposed to radiation from waste combustion.

In light of the findings various recommendations were made, for instance there is need for rural hospital authority to provide adequate PPE/C to those involved in solid waste management EHTs must carry out trainings focusing on enlightening health workers on aspects related to hospital solid waste management. EMA officers should carry out workshops where they inform health workers on policies, guide lines and legislation applied in hospital solid waste management. Zimbabwe Ministry of Health and Child Care (ZMoHCC) should channel enough financial resource to hospital solid waste management aspects at rural hospitals. Collaboration of ZMoHCC and NSSA among other stakeholders in mapping out approaches to minimise occupational health risks associated with solid waste generated at rural hospitals is required. Rural District Authorities must assist rural hospitals in dealing with solid waste, since rural hospitals generate solid waste with similar characteristics to urban health facilities.

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Chapter 5

Developing a Sustainable Integrated Solid Waste Management Framework for Rural Hospitals in Chirumanzu District, Zimbabwe

Takunda Shabani¹, Vurayayi Timothy Mutekwa¹ and Tapiwa Shabani¹

¹Midlands State University, Department of Geography, Environmental Sustainability and Resilience Building, P. Bag 9055 Gweru, Zimbabwe.

Corresponding Author: Shabani Takunda, Email: shabstaku@gmail.com

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Abstract

This paper focuses on developing a sustainable integrated hospital solid waste management framework for rural hospitals in Chirumanzu district. Descriptive cross-sectional design encompassing qualitative and quantitative paradigms was used to collect data from 105 and 55 healthcare workers at STT and HC, respectively, and 9 interviewees. Questionnaires, observations, interviews, existing literature, water, and soil samples were data sources. SPSS and ME were used to analyse quantitative data and content analysis for qualitative data. Hospitals generated pharmaceutical, chemical, radioactive, cytotoxic, sharps, infectious, pathological, general waste, construction, demolition, and electronic waste. General waste was 77.35% at STT and 79% at HC, and hazardous waste was 22.65% at STT and 21% at HC. Sharp containers, pedal bins, buckets, plastic bags, and cardboard boxes were storage receptacles. Respondents at STT (72.4%) and HC (69.1%) demonstrated that sharp containers and pedal bins were highly used. Participants at STT (86.7%) and HC (78.2%) noted that solid waste receptacles were emptied on daily basis. Open pits, burning, dumping, incineration, and auto-way pits were disposal strategies used. Respondents at STT (44.8%) and HC (41.8%) indicated that incineration was highly used. Disposal strategies cause soil, water, and air contamination while causing ailments to people. Solid waste management improvement requires resources, raising healthcare workers' awareness, technology utilization, stakeholders' collaboration, and PPE/C. The framework assists to guide hospitals to apply recycle, reuse, and recovery which support CE. The framework enhances socio-economic development, stakeholder participation, and conformity to legal frameworks and reduces waste management cost while facilitating attainment of SDGs, AA 2063, and ZV 2030 goals.

Research Highlights This paper focuses on developing a sustainable integrated hospital solid waste management framework for rural hospitals in Chirumanzu district. Chemical, pathological, cytotoxic, radioactive, pharmaceutical, infectious, sharps and general waste, electronic, construction, and demolition solid waste are generated at STT and HC hospitals.

Solid waste generated at HC hospital consists of 79% general waste and 21% hazardous waste. STT hospital produced 77.35% general waste and 22.65% hazardous waste. Waste increase was ascribed to outbreak of diseases, population increase, high use of disposable PPE/C, and discarding of outdated materials and equipment.

Solid waste generated at these hospitals is stored in buckets, pedal bins, sharp containers, plastic bags, and cardboard boxes. Major storage receptacles utilized were sharp containers and pedal bins as noted by 72.4% of the respondents at STT and 69.1% at HC hospital.

Hospital solid waste was separated into organic and inorganic waste, sharps and non sharps, and infectious and non-infectious waste during storage. Infectious waste was disinfected through chlorination or autoclaving at HC and STT hospitals. Solid waste was disposed through incineration, open pits, dumping, auto-way pits, and open burning. Incineration was highly used at STT (44.8%) and HC (41.8%) hospitals. Disposal of hospital solid waste was mostly carried out on a daily basis as indicated by 86.7% at STT hospital and 78.2% at HC hospital.

Disposal approaches utilized at these hospitals cause air, soil, water contamination, visual pollution, outbreak of veld fires, and affecting flora and fauna negatively. Occupational health risks associated with management of hospital solid waste encompass pricks, cuts, contacting infectious waste, inhaling noxious odours, musculoskeletal disorders, and being exposed to radiation from waste combustion. There is a need for rural hospital authority to provide adequate PPE/C to those involved in solid waste management. EHTs must carry out training focusing on enlightening health workers on aspects related to hospital solid waste management.

EMA officers should carry out workshops where they inform health workers on policies, guidelines, and legislation applied in hospital solid waste management. ZMoHCC should channel enough financial resources to hospital solid waste management aspects. Collaboration of ZMoHCC and NSSA among other stakeholders in mapping out approaches to minimize occupational health risks associated with solid waste generated at rural hospitals is required.

Rural district authorities must assist rural hospitals in dealing with solid waste, since rural hospitals generate solid waste with similar characteristics to urban health facilities. There is a

need to uphold the use of current technology like GIS and RS in management of hospital solid waste. Application of GIS and RS facilitates determination of solid waste collection routes, location of disposal sites, and determining environmental attributes which are vulnerable to pollutants from hospital disposal sites.

The proposed framework supports solid waste recycling, reuse, recovery, and repair of materials, therefore facilitating reduction of solid waste disposed into the environment. The framework upheld involvement of all stakeholders, conformity to national and international legal frameworks, continuous improvement of waste management system, and reduced cost in managing waste while protecting the environment, hence narrowing the gap to reach SDGs, AA 2063, and ZV 2030. SIHSWM (Fig. 13) urges hospitals to consider raw disposal of hospitals as a waste of resources. By adopting this framework, solid waste can be utilized as a resource to catalyse economic growth.

Keywords: Rural hospitals · Hospital solid waste · Management strategies · Environmental health risks · Framework · Circular economy

List of Acronyms

AA	Africa Agenda
Ad	Arsenic
CBA	Cost benefit analysis
Cd	Cadmium
CE	Circular economy
COD	Chemical oxygen demand
DMO	District medical officer
EC	Electrical conductivity
EHT	Environmental health technician
EMA	Environmental Management Agency
HC	Holy Cross
HCD/S	Head of cleaning department/supervisor
Hg	Mercury
LCA	Life cycle assessment
MCDMA	Multi-criteria decision making analysis
ME	Microsoft Excel
NSSA	National Social Security Authority
Pb	Lead
PPE/C	Personal protective equipment/clothing
SDGs	Sustainable Development Goals
SIHSWM	Sustainable integrated hospital solid waste management
STT	ST Theresa
SPSS	Statistical Package for Social Sciences

TDS	Total dissolved solids
UN	United Nations
UNCD	United Nations Conference on Environment and Development
US EPA	United States Environmental Protection Agency
WHO	World Health Organization
ZIMSTAT	Zimbabwe National Statistical Agency
ZMoHCC	Zimbabwe Ministry of Health and Child Care
ZV	Zimbabwe Vision

5.1 Introduction

Solid waste management requires comprehensive sustainable approaches and models [1, 2], including the healthcare waste generated in hospitals. Hospital solid waste is produced during patients' diagnosis and care, consisting of 85% non-hazardous and 15% hazardous waste [3]. This kind of waste is becoming problematic worldwide due to its hazardous characteristics, population increase, and disease outbreaks [4]. Hospital solid waste generation is inevitable since hospitals serve human lives daily. A view upheld by Ripa et al. [5] and Tisserant et al. [6] that generation of solid waste is unavoidable owing to human existence and related activities and generation of hospital solid waste is not exempted. Hospital solid waste includes pharmaceutical, pathological, sharps, chemical, infectious, radioactive, cytotoxic, and general waste [7, 8]. An integrated management model that caters for various hospital solid waste categories is required to achieve sustainability.

Improper management of hospital solid waste poses detrimental impacts to aquatic, terrestrial, atmospheric ecosystems, and people [3, 9]. Hospital solid waste pollutants hinder the ecosystem's ability to supply cultural, provisional, supporting, and regulating services while affecting humans negatively. In order to minimize environmental health risks, hospital solid waste management strategies should conform to World Health Organization standards (WHO [10]). Solid waste management hierarchy stages, namely, disposal, treatment, recovery, recycle, reduction, and prevention are utilized to manage solid waste worldwide (US EPA [11]), including hospital solid waste. Approaches that occupy upper part of waste hierarchy are used to manage solid waste in Australia [12], Sweden [13], Germany, Italy, and France [14, 15]. Solid waste management hierarchy guides decision makers to adopt approaches that minimize quantity of disposed hospital solid waste. In developing nations like Zimbabwe, strategies that occupy the base of the waste hierarchy framework are utilized [16–18]. Landfilling and incineration are highly applied while recycling, reuse, and recovery application is low. Hierarchy framework is silent about life cycle of materials, waste segregation, and transportation and requires experts and resources [19]. Its applicability at incapacitated rural hospitals is difficult. Rural hospitals and urban hospitals differ in several aspects, including their location, patient population, services provided, resources available, and challenges faced [20, 21]. These differences can have significant implications for healthcare delivery and waste management strategies, particularly in rural areas. The life cycle assessment (LCA) model is

effective in managing solid waste from households and institutions like hospitals [22], for instance, in Canada [23]. Superiority of LCA is owed to its ability to monitor impacts of products throughout their life cycle [24]. Hence, LCA can assist in selection of proper hospital solid waste management techniques which suit each useless material.

LCA ineffectiveness in developing countries, namely, India and Mexico is due to weak policies and inadequate waste data and resources Gallego and Tarpani [25]. Zimbabwe may experience difficulties in utilizing LCA in management of rural hospitals solid waste since Kwenda et al. [26] pointed to a lack of adequate solid waste data in Zimbabwe. Application of the LCA model in solid waste management from hospitals remains almost subjective since it deals with assumptions. Limitations associated with LCA pave the route for multi-criteria decision-making analysis (MCDMA)'s popularity [27]. Utilisation of MCDMA in hospital solid waste management in developing nations is lagging due to insufficient waste data and resources, healthcare workers' unawareness, and ineffective policies [28, 29]. Solid waste management is a complex problem which requires triangulation of models, namely, MCDMA and cost benefit analysis (CBA) [30]. CBA model evaluates solid waste management strategies and impacts considering monetary terms [31]. CBA is feasible worldwide since it facilitates the adoption of low cost and environmentally acceptable solid waste management approaches. CBA's accounting scheme deals with estimations so it is difficult to express environmental benefits and costs through monetary terms [32]. CBA assesses the costs and benefits of the waste management approach considering economic aspects while neglecting environmental and social issues and failing to consider the fluctuation of cost and benefits associated with management approaches [33]. A model that considers all pillars of sustainability, namely, environmental, socio-economic, and political aspects is required.

The application of integrated sustainable methods and models in solid waste management is still lagging in developing countries [34] including management of hospital solid waste in Zimbabwe. In Zimbabwe, the scenario is worsened by socio-economic and political problems [7, 8], particularly in rural areas. Implementation of waste management models which suit hospitals, specifically rural hospitals, is at infancy stage. Hospital solid waste is managed as general domestic waste and disposed of through open burning, dumping, open pits, and incineration [7, 8, 35]. Incinerators in Zimbabwe are not built to standard, posing various

environmental challenges and concerns [7, 7, 8, 8]. These disposal approaches pose negative impacts on air, water, soil, flora, and fauna. In order to minimise the risks caused to the environment in the twenty-first century and beyond the Rio Declaration and Development Agenda 21 (UNCD [36]), complemented by Sustainable Development Goals require appropriate management of solid waste encompassing hospital solid waste (UN [37]). In Zimbabwe, proper solid waste management including rural hospital solid waste is a prerequisite to attain Vision 2030 and National Development Strategy 1 goals (RoZ [38]) Without a comprehensive rural hospital solid waste management framework which considers political, socio-economic, engineering, financial, legal, and environmental aspects, efforts to attain global and local goals will remain in vain. In order to overcome the complexity of solid waste management various stakeholders, technologies and techniques should unify, interact, and communicate positively [39, 40].

Sustainable management of solid waste from rural hospitals requires models which consider real world scenarios in terms of prevailing socio-economic, environmental, political, and legal issues in Zimbabwe. Institutions including rural hospitals should implement their waste management models which consider waste volume and characteristics [41]. A unique model which addresses current and projected future issues related to rural hospital solid waste management is required in Zimbabwe. Solid waste management including at rural hospitals is based on usually unacceptable approaches which is mostly referred to as a traditional closed system [16–18, 42]. Traditional waste management system is generally a waste management approach that lacks coordination and synergy among its various components and stakeholders, and less effort is directed towards waste minimization. Most hospital solid waste management studies are confined in urban areas for instance Harare and Kwekwe in the Zimbabwean context. The studies are also cantered on proffering of recommendations while neglecting development of frameworks which narrow the gap to attain sustainable waste management. Developing an integrated framework to achieve sustainable hospital solid waste management is the major target of the research, as it seeks to contribute to the attainment of Sustainable Development Goals by 2030 and Africa Agenda 2063 targets, particularly those related to environmental protection and human health.

Integrated solid waste management approaches are associated with numerous merits in various countries like India (Ganguly and Chakaraborty [43]), Brazil [44], Turkey (Bahçelioğlu et al. [45]), and Germany [46]. This research focuses on developing a sustainable integrated hospital solid waste management framework for two rural hospitals in Chirumanzu district, Zimbabwe. The research was guided by four objectives, namely, to characterize hospital solid waste generated by rural hospitals in Chirumanzu district. The study analyzed environmental risks of hospital solid waste management strategies employed by rural hospitals in Chirumanzu district. It also evaluates hospital solid waste management framework utilized by rural hospitals in Chirumanzu district and develops a sustainable integrated hospital solid waste management framework for rural hospitals in Chirumanzu district. The developed framework could act as a catalyst for different stakeholders and organizations to work hand in hand when dealing with hospital solid waste. Gathered and analysed data would enable Zimbabwe Ministry of Health and Child Care, Environmental Management Agency, Hospital Environmental Health Departments, and Local Authorities to collaborate and formulate strategies which support correct hospital solid waste management. Narrowing the gap to attain Zimbabwe National Development Strategy 1's cross cutting objective of environmental protection and natural resources management can also be achieved through using the proposed model. Policy makers can utilize the findings, particularly the framework to formulate policies related to hospital solid waste management in order to attain ZV 2030 and SDGs like life below water, life on land, good health and wellbeing, and sustainable cities and communities.

5.2 Materials and Methods

5.2.1 Description of the Study Area

The research was carried out in Zimbabwe, a landlocked country located in Southern Africa. The research was conducted in one of Zimbabwe's rural districts namely Chirumanzu rural district which is in the Midlands province of Zimbabwe. Chirumanzu is mainly covered by sandy loam soil which supports vegetation species like *Brachystegia spiciformis* like Musasa *Julbernardia globiflora*, namely, Mutondo and *Collospermum* (mopane) [47], and patches of grass [48]. Most of the people in Chirumanzu district often rely on subsistence agriculture as a primary means of sustenance and livelihood. The district's population grows at 1.2% per annum and is around 95 272 (ZIMSTAT [49]). Population growth and need for health services add burden to hospitals leading to generation of large volumes of solid waste. The study focuses on two rural hospitals, namely, ST Theresa (STT) and Holy Cross (HC) hospitals, which are

located in ward 8 and ward 6, respectively. Population of ward 8 and 6 is approximately 3,156 and 3,478 people, respectively (ZIMSTAT [49]). These hospitals were selected purposively since they receive patients from health institutions in the primary level within the district and beyond. STT hospital was constructed in 1958 with a bed capacity of 80, while HC hospital was constructed in 1960 with a bed capacity of 50.

5.2.2 Methods of Data Collection and Analysis

Descriptive cross-sectional research design that employs qualitative and quantitative paradigms in data collection, analysis, and presentation was adopted. Targeted healthcare workers were 147 and 64 employees at STT and HC, respectively. Sample size for questionnaire survey was determined using Taro Yamane [50] formula, translating to 105 at STT and 55 at HC hospitals. Utilization of stratified sampling procedure facilitates division of health workers into groups according to their occupation at hospitals. Representatives of each stratum were proportionally determined based on strata size using Bowley's [51] formula, Eq. 1.

$$\frac{\text{Required Sample Size}}{\text{Population size}} \times \text{stratum size}.$$

Equation 1: Bowley's formula for determining strata size.

Individuals for each stratum were numbered, and a computer generated random table was used to select strata representatives. Healthcare workers, namely, nurses, doctors, physiotherapists, laboratory technicians, radiologic technologists, eye-opticians, cleaners, and anesthetists were targeted as questionnaire respondents. Questionnaires with open and closed ended were self-administered to minimise margin of error. Questionnaires were used to collect demographic data, characteristics of hospital solid waste, management strategies, challenges, potential environmental health risks, and approaches to improve solid waste management strategies. Interviews were utilized to solicit data from key informants, namely, DMO, EMA Officer, EHT, Hospital HCD/S, and Hospital Matron which were purposively selected. Semi-structured interview guides were prepared and used to collect data from key informants. Interviews were used to collect data regarding types of hospital solid waste, management systems and challenges, environmental problems associated with solid waste, and strategies to minimize the problems.

The researcher conducted field observations. An observation checklist with aspects related to the study was prepared and used to collect data during observations. Observations were used to collect data on hospital solid waste characteristics, management approaches, potential environmental health risks, and fauna with access to disposal sites. A digital camera was utilized to capture photographs during observations. A digital weighing scale was used to weigh each plastic bag in order to determine the weight of solid waste. Quantity of solid waste obtained during the weighing process was recorded in a notebook. Ahmed's (1997) formula: Waste Generation Rate = Average Waste Production / Patient/day $\times$ Total Number of Patients admitted ($WGR = AWP/P/D \times T$ No of P), was utilized to quantify solid waste generated by the hospital in relation to admitted patients per day. Characterization of hospital solid waste in different categories was done using WHO/UNICEF [52]. Data on flora was collected through the use of transect lines and quadrants. Drawing of the transect line and placing of the quadrant along the line was carried out using Roshni et al.'s [53] procedure. A 320-m transect line was drawn down the slope from the dumpsite and quadrants were placed at 0 m, 160 m, and 320 m. The selected point acted as the center of the quadrant during quadrant drawing. Quadrant size was determined using the Roshni approach of 5 $\times$ 5 for shrubs (less than 1.37 m) and 10 m $\times$ 10 m for trees (1.37 m and above). The quadrant size for grass was adopted from Barker's (2001) method of 1 m $\times$ 1 m. Data on flora facilitates understanding potential effects of dumpsite pollutants on vegetation.

Soil and water samples were collected and submitted to the laboratory for analysis to understand impacts of disposal sites pollutants to soil and proximity water sources. Pollutant concentration commonly varies in soil samples collected at 10 m (m), 30 m, and 60 m from the waste site due to pollutants attenuation [54]. Hence, soil samples to determine concentration of contaminants were collected following a 60-m transect line at points which are 10 m, 30 m, and 60 m from the dumpsites for comparative analysis. However, for this study, another soil sample 0 m was located at the edge of the dumpsite to understand concentration of pollutants within the dumpsite and draw valid conclusions during comparison. All samples were collected at a depth of 5 cm at different points using soil sampling stainless hand Auger. The collected soil samples were packed in properly labelled 1-kg polythene bags. Water source with least distance from the waste site and the one with highest distance were purposively selected, translating to 2 water samples at each hospital under study. Water samples were collected utilising labelled brown polythene sterile 1-L containers.

Quantitative data was analysed using Statistical Package for Social Sciences version 25.0 at 95% confidence level and ME. Descriptive statistics such as mean, frequencies, and mode were used to show response rate for questionnaires. Chi-square was used to test association between quantity of solid waste and number of patients. Quantitative data was presented in the form of tables, charts, and graphs. Water samples were subjected to laboratory analysis to test pH, electrical conductivity, chemical oxygen demand, and total dissolved solids. Similarly, soil and water samples collected were submitted to the laboratory to be tested for lead (Pb), arsenic (As), mercury (Hg), and cadmium (Cd) levels. T-test was carried out at $p < 0.05$ and 95% confidence level to compare pollutants concentrations in soil and water samples collected from various distances from the waste site. Results from water and soil sample analysis were analysed by comparing them with WHO water and soil quality standards. Qualitative data was analysed through content analysis and presented using expressive and persuasive narratives as well as direct and indirect quotations. Development of an integrated sustainable hospital solid waste management framework was informed by configurative synthesis of these already existing frameworks and primary data. The Deming circle (observe, plan, do, check, and act) was used as a bedrock to develop a sustainable integrated framework.

5.3 Results and Discussion

5.3.1 Socio-demographic Characteristics of Respondents

Majority of questionnaire respondents at HC and STT hospitals were females rather than males (Table 1). Gender disparity can be explained by the fact that culturally and socially females are interested in offering health services compared to males in Zimbabwe. This gender disparity is already reported in the literature for healthcare services [55]. Respondents at both hospitals consist of healthcare workers of different age groups (Table 1), for instance, 18–26 years and 45 to 53 years. Healthcare workers include those with significant work experience and new workforce. This translates to variation in terms of healthcare workers' knowledge, awareness, and perspectives towards hospital solid waste management. Educational level of HC and STT healthcare workers varies since it includes people with certificates, diplomas, degrees, masters, and those who reach secondary level (Table 1). This helps to explain differences in awareness of healthcare workers towards hospital solid waste management. Differences in level of education entail that a comprehensive solid waste management framework which considers the level of knowledge of all healthcare workers is required. Work experience of healthcare

workers at hospitals under study was different, some with 0 to 5, 6 to 11, and 12 + years of work experience (Table 1). This potentially affects hospital solid waste management, since generally, health workers with more work experience have better understanding of solid waste issues. Their knowledge is probably enhanced by having attended more training and workshops related to hospital solid waste management than those with less experience. Attending more training workshops and training enhances knowledge on waste management issues in several ways [56].

Table 1: Socio-demographic data of healthcare workers at STT and HC hospitals

Variable	Response category	Respondents at each hospital			
		STT Hospital		HC Hospital	
		Frequency	%	Frequency	%
Gender	Males	39	37.1	24	43.6
	Females	66	62.9	31	56.4
Age	18-26	14	13.3	6	10.9
	27-35	31	29.5	12	21.8
	36-44	23	21.9	17	30.9
	45-53	26	24.8	11	20.0
	54 ⁺	11	10.5	9	6.4
Educational level	Secondary	9	8.6	10	18.2
	Certificate	20	19.0	13	23.6
	Diploma	63	60.0	29	52.7
	Degree	7	8.6	3	5.5
	Masters	4	3.8	0	0
Work experience	0-5	56	53.3	13	23.6

(years)	6-11	33	31.4	31	56.4
	12 ⁺	16	15.2	11	20.0

Source: Field data (2023)

5.3.2 Characteristics of Generated Hospital Solid Waste

Broad categories of solid waste produced at STT and HC hospitals were pharmaceutical, sharps, infectious, pathological, cytotoxic, radioactive, chemical, and general solid waste (Table 2). Results are similar to other rural hospitals in Uganda [57] and India [58]. Interviews, observations, and questionnaire results indicated that each category of hospital solid waste was represented by various components (Table 2). Considering Table 2, these two hospitals produce non-hazardous and hazardous waste which require proper segregation to enable sustainable management. A view upheld by Nyakatswau et al. [59] and Shabani and Jerie [7, 8] that health institutions like hospitals in Zimbabwe produce hazardous and non-hazardous waste. General solid waste produced include food waste, stationary, boxes, water, and drink bottles. These hospitals produce a certain proportion of solid waste which can be reused, recycled, or composted. This can be achieved if hospital solid waste is properly segregated. Existence of various waste categories (Table 2) entails that an integrated management approach is required to achieve sustainability. The two institutions produced electronic waste and construction and demolition waste, like Shabani and Jerie [7, 8] reported.

Table 2: Hospital solid waste generated at STT and HC hospitals

Major types of solid waste generated	Components of the solid waste
Pharmaceutical	Outdated/expired drugs, soiled drugs (tablets), remains of drugs, defective tablets, empty containers, and sachets of drugs/medicine
Sharps	Iron/steel nails, surgical knives, hypodermic needles, syringes with needles, broken glasses, infusion tubes or sets, blades, slides, pipettes, and metal scrap

Infectious	Culture/specimen containers, contaminated (cotton wool, gauze, mattresses, cotton swabs, plaster casters, and bed linen), soiled gloves, towels, masks, gowns, bandages, diapers, pads, and theater caps
Pathological	Severed limbs, health and unhealthy tissues, body parts, and organs
Cytotoxic	Remains of cytotoxic drugs, materials contaminated by materials used to suppress cell growth and cancer
Radioactive	Unsealed radionuclides, materials contaminated by radioactive materials, and absorbent paper
Chemical	Containers of chemicals such as reagents and disinfectants
General	Food waste (sadza, vegetables, maize cobs, and fruits), stationary (files, papers, and book covers), water and drink bottles, and package materials (empty boxes and plastics)

Source: Field data (2023)

5.3.3 Generation Trend and Quantity of Solid Waste

Figure 1 shows respondents' perceptions on hospital solid waste generation trends. Approximately more than half of the respondents 53.3% at STT and 50.9% at HC hospitals agree that solid waste was increasing. A scenario is indicated by the DMO and hospital matrons during interviews. Hospital solid waste increase was ascribed to increase of patients, special diagnosis procedures, and disposal of outdated materials (Fig. 2). High use of disposable personal protective equipment/clothing was highlighted by a significant number of respondents at HC (42.5%) and 35.1% at STT hospital. Utilisation of non-reusable materials to curb spread of infectious diseases like COVID-19 was accelerating generation of solid waste at these two hospitals. Adoption of single use approach when using hospital PPE/C contributed to increase of hospital solid waste [60]. Increase of patients was pointed as one of the driving forces since

besides generating solid waste during diagnosing those patients, their visitors produced solid waste particularly food waste, paper, and plastics. Hospital solid waste generated was dominated by general solid waste accounted for 77.35% at STT hospital and 79% at HC hospital (Fig. 3).

Large volumes of solid waste were similar to household general waste; hence, the materials can be recycled and reused to achieve circular economy. Infectious, cytotoxic, sharps, radioactive, pharmaceutical, pathological, and chemical waste's total accounted for 22.65% at STT hospital and 21% at HC hospital (Fig. 3). A certain proportion of solid waste generated at these hospitals was hazardous, which was even higher than what Rahman et al.'s [3] studies reported. Hazardous solid waste from STT and HC hospitals needs adequate attention. Existence of hazardous and non-hazardous solid waste at STT and HC hospitals emphasizes the significance of effective solid waste segregation during storage, treatment, and disposal. Results were slightly similar to other studies that about 75 to 90% of hospital solid waste is non-hazardous, while 10 to 25% is hazardous [61]. Disparity of hospital solid waste composition at these health facilities means a sustainable integrated management approach is required to manage different types of solid waste effectively.

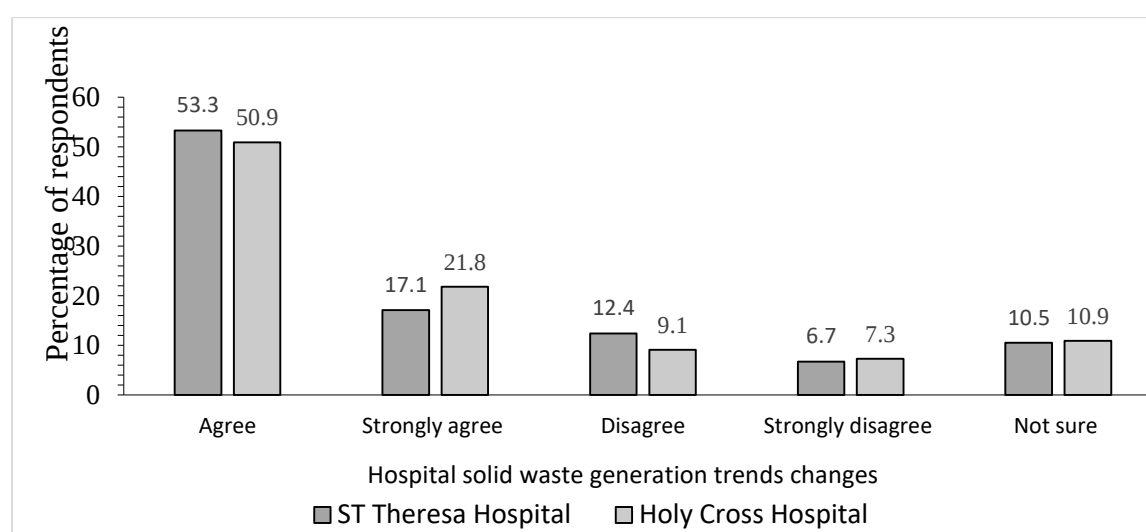


Fig. 1: Respondents' perceptions on hospital solid waste generation trends changes.

Source: Field data (2023)

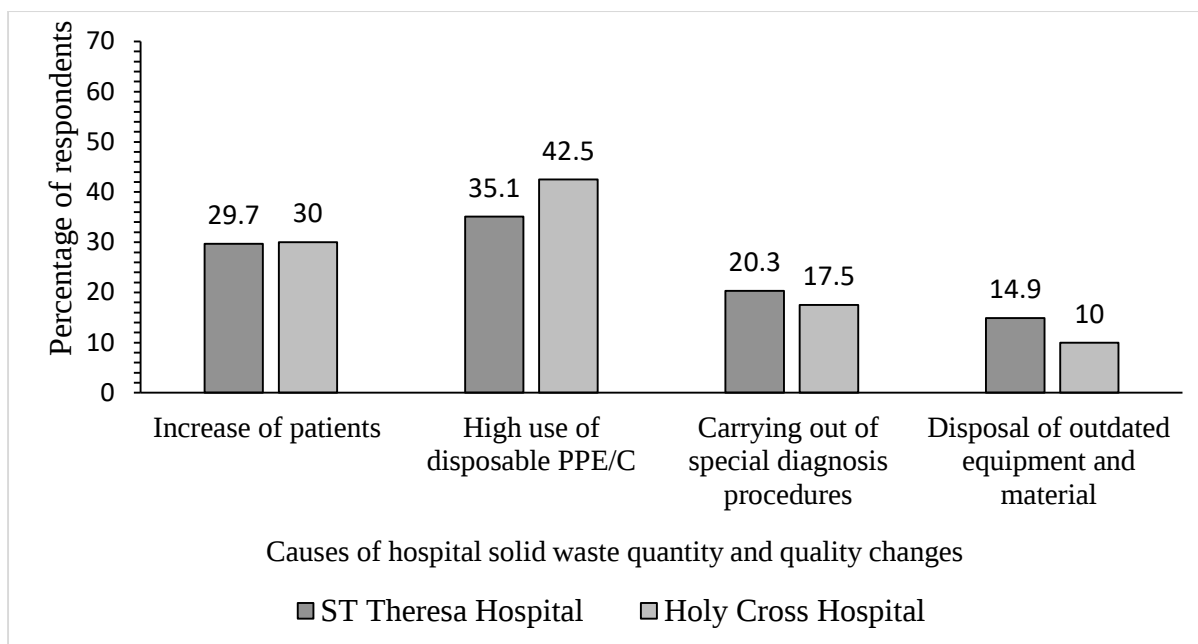


Fig. 2: Causes of hospital solid waste quantity and quality changes.

Source: Field data (2023)

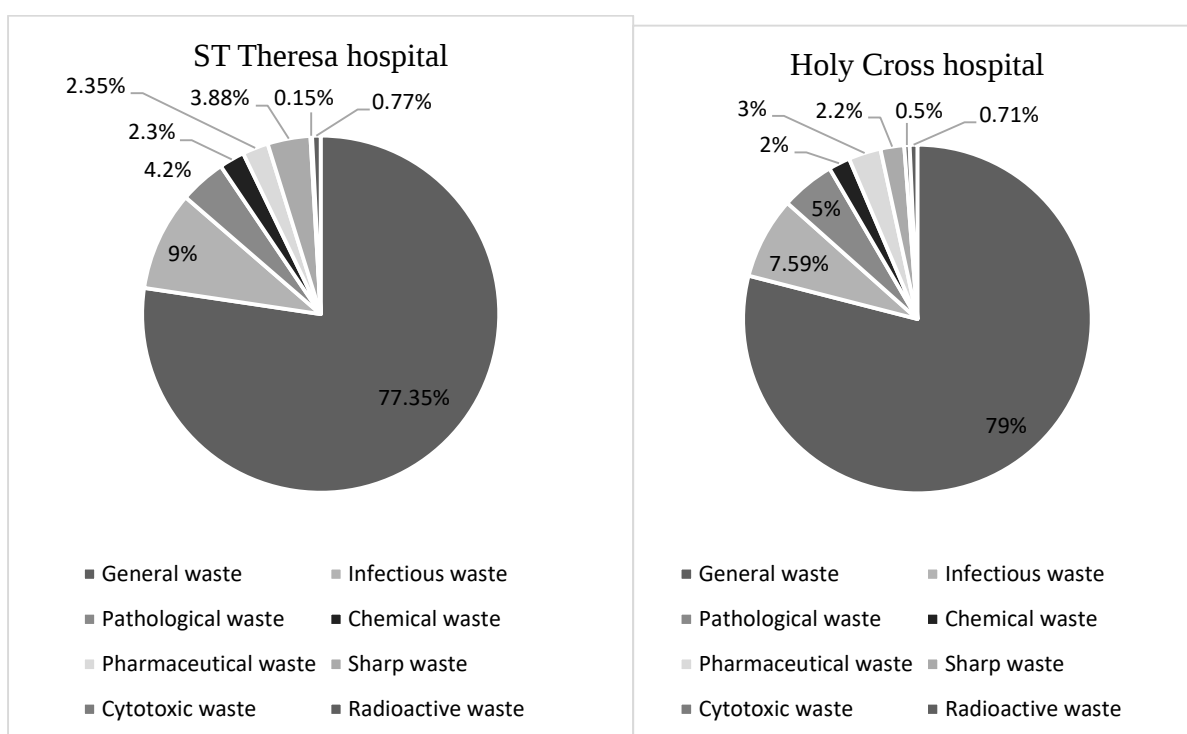


Fig. 3: Average composition of hospital solid waste generated per week (% by weight).

Source: Field data (2023)

5.3.4 Relationship of Hospital Solid Waste Generated and Number of Patients

Verdicts in Table 3 demonstrated the quantity of hospital solid waste generated. The table indicated that when the number of patients was high, the quantity of waste was also high. Similarly, a small amount of solid waste was generated when the number of patients was low. This presents an undeniable relationship between the number of patients and hospital solid waste increase. This was supported by Pearson Chi-square test results which indicated that there was an association between quantity of hospital solid waste generated and number of patients. Pearson Chi-square test of data collected at STT hospital and HC hospital indicated that χ^2_{cal} was 0.000, which is less than 0.05. Quantity of solid waste from health facilities is usually directly proportional to the number of patients [9].

Table 3: Demonstrates the average quantity of hospital solid waste generated per day

Hospital Name	Days when data was collected	Number of admitted patients per day of data collection	Average quantity of waste generated per day (Kg) per each day of data collection
HC	1	46	38.18
	2	41	34.03
	3	36	29.88
	4	43	35.69
	5	33	27.39
	6	38	31.54
	7	29	24.07
STT	1	91	79.17
	2	88	76.56
	3	68	59.16
	4	77	66.99

	5	83	72.21
	6	61	53.07
	7	54	48.72

Source: Field data (2023)

5.3.5 Hospital Solid Waste Management Approaches

5.3.5.1 Types of Hospital Solid Waste Storage Receptacles Used

Solid waste storage receptacles used at HC and STT hospitals include cardboard boxes, plastic bags, metal and plastic buckets, sharp containers, and pedal operated bins (Fig. 4). Findings coincide with research carried out by Theodore and Theodore [62] and Lemma et al. [63]. A considerable number of respondents at STT (72.4%) and HC (69.1%) highlighted the use of sharp containers and pedal operated bins. Popularity of sharp containers was probably attributed to its characteristics, namely, puncture resistant materials which facilitate storage of sharps. Dominance of pedal operated bins was ascribed to its hygienic nature where bins are opened without using hands, thus minimizing potential risk of cross infection, as reported by Rostvik's [64] studies. In terms of hospital solid waste segregation at storage level, the majority of respondents at STT (35.2%) and 67.3% at HC hospital indicated infectious and non-infectious (Fig. 5). Hospital contaminated materials and non-contaminated materials were stored in distinct waste receptacles. In most hospitals, solid waste is separated into infectious and non-infectious as well as sharps and non-sharps [62, 65]. However, other healthcare workers asserted that solid waste was separated into sharps and non-sharps during storage (Fig. 5). Hospital solid waste was also separated into organic and non-organic waste as noted by 23.8% respondents at STT hospital and 25.5% at HC hospital. Non-degradable and degradable useless materials were stored in separate receptacles. Nevertheless, at STT and HC hospitals, core storage of solid waste was observed, where food waste, plastics, and papers were stored together. Solid waste is indiscriminately stored at most medical institutions in Zimbabwe [7, 8].

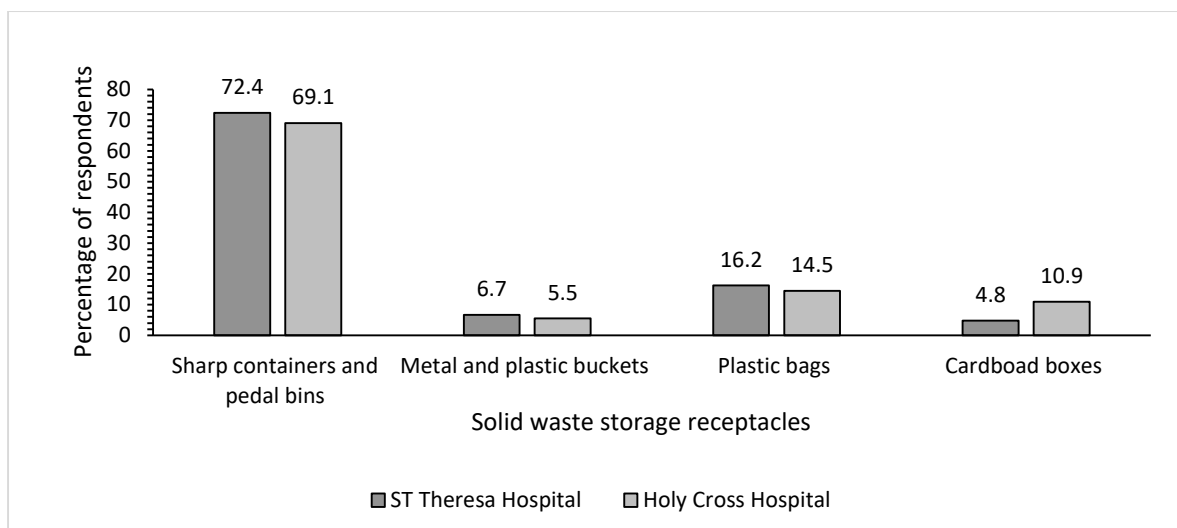


Fig. 4: Types of hospital solid waste storage receptacles used.

Source: Field data (2023)

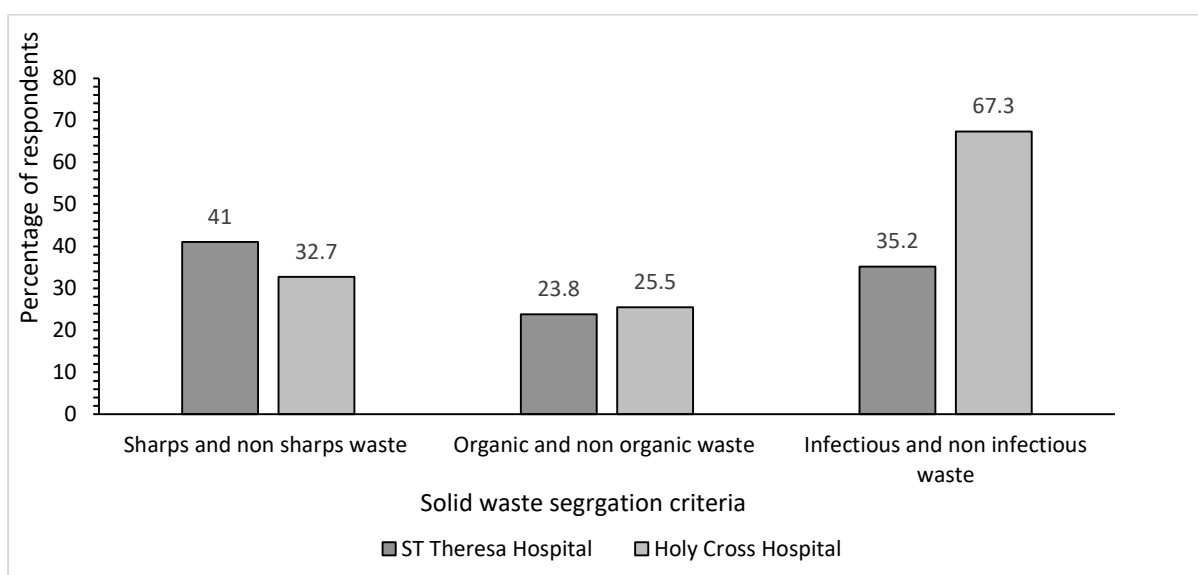


Fig. 5: Hospital solid waste segregation during storage.

Source: Field data (2023)

5.3.5.2 Treatment of Hospital Solid Waste

Highly infectious hospital solid waste particularly from isolation wards was disinfected through autoclaving and chlorination. Chlorination of hospital waste at these institutions involves utilization of chlorine-based disinfectants to eliminate or reduce the presence of

harmful microorganisms on contaminated materials. At STT and HC hospitals, chlorine is added to water and reacts with organic matter and other substances present in the water to form disinfection by products used to treat contaminated materials. Hospitals in Africa apply other approaches which destroys pathogens, thus minimizing impacts of infectious waste on human beings [66], and Zimbabwe is not spared. Effluent produced during chlorination is disposed together with other types of waste water disposed through the hospital sewer system. However, solid non-reusable hospital materials were incinerated after chlorination and autoclaving. Treatment of medical solid waste through chlorination and autoclaving is necessary to destroy micro-organisms on infectious solid waste before disposal [67]. In countries with limited resources, chlorination and autoclaving are usually used to treat solid waste expected to contain bacteria, fungi, and viruses [66]. This also explains high utilization of chlorination and autoclaving at STT and HC rural hospitals. Results from interviews indicated that use of autoclaving machines was hampered by power shortages owing to load shedding experienced in the country, hence, chlorination remains the chief treatment method. In developing nations, chlorination is mostly preferred under conditions where autoclaving is not feasible [67].

5.3.5.3 Transportation of Hospital Solid Waste

In terms of conveying hospital solid waste, observations, interviews, and questionnaire results correspond that utilization of wheelbarrows and manual handling by workers was common at HC and STT hospitals. Manual transportation of hospital solid waste to disposal sites was possibly due to minimal cost experienced when purchasing wheelbarrows. Manual handling of hospital solid waste receptacles to disposal sites is attributed to limited resources, specifically finance at STT and HC hospitals. Most rural hospitals in various developing countries are operated devoid of enough resources [68]. Improvising shortage of resources by manual handling of waste receptacles averts continuous accumulation of solid waste at generation source at these hospitals. Healthcare workers involved in manual handling of waste receptacles and pushing wheelbarrows at these hospitals are vulnerable to hand, shoulder, and wrist pain. Manual handling of solid waste receptacles, solid waste loading, and unloading results in occurrence of musculoskeletal disorders among involved workers [69, 70]. Handling of receptacles with infectious solid exposes healthcare workers to various pathogens, sharp injuries, and pricks. Manual handling of waste containers is less expensive and convenient but has the potential to increase sharp waste injuries among healthcare workers [16–18].

Sophisticated alternatives to convey hospital solid waste to disposal sites are required at HC and STT rural hospitals.

5.3.5.4 Frequency of Conveying and Emptying Hospital Solid Waste Receptacles

According to verdicts of the research conducted at STT and HC hospitals, solid waste receptacles were conveyed and emptied on a daily basis. This was postulated by significant respondents at STT hospital (87%) and 78% at HC hospital (Fig. 6). Daily emptying of hospital solid waste receptacles is crucial to reduce spread of infections and odours within hospital premises. Emptying and conveying of solid waste receptacles on a daily basis is recommended by WHO standards (WHO, 2014). Considering the physical appearance of stored hospital solid waste, it was clear that solid waste was conveyed to disposal sites after two or more days. A situation is noted by respondents at STT hospital (10%) and HC (15%) (Fig. 6). Sometimes, the frequency of emptying waste storage receptacles at STT and HC hospitals fails to conform to WHO and Zimbabwe Ministry of Health and Child Care standards. Delaying emptying of solid waste containers at these hospitals causes continuous accumulation of solid waste in already overwhelmed containers, resulting in spilling of solid waste on hospital floors. This poses significant health risks to human beings including patients, visitors, and health workers. Interview results of study conducted at STT and HC hospitals illustrated that sharp containers are disposed when they are $\frac{3}{4}$ full. A standard is also recommended by WHO [71]. Disposal of sharp waste containers when they are $\frac{3}{4}$ full minimizes risks of sharp injuries experienced when the containers are filled to capacity. Considering results related to sharps, disposal of sharp waste containers at STT and HC hospitals was determined by quantity in the container rather than days.

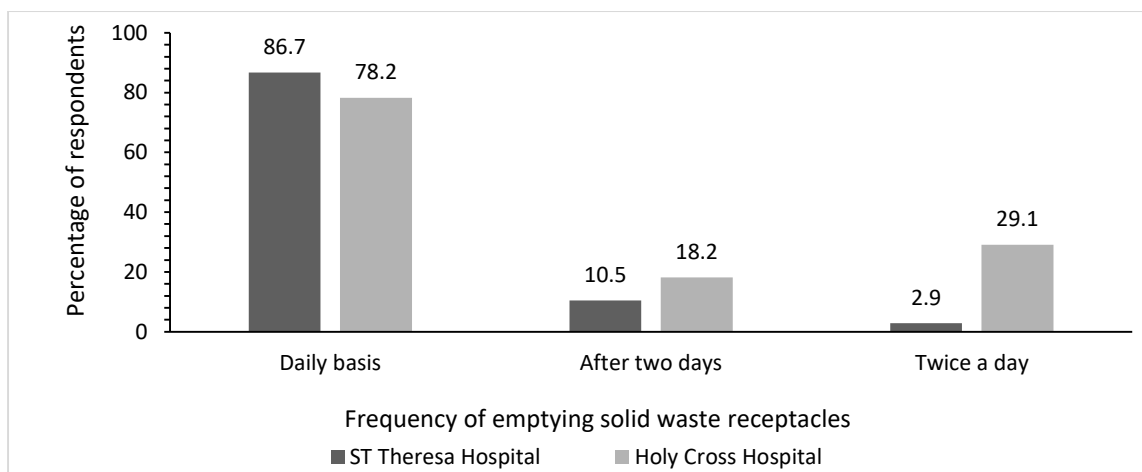


Fig. 6: Frequency of emptying solid waste receptacles.

Source: Field data (2023)

5.3.5.5 Disposal of Hospital Solid Waste

Results in Fig. 7, interviews and observations illustrated that at HC and STT hospitals, various solid waste disposal strategies are used, namely, incinerators (Plate 1), auto-way pits (Plate 2), open pits (Plate 2), and open burning. Observations indicated that solid waste exists on non-designated sites on hospital corners and under trees where visitors reside. This is supported by Chireshe et al. [69, 70] that solid waste was disposed following both recommended and non-recommended approaches in Zimbabwe.

Respondents at STT (44.8%) and HC hospital (41.8%) (Fig. 7) postulated that incinerators (Plate 1) were used to dispose solid waste for instance sharps, papers, plastics, infectious waste like soiled masks, gloves, bandages, cotton wool, and textiles. Majority of questionnaire respondents and interviewees indicated that incineration was regarded as the most effective strategy compared to other disposal approaches. Popularity of incineration at rural hospitals was attributed to its ability to destroy pathogens and turning bulk waste into ashes. Incineration is considered a golden approach used to dispose solid waste at urban and rural hospitals [57]. It was observed that at HC and STT hospitals, both combustibles and non-combustibles materials were loaded together in incinerators. This reduces efficiency of incinerators resulting in generation of partially burnt incinerator residues. Incineration of non-segregated solid waste is indeed a challenging task since materials contain different combustion properties [72]. At STT hospital, inefficiency of the incinerator was exacerbated by utilisation of an incinerator

with a cracked combustion chamber. Maintenance of the incinerator is required to propel its efficiency.

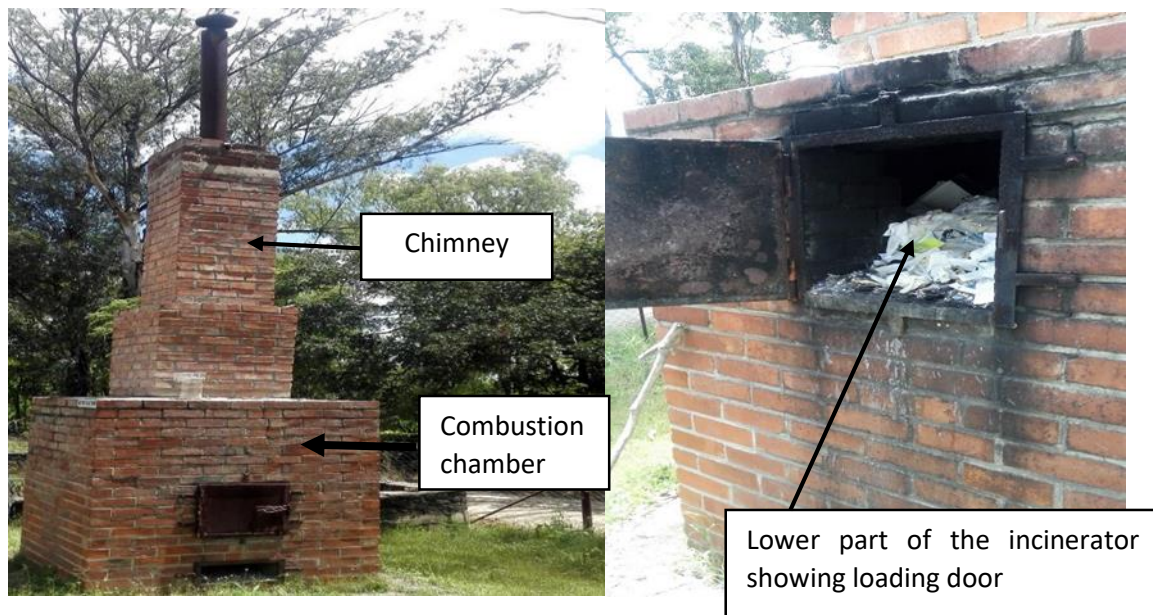


Plate 1: Incinerator used to dispose medical waste at HC hospital.

Source: Field data (2023)



Plate 2: Auto-way pit and organic open pit used to dispose pathological waste and organic waste respectively at STT hospital.

Source: Field data (2023)

Questionnaire respondents (16.2%) and HC (16.4%) (Fig. 7) and STT hospital EHT stipulated that hospital organic solid waste like food remains was disposed in open pits. Non-organic products such as plastics and papers were observed in the pit. Existence of inorganic and organic waste in similar pits was a result of indiscriminate storage of hospital solid waste at generation source. Indiscriminate storage and disposal of hospital solid waste is common among various hospitals in developing countries [9]. At these two hospitals, open burning was also used to dispose hospital solid waste. Uncontrolled open burning is associated with incomplete burning which generates toxic gasses leading to various respiratory problems. Most of the approaches used to dispose hospital solid waste at these two hospitals are least prioritized by the waste management hierarchy. In Zimbabwe, a number of approaches used to dispose solid waste of medical nature occupy the base of solid waste management hierarchy [7, 8]. HCD/S at STT hospital denotes that soft drink bottles are reused to store water while food leftovers are given to those who want to feed dogs and chicken, although a large fraction of hospital waste was discarded. Robust approaches to enhance solid waste minimisation strategies are required at these hospitals.

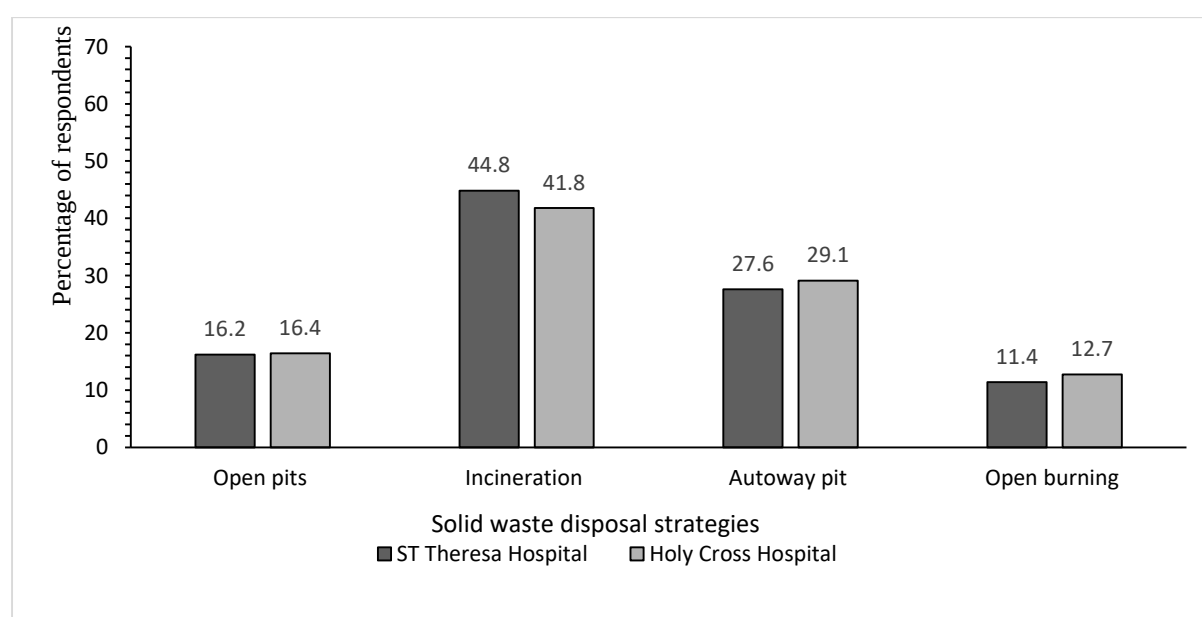


Fig. 7: Hospital solid waste disposal strategies.

Source: Field data (2023)

5.3.6 Environmental Risks Associated with Hospital Solid Waste Management Strategies

Environmental problems associated with various hospital solid waste disposal strategies used at STT and HC hospitals include air, water, soil contamination, visual pollution, and fire outbreaks (Fig. 8). Respondents at STT hospital (59%) and 56.4% at HC hospital articulated that incineration results in air pollution. Majority of respondents at HC hospital (58.2%) and at STT hospital (73.3%) highlighted that open burning cause air contamination. Interviews revealed that open burning and incineration processes cause air pollution. Incineration and uncontrolled open burning are major contributors of air contamination (Fig. 8). This is because they generate toxic gasses, namely, carbon dioxide, nitrous oxide, and carbon monoxide, as well as dioxins, furans, fumes, and smoke which deform air quality. Incineration and open combustion of hospital solid waste release various pollutants and particulate matter which alter natural concentration of gasses in the atmosphere [62]. Decomposition of solid waste in open pits and auto-way pits was noted among causes of air pollution by EMA officer and respondents at STT (22.9%) and HC (27.3%). Decomposing organic encompassing pathological waste generates methane into the atmosphere [73], thus, increasing global warming since methane is a greenhouse gas. Additionally, 20% of STT and HC hospitals respondents agree that pollutants from open pits cause groundwater pollution (Fig. 8). The EMA officer and 49.5% respondents at STT hospital and 40% at HC hospital concur that auto-way pits pose groundwater contamination. This was ascribed to the fact that pollutants from unlined auto-way pits and open pits infiltrate and percolate to reach ground water. Non-lined solid waste disposal structures produce pollutants which reach ground water [74].

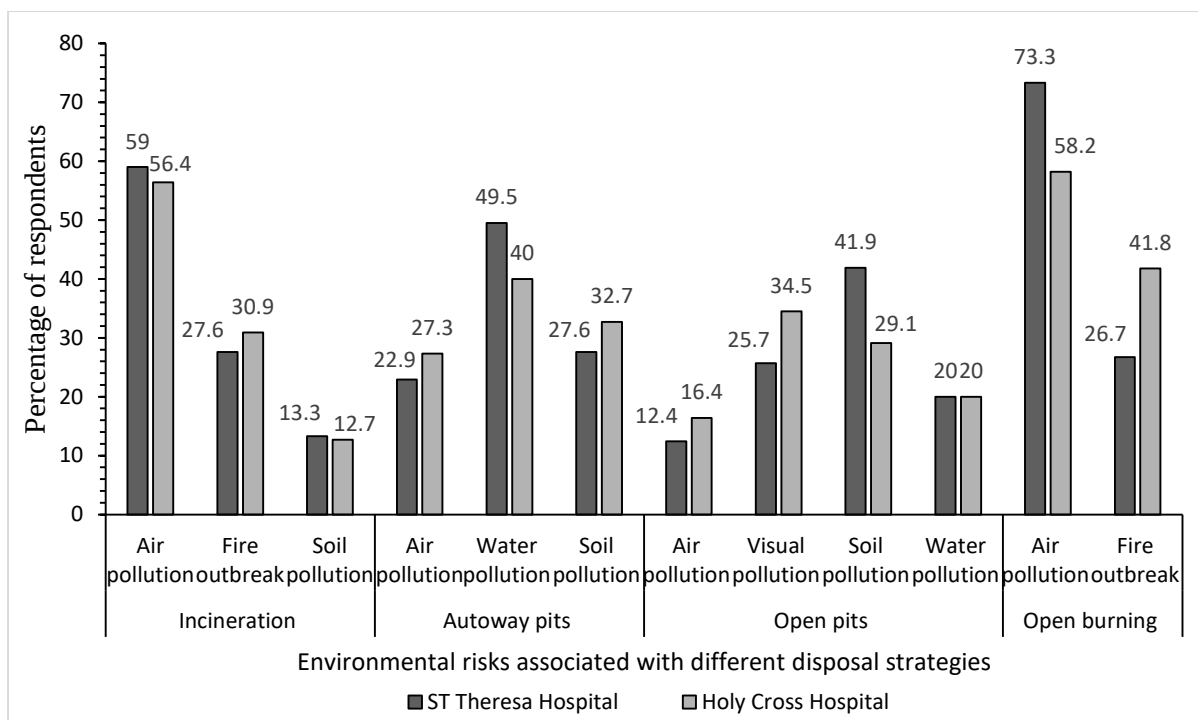


Fig. 8: Environmental risks associated with various hospital solid waste disposal strategies.

Source: Field data (2023)

Impacts of hospital solid waste dumpsite to groundwater were shown by the existence of high heavy metals concentration in ground water sources near hospital solid waste disposal sites. At STT hospital, water sample from water source A contain 0.009 mg/L of arsenic in wet season and 0.006 mg/L in dry season (Table 4); however, it was not detected in water samples of water source B. At HC hospital, level of cadmium in water source A was 0.003 mg/L in wet season and 0.001 mg/L although cadmium was not detected in samples of water source B. This situation was due to variation in distance from the dumpsite, since A was a label for water source in proximity to hospital dumpsite as compared to water source labelled B. The presence of elevated levels of heavy metals in groundwater sources near hospital solid waste disposal sites indicates that the dumping of hospital solid waste has a significant impact on groundwater quality [75]. At STT hospital, concentration of lead in samples from water source A was 0.006 mg/L in wet season and 0.0013 mg/L in water samples from water source B. There is association as well as correlation between concentration of pollutants (heavy metals) in water samples and distance from the dumpsite, since water source A was closer to dumpsite than B. Concentration of heavy metals in water sources that are in vicinity to dumpsites is high [76]. Additionally, concentration of mercury in water samples collected from water source A at STT

hospital was 0.008 mg/L in wet season and 0.006 mg/L. At HC hospital, concentration of lead was 0.007 mg/L in wet season and 0.005 mg/L in dry season (Table 5). High concentration of heavy metals in water sources during the wet season was possibly due to rainfall which facilitated easy movement of heavy metals from dumpsites to groundwater. Concentration of heavy metals in water samples was below WHO limits. Attention is needed to avert continuous accumulation of heavy metals in water sources, particularly water sources labelled as A.

Table 4: Metal concentration in ground water sources in proximity to STT hospital dumpsite, during dry and wet seasons.

Metal	Water Source A		Water Source B	
	Wet season	Dry season	Wet Season	Dry season
Arsenic	0.009mg/L	0.006mg/L	<i>ND*</i>	<i>ND*</i>
Lead	0.006mg/L	0.004mg/L	0.0013mg/L	0.0012mg/L
Cadmium	0.004mg/L	0.003mg/L	0.001mg/L	0.001mg/L
Mercury	0.008mg/L	0.006mg/L	<i>ND*</i>	<i>ND*</i>

Key: *ND**-Not Detected

Source: Field data (2023)

Table 5: Metal concentration in ground water sources in proximity to HC hospital dumpsite, during dry and wet seasons.

Metal	Water Source A		Water Source B	
	Wet season	Dry season	Wet Season	Dry season
Arsenic	0.005mg/L	0.003mg/L	<i>ND*</i>	<i>ND*</i>
Lead	0.007mg/L	0.005mg/L	0.002	0.0012
Cadmium	0.003mg/L	0.001mg/L	<i>ND*</i>	<i>ND*</i>
Mercury	0.006mg/L	0.004mg/L	<i>ND*</i>	<i>ND*</i>

Key: *ND**-Not Detected

Source: Field data (2023)

At HC hospital, pH was 7.18 in wet season and 7.21 in dry season in water source A; however, in water source B, pH was 6.21 in wet season and 6.28 in dry season (Table 6). This signifies slight differences in water samples pH in dry and wet season, although range of the pH was within WHO acceptable limits of 6.5 to 8.5. The pH of water samples collected during the wet season presents to be slightly acidic as compared to dry season samples which are slightly alkaline. Slight acidity during the wet season was probably attributed to influx of pollutants from dumpsites into ground water sources. A scenario is noted by Abiringa et al.'s (2020) studies. EC was 395 and 389 in wet and dry season, respectively, in water source A and in water source B, it was 229 in wet season and 221 in dry season at STT hospital (Table 6). This was possibly due to high infiltration and percolation of pollutants, specifically inorganic contaminants, namely, ions during the rainy season. In water source A at HC hospital, TDS was 128 in wet season and 123 in dry season but in water source B, TDS was 118 and 115 in wet and dry seasons, respectively. TDS presents to be high in water sources during wet season maybe due to availability of rainfall which drives both organic and inorganic solids to reach underground water through infiltration and percolation. TDS was 128 in water source A in wet season and 118 in water source B at HC hospital. Water source A is highly affected by dissolved solid since it was close to dumpsites in comparison to water source B; therefore, distance is triggering the variation. STT and HC dumpsite pollutants are causing detrimental impacts to underground water sources particularly those in close proximity to hospital dumpsites.

Table 6: Characteristics of water samples in terms of pH, electrical conductivity, chemical oxygen demand, and total dissolved solids.

STT hospital				
	Water Source A		Water Source B	
	Wet season	Dry season	Wet Season	Dry season
P.H	6.88	7.73	6.16	6.23
Electrical Conductivity (EC)	395	389	229	221
Chemical Oxygen	7.38	7.28	5.42	5.36

Demand (COD)				
Total Dissolved Solids (TDS)	123	117	115	113
	HC hospital			
	Water Source A		Water Source B	
	Wet season	Dry season	Wet Season	Dry season
p.H	7.18	7.21	6.21	6.28
Electrical Conductivity	426	420	301	294
Chemical Oxygen Demand	6.53	6.48	3.86	3.77
Total Dissolved Solids	128	123	118	115

Source: Field data (2023)

Results from questionnaire respondents (Fig. 8) and EMA officer alluded that auto-way pits, open pits, and incineration residues generate pollutants which affect soil particles and characteristics negatively. Pollutants from solid waste disposal sites affect soil quality negatively [77]. Respondents at HC hospital (29.1%) and STT hospital (41.9%) noted that open pits generate pollutants which cause soil contamination. Pollutants from auto-way pits were among drivers of soil pollution as highlighted by 27.6% and 32.7% respondents at STT and HC hospitals, respectively. There is a need to curb negatives caused by open and auto-way pits through lining the bottom and sides of the structures with concrete. Laboratory analysis of soil samples collected from various distances from STT and HC dumpsites revealed that the soil samples contain lead, mercury, arsenic, and cadmium (Table 7). Soil samples collected at 0 m from STT hospital dumpsite contain 52.4 mg/kg of lead and samples collected at 0 m from HC hospital contain 56.3 mg/kg of lead. Concentration of lead in soil samples collected at a distance 0 m from the dumpsites was above WHO limits of 50 mg/kg. Hospital solid waste

dumpsites are sources of heavy metals with potential to increase soil acidity, hence affecting soil fertility and microorganisms. Dumpsites generate heavy metals which affect soil quality [78]. Concentration of lead in soil samples collected at 30 m from HC and STT dumpsites was 30.2 mg/kg and 33.2 mg/kg, respectively. Concentration of lead was below WHO limits at 30 m from dumpsites. Concentration of heavy metals in soils decreased as distance from the hospital dumpsite increased, since lead concentration was higher in soils at 0 m than at 30 m. This was supported by a T-test which was used to compare concentration of lead at 0 m, 10 m, 30 m, and 60 m. T-test results indicated P value at 0.000 and 0.001 which is less 0.05; therefore, it is statistically significant. There is a difference in concentration of lead as distance increases from the dumpsites. These verdicts correspond with that concentration of heavy metals such as lead, mercury, cadmium, and arsenic in soil commonly depend on distance from dumpsites [78].

Table 7: Concentrations of heavy metal pollutants in soil samples.

Distance from the dumpsite	Name of metal	ST Theresa	HC
		Metal content (mg/kg)	Metal content (mg/kg)
0m	Lead	52.4	56.3
	Cadmium	3.16	3.9
	Mercury	1.09	1.04
	Arsenic	0.2	0.4
10m	Lead	46.7	42.8
	Cadmium	3.11	3.3
	Mercury	1.073	1.077
	Arsenic	0.06	0.09
30m	Lead	33.2	30.2
	Cadmium	1.2	1.4
	Mercury	0.88	0.63
	Arsenic	0.001	0.004
60m	Lead	19.6	21.3
	Cadmium	0.7	0.10
	Mercury	0.023	0.029

	Arsenic	<i>Not Detected</i>	<i>Not detected</i>
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Source: Field data (2023)

Scavenging animals that visit STT and HC hospitals dumpsites include cats (*Felis catus*), dogs (*Canis lupus familiars*), chicken (*Gallus gallus domesticus*), and wild foxes (*Vulpes vulpes*). Domestic and wild animals consider hospital dumpsites as dietary sources since they consume edible items on the dumpsites. Different types of animals visit dumpsites looking for food [79]. Interviews revealed that other animals consume plastics which are attached to food scraps. The animals are vulnerable to intestinal blockage, throat choking leading to death, and internal bleeding due to laceration caused by plastics. Plastics including those used in hospitals are sources of health problems affecting animals that visit dumpsites [80]. Birds such as crows (*Corvus spp.*), vultures (*Cathartes aura*), eagles (*Accipitridae*), and red-whiskered bulbul (*Pycnonotus jocosus*) always visit hospital dumpsites (Table 8). Wild birds visiting the dumpsites were dominated by *Corvus spp.* at both hospital dumpsites representing 37% at STT dumpsite and 32% at HC hospital. Dominance of *Corvus ssp.* was a result of its high availability in the areas where the two hospitals are located. Composition of vultures (*Cathartes aura*) at STT hospital was 29% and 25% at HC hospital dumpsite. Large number of vultures (*Cathartes aura*) scavenging for food on dumpsites was observed by McGrady et al.'s [81] research. These birds are affected negatively by hospital solid waste since they consume pathogens and can be trapped within the dumpsites translating to death.

Table 8: Average % of different birds visiting hospital dumpsites.

Name of the bird			STT dumpsite	HC dumpsite
Shona	English	Scientific		
Makunguwo	crows	<i>Corvus spp</i>	36	32
Magora	vultures	<i>Cathartars aura</i>	29	25
Makondo	eagles	<i>Accipitridae</i>	12	17
Makwenhure	red-whiskered bulbul	<i>Pycnonotus jocosus</i>	23	26

Source: Field data (2023)

Vegetation survey indicated that characteristics of vegetation species, namely, grass, trees, and shrubs vary with distance from HC and STT dumpsites (Table 9). The nature of vegetation at and close to solid waste disposal sites differs significantly from that found in the natural

environments [7, 8]. Composition of grass in quadrant at 0 m from HC hospital dumpsite was 73% invasive species and 27% native species, 61% invasive species and 39% native species at 160 m, and 9% invasive species and 91% native species. At STT hospital, quadrants located at 0 m, 160 m, and 320 m composed 81%, 61%, and 23% invasive shrubs, respectively, while native shrubs were 19.39% and 77% in quadrants located at 0 m, 160 m, and 320 m, respectively. Quadrants in proximity to dumpsites were found to accommodate higher prevalence of invasive vegetation species than native species. Hospital solid waste dumpsites generate pollutants which support growth of invasive grass and shrubs which are aggressive and have potential to outcompete native plants. Dumpsite contaminants have potential to alter vegetation composition (Vaverkova et al. [82]).

Table 9: Composition (%) of invasive and native vegetation species at different locations from dumpsites.

Distance from dumpsite	Grass				Shrubs				Trees			
	HC		ST Theresa		HC		STT		HC		STT	
	I	N	I	N	I	N	I	N	I	N	I	N
0 m	73	27	78	22	79	21	81	19	0	0	0	0
160 m	61	39	56	44	55	45	61	39	57	43	51	49
320 m	9	91	16	84	36	64	23	77	3	97	7	93

Key: I- Invasive species

N- Native species

Source: Field data (2023)

5.3.7 Occupational Health Risks Associated with Hospital Solid Waste Management Strategies

Results indicated that healthcare workers are aware of occupational health risks associated with hospital solid waste management as demonstrated by 89.5% at STT and 83.6% at HC hospitals. High level of awareness can be attributed to their work which deals with health issues and active participation in awareness programs. Existence of knowledgeable healthcare workers is crucial since awareness is essential in minimising occupational health risks associated with handling hospital solid waste [83]. Occupational health risks highlighted by respondents

include pricks, cuts, contacting infectious waste, inhaling noxious odours, hand pain, back pain, and being exposed to heat or radiation from combustion of hospital solid waste (Fig. 9). Majority of healthcare workers 28.7% at STT and 23.9% at HC indicated that pricks occur at solid waste storage stage. Similarly, 19.1% at STT hospital and 15.2% at HC hospital highlighted cuts at storage stage. Most sharp injuries experienced by health workers occurred during handling of sharps at the storage stage. This is an issue of concern since injuries caused by hospital sharp waste puts health workers at risk of contracting diseases, namely, hepatitis, HIV and AIDS, tetanus, tuberculosis, and COVID-19. Individuals who are vulnerable to hospital sharp waste are at high risk of being affected by sharp injuries translating to occurrence of infectious ailments [4].

Healthcare workers contact infectious materials during storage, transportation, and disposal of hospital solid waste (Fig. 10), hence are vulnerable to various pathogens. Healthcare workers should prioritize use of PPE/C such as gloves, masks, and aprons to safeguard themselves. Incinerator operators highlighted that they are threatened by back and hand pain due to manual lifting of solid waste receptacles when loading incinerators. Owing to repetitive nature of the work coupled by weight of receptacle waste, waste workers are affected by musculoskeletal disorders, namely, muscle pain alongside joint injuries. Musculoskeletal disorder occupational hazard is common among workers involved in manual waste management tasks [16–18]. At STT hospital, an incinerator operator was observed performing daily duties without enough safety gear (Plate 3). Performing this hazardous activity without enough PPE/C can be highly attributed to lack of awareness regarding the potential hazards associated with their work. Incinerator operators are susceptible to excessive radiation translating to dehydration, heat stress, skin irritation, rash, neurological problems, and high blood pressure. Findings illustrated that healthcare workers inhale noxious odours during storage, collection, treatment, and disposal of hospital solid waste. Exposure to noxious odours results in respiratory problems like coughing, nausea, throat irritation, dizziness, throat and eye irritation, and headache. Provision of adequate PPE/C to healthcare workers and incinerator operators is crucial to uphold their health, since they are exposed to acute and chronic health problems [84].



Plate 3: Incinerator operator wearing inadequate safety gear at STT hospital.

Source: Field data (2023)

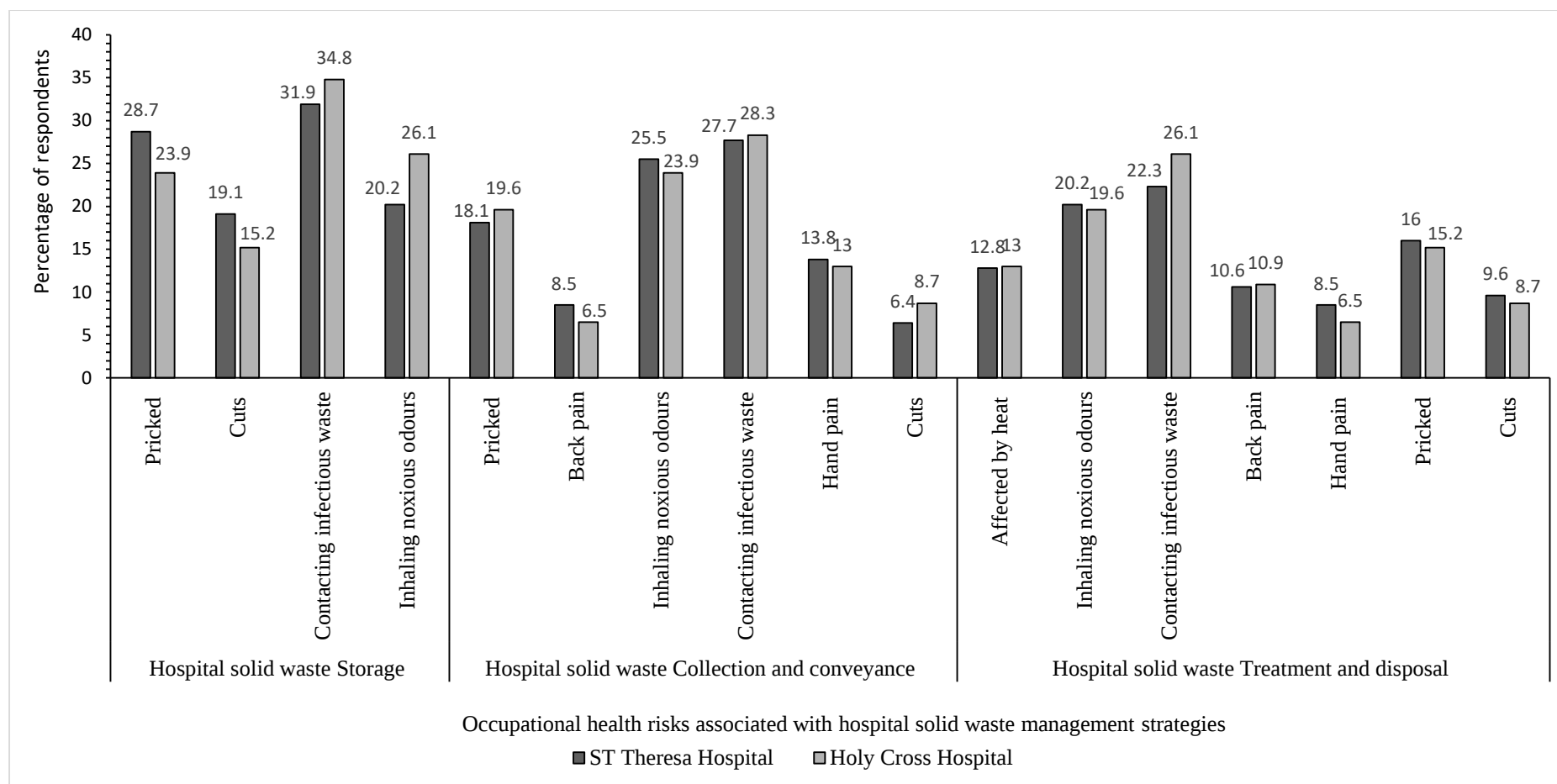


Fig. 9: Occupational health risks associated with hospital solid waste management strategies.

Source: Field data (2023)

5.3.8 Challenges in Management of Hospital Solid Waste

EMA officer asserted that most healthcare workers are unaware of legal frameworks that address hospital solid waste. Unawareness of legislation was articulated by majority of respondents at HC 58.2% and 54.3% at STT. Lack of understanding of the legal framework guiding solid waste management causes improper hospital solid waste management [85]. Knowledgeable healthcare workers noted that hospital solid waste management was guided by Ministry of Health and Child Care waste management guidelines, Environmental Management Act Chapter 20:27, and Public Health Act Chapter 15:09. Failure to mention Zimbabwe Integrated Solid Waste Management Plan means involvement of stakeholders and different approaches in management of hospital solid waste is still at infancy stage. Problems are fueled by lack of awareness towards WHO hospital solid waste guidelines. Conformity to hospital solid waste management legal framework was considered less by 45.8% respondents at STT hospital and 47.8% at HC. Solid waste management approaches at these two hospitals are far from recommended legislation and policies, hence can be termed less sustainable. Limited conformity to legislations at rural hospitals can be attributed to unawareness coupled by inadequate law and policy enforcement and follow-ups. Without appropriate enforcement, compliance to solid waste legislations, standards, and policies remains low [86]. Respondents (Fig. 10) and interview results illustrated that hospital solid waste management challenges involve waste increase, inadequate finance, unawareness among healthcare workers, and shortage of labour as well as neglect of solid waste issues by responsible authority.

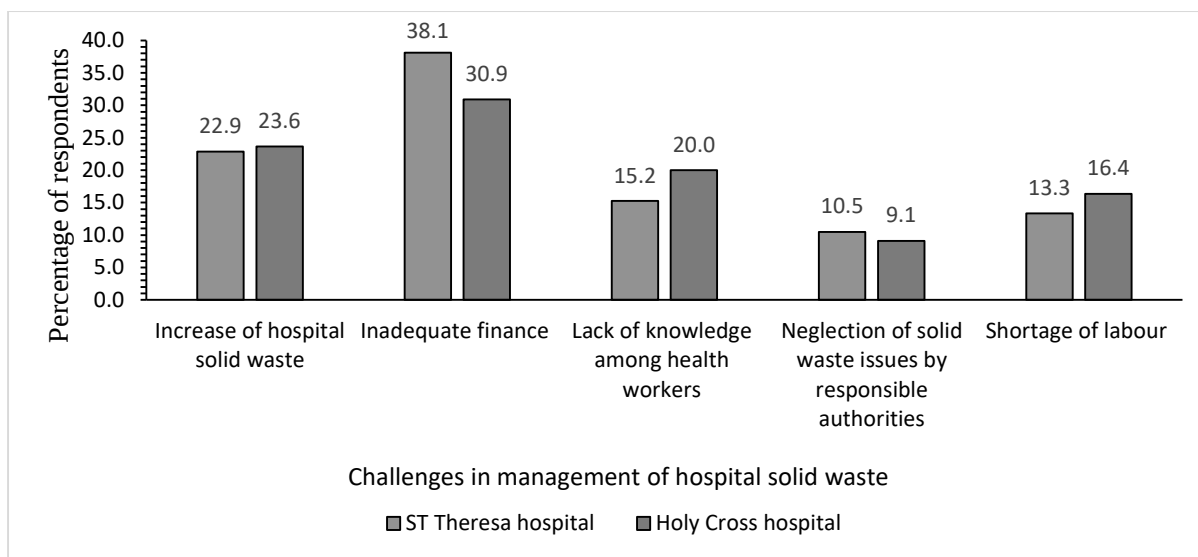


Fig. 10: Challenges faced by STT and HC hospitals in management of solid waste.

Source: Field survey (2023)

A significant number of healthcare workers at STT (79.0%) and HC (76.4%) noted that there was no room for all stakeholders to provide ideas in solid waste management issues. Participation and inclusion of all healthcare workers in management planning for management of solid waste is limited at these hospitals, resulting in difficulties in achieving sustainable hospital solid waste management. Inclusion of various relevant stakeholders in management of solid waste is an essential ingredient to achieve apt solid waste management [87]. Challenges posing problems in management of hospital solid waste include shortage of labour, lack of knowledge among health workers, and neglect of hospital solid waste issues by hospital authority. Irresponsible hospital authorities are among contributors of problems experienced in management of hospital solid waste. Large proportion of health workers at STT hospital (38.1%) and 30.9% at HC hospital revealed inadequate finances as a challenge. Shortage of finance limits purchasing enough resources, namely, hospital waste receptacles, hinders construction of standard waste disposal infrastructure, and impedes recruiting of enough labour. Healthcare waste mismanagement in Zimbabwe is ascribed to inadequate enforcement of legal frameworks, insufficient finance, and non-involvement of all stakeholders and health workers' unawareness [7, 8]. EMA officer, 22.9% respondents at STT and 23.6% HC hospitals, concurs that increase of solid waste causes obstacles in management of solid waste. Solid waste increases overwhelm capacity of available solid waste receptacles, disposal structures, and available workforce at these rural hospitals, resulting in improper management of hospital solid waste.

Respondents at STT (73.3%) and HC (69.1%) hospitals indicated that the existing solid waste management framework follows collection to disposal approach. The implemented frameworks at these hospitals give minor attention to CE and the upper part of the waste management hierarchy. This is supported by Ahmad et al. [85] that the application of hospital solid waste recycling, reuse, and recovery is indeed low in developing countries due several factors including limited resources. Low utilization of solid waste minimization strategies was indicated by participants at STT (26.7%) and HC (30.9%). This may be attributed to the fact that practicing reuse of hospital materials is controversial due to the nature of hospital materials which may pose health risks. Application of waste minimization techniques, namely, reuse and recycling is still at infancy stage in Zimbabwe (Jerie and Mandeverere, 2018). Observations illustrate that indiscriminate storage of solid waste was practiced at these hospitals, translating to difficulties in management of solid waste. In terms of training intervals, respondents noted weekly basis, monthly basis, after month, and above as well as not known (Fig. 11). Variation of respondents' views denotes that the framework's training system can be described as inconsistent and erratic.

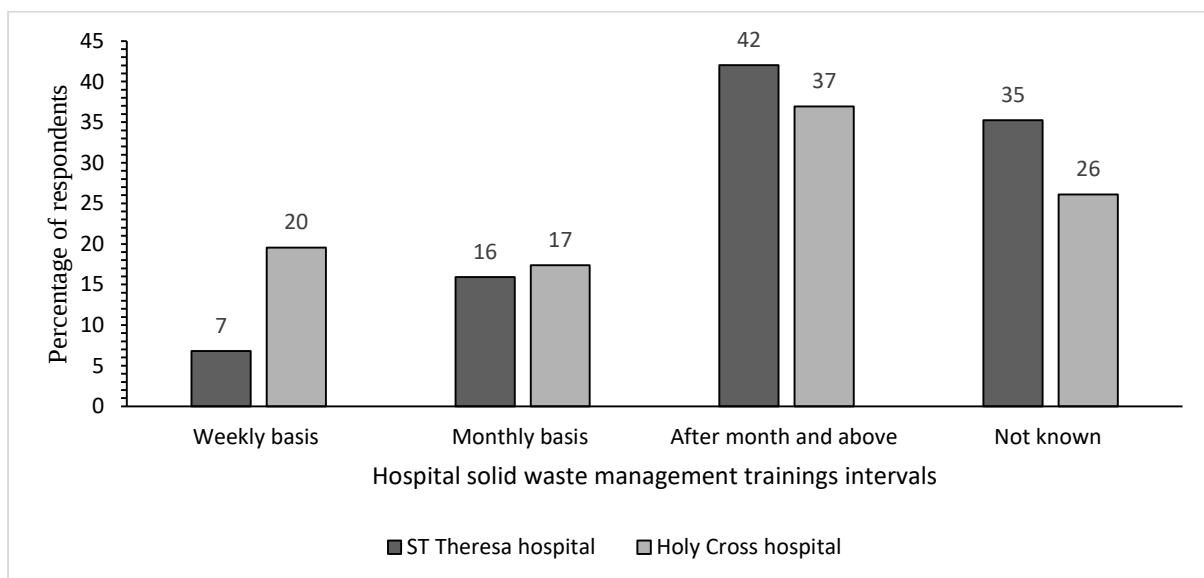


Fig. 11: Hospital solid waste management training intervals STT and HC hospital.

Source: Field survey (2023)

5.3.9 Strategies to Minimise Environmental Health Risks Associated with Hospital Solid Waste

Respondents (Fig. 12) and interviews illustrated that raising awareness of healthcare workers, use of appropriate storage and disposal facilities, and budgeting enough resources for solid waste were required at these two hospitals. Figure 12 revealed that adequate supervision of healthcare workers and provision of proper PPE/C to workers is essential. NSSA Safety Officer and healthcare workers at STT (29.5%) and HC (29.1%) agreed that occupational health risks associated with hospital solid waste can be averted by use of PPE/C. PPE/C is regarded as a golden approach to safeguard workers involved in management of solid waste not sparing hospital solid waste [84]. PPE/C occupies the base of occupational hazard control hierarchy, hence can be less effective in protecting health workers from hospitals solid waste impacts. These hospitals should invest in strategies which are highly prioritized by hazard control hierarchy, namely, elimination, substitution, and engineering controls. Adoption of most effective approaches on hazard control hierarchy minimizes occurrence of occupational health problems [16–18]. Respondents at STT (23.8%) and HC (25.5%) and EHTs alluded that budgeting enough resources for hospital solid waste management was required. Hospital solid waste management is a complex process which requires adequate resources.

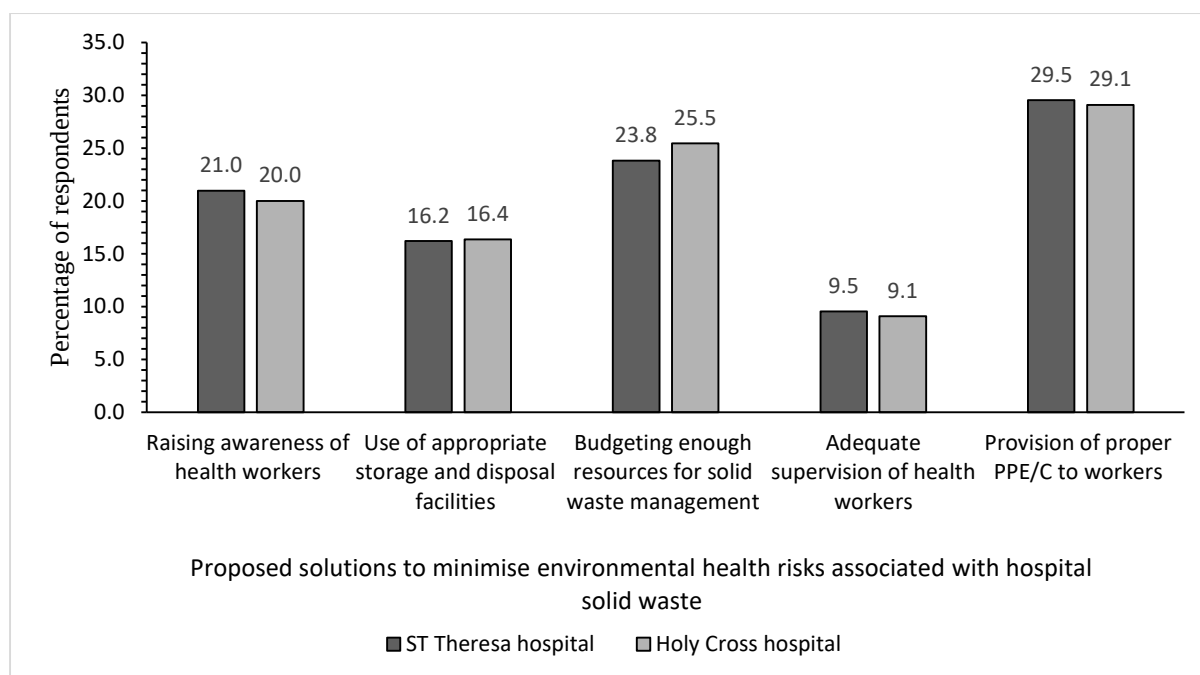


Fig. 12: Solutions proposed by respondents to minimize environmental health risks associated with hospital solid waste.

Source: Field survey (2023)

Research results indicated that awareness of healthcare workers regarding hospital solid waste management needs to be raised, through workshops and training programs involving health workers during planning. Raising awareness of involved stakeholders is essential to achieve sustainable solid waste management [88]. Utilization of appropriate storage and disposal facilities and adequate supervision of healthcare workers could reduce environmental health risks. If these two hospitals adhere to ZMoHCC and WHO guidelines when storing solid waste, appropriate segregation can be achieved. Appropriate segregation and storage of solid waste reduce difficulties during waste treatment, transportation, and disposal while preventing spilling over on non-designated areas [9]. According to EMA officer, disposal strategies at STT and HC hospitals must focus on approaches which support CE. This entails that these two hospitals should prioritize waste recycling, reuse, and recovery which leads to attainment of CE. Solid waste recycling, recovery, and reuse support CE [16–18]. The EMA officer revealed that hospital solid waste dumpsites must be fenced and secured with proper gates to limit accessibility of animals. Securing of dumpsites protects domestic animals from health risks that emanate from hospital solid waste while preventing cross infection to homesteads.

5.3.10 Proposed Sustainable Integrated Hospital Solid Waste Management (SIHSWM) Framework

The framework (Fig. 13) highlighted engagement of all stakeholders when planning, revising, adopting, implementing, documenting results of executed plans, and evaluating the gathered results towards hospital solid waste management. The framework upheld involvement of various individuals like District Medical Officer, Environmental Health Technicians, health workers, hospital cleaners, hospital departments such as Environmental Health Department members, organisations such as Environmental Management Agency, National Social Security Authority and ministries exemplified by Ministry of Health and Child Care and institutions like Rural District Councils and companies involved in turning solid waste into resources in hospital solid waste management, thus enabling sharing of ideas among different people. Inclusion of stakeholder facilitates sustainable solid waste management [89] including medical waste management [7, 8]. All responsible stakeholders can be involved through carrying out public meetings, workshops, and consultation programs, allowing them to participate and consider their views. Engagement of all stakeholders is a process which requires appropriate techniques and experts since stakeholders would have different educational, political, and social backgrounds impeding their ability to agree on certain aspects. The framework assumes that stakeholders provide crucial information which is essential to achieve sustainable integrated hospital waste management. Stakeholders offer information which plays a pivotal role during solid waste management [90]. The framework circular stages indicated that plans should be revised to check if they suffice economic development, CE, and sustainable environmental management goal demands before being implemented. Gaps and opportunities associated with the plans are unearthed; hence, corrective measures are put in place resulting in adoption of the plans. Revision and reviewing plans facilitate checking and amendment of errors [91]. After implementation of the adopted plans, results of the implemented plans are documented and evaluated to observe if they are in line with targets noted during planning. If the results fail to address the plans adequately, accountable stakeholders repeat the planning stage. Through carrying out these processes, the proposed framework offers an opportunity for continuous improvement of hospital solid waste management at these hospitals.

The framework illustrated that aspects of recycling, reusing, recovery, repair, and restructuring should be considered to achieve sustainable hospital solid waste management. Rural hospital solid waste management techniques must apply strategies which support CE, economic growth, ZERO waste, and clean environment. This framework offers a foundation to implement policies which support recycling, reuse, and recovery. Application of recycling is possible since the study illustrated that almost 80% of solid waste generated at these rural hospitals is non-hazardous. Hospital solid waste recycling and reuse minimizes cost of purchasing new products while generating finance through selling of recycled products. Sustainable framework asserted that raw disposal of hospital solid waste is a waste of resources which can accelerate economic growth. This goes in line with Dlamini et al. [92] that appropriate management of solid waste may act as a base for economic growth as well as sustainable environmental management in Africa. The framework (Fig. 13) includes Rs of reputation and response to change when managing solid waste from rural hospitals. In terms of reputation, rural hospitals should utilize solid waste management techniques which do not tarnish hospital image directly. Response to change generally entails that hospitals must have plans dealing with future projections so that they are not affected if trends and quality of hospital solid waste changes. Thus, carrying out proactive planning increases resilience of rural hospitals when hospital solid waste presents to be beyond their capacity. Integrated solid waste management plan must deal with existing and projected future scenarios (Kurniawana et al. [93]). The framework regards sanitary landfilling as part of sustainable integrated solid waste management at rural hospitals. This may be ascribed to the fact that although rural hospitals solid waste can go through processes like recycling, reuse, and recovery, a certain proportion might be highly contaminated, therefore suitable for treatment and landfilling only. Sanitary landfilling remains essential because even reused and recycled rural hospitals materials may also reach disposal period. Importance of sanitary landfilling was confirmed in studies by Vaverkova [94].

When planning, revising, adopting, and implementing plans and documenting and evaluating the results, involved stakeholders should consider SHABANITT principle (Fig. 13). According to the principle, Safety of workers involved in waste management is considered. Health risks associated with dealing with hospital solid waste need to be reduced through use of provision PPE/C, elimination, substitution, engineering, and administrative measures. Proper conformity to safety hierarchy of control methods minimizes workplace related health problems [16–18]. The principle includes aspects of Human well-being, indicating that management approaches

must support approaches which avert outbreak of various ailments among people of all ages and gender. SHABANITT principle takes into account Atmospheric, Aquatic, and Terrestrial ecosystems when managing rural hospitals solid waste. This upholds the safety of natural ecosystems which offer various services to people. The principle asserted that appropriate rural hospital solid waste management should conform to National and International guidelines and legal frameworks. Conformity to legal frameworks reduces risk of losing finance from rural hospitals through paying environmental fines and taxes. Adherence to solid waste management international and national standards is of utmost significance in ensuring sustainability [95].

In order to attain sustainable hospital solid waste management, integration of Technology including remote sensing (RS) and Geographic Information Systems (GIS) is significant at rural hospitals. GIS and RS have potential to assist in planning solid waste collection routes and sustainable location of disposal sites. The framework urges the government to formulate policies which support utilization of GIS and RS in solid waste management at rural hospitals. Technologies which support conversion of rural hospitals solid waste into energy are important, since energy is scarce in Zimbabwe. Rural hospitals must phase out manual handling of solid waste receptacles during transportation and loading of incinerators through the use of automated machines. SHABANITT principle revealed that Background information is required when dealing with rural hospitals solid waste. Understanding solid waste qualitative and quantitative information is crucial for effective waste management [96]. Essential background information includes the nature of existing solid waste management approaches, environmental health risks associated with the approaches, and stakeholders involved in management of rural hospitals. Background information regarding hospital solid waste management national and international legislation, guidelines, and policies is vital when planning. Background information gathered through research provides a roadmap to attain sustainable hospital waste management [7, 8].

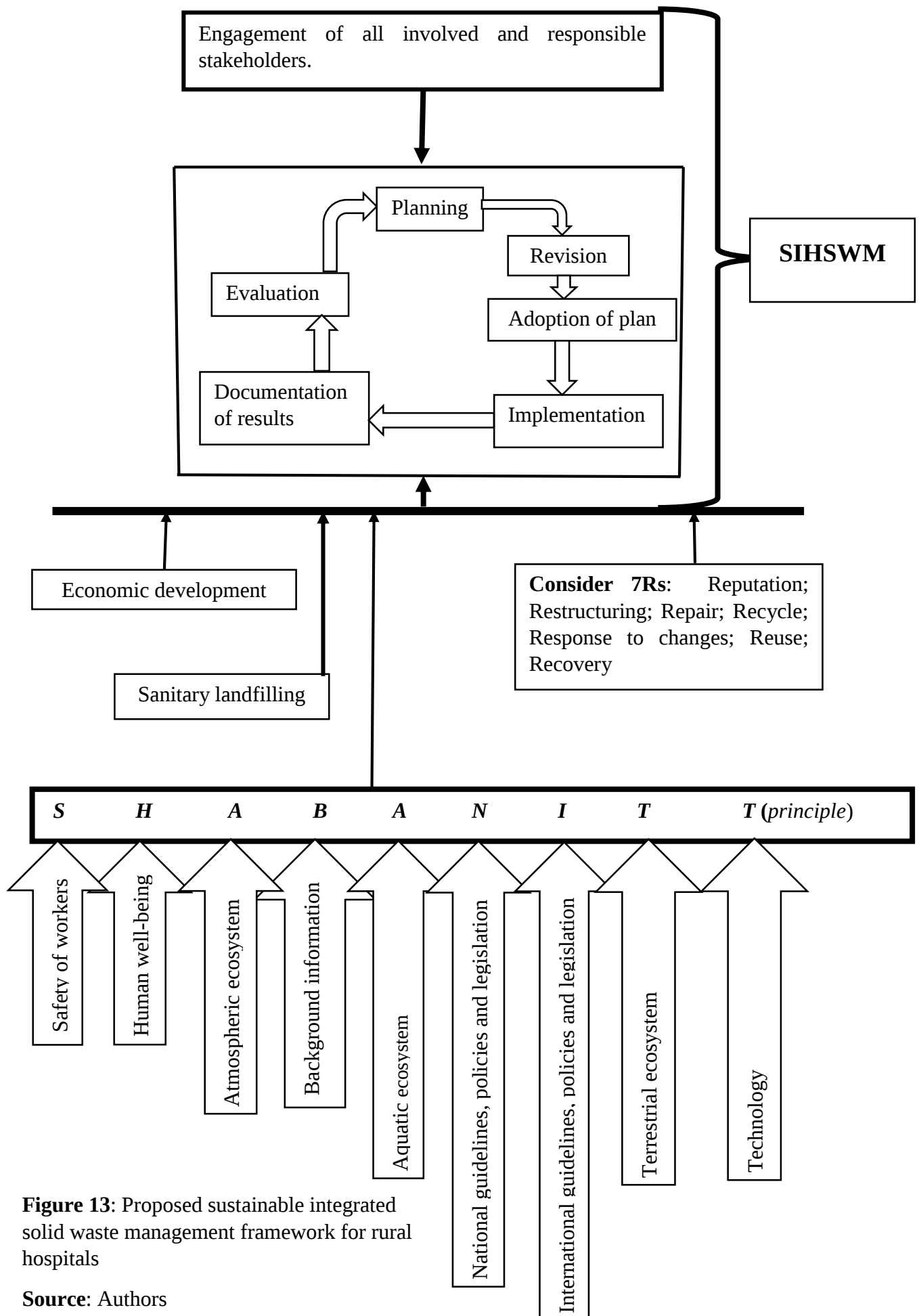


Figure 13: Proposed sustainable integrated solid waste management framework for rural hospitals

Source: Authors

5.4 Conclusions and Recommendations

Hospital solid waste management is among pressing issues impacting Zimbabwe's rural hospitals due to population increase and disease outbreak. Chemical, pathological, cytotoxic, radioactive, pharmaceutical, infectious, sharps, and general waste as well as electronic and construction and demolition solid waste are generated at STT and HC hospitals. Solid waste generated at HC hospital consists of 79% general waste and 21% hazardous waste. STT hospital produced 77.35% general waste and 22.65% hazardous waste. Waste increase was ascribed to outbreak of diseases, high use of disposable PPE/C, and discarding of outdated materials and equipment. Solid waste generated at these hospitals is stored in plastic and metal buckets, pedal operated bins, sharp containers, plastic bags, and cardboard boxes. Major storage receptacles utilised at STT hospital were sharp containers and pedal bins as noted by 72.4% of the respondents. This was a similar case at HC hospital where use of sharp containers and pedal bins was highlighted by 69.1% respondents. Hospital solid waste was separated into organic and inorganic waste, sharps, and non-sharps as well as infectious and non-infectious waste during storage. Indiscriminate storage plastics and food waste was common. Infectious waste was disinfected through chlorination or autoclaving at HC and STT hospitals. Solid waste was transported to disposal sites through manual handling and use of wheelbarrows. Solid waste was disposed through incineration, open pits, auto-way pits, and open burning. Incineration was highly used at STT (44.8%) and HC (41.8%) hospitals. Solid waste was disposed under trees and building corners, while composting and reuse were also applied. Disposal of hospital solid waste was mostly carried out on a daily basis as indicated by 86.7% at STT hospital and 78.2% at HC hospital. Disposal approaches mostly utilized at these hospitals occupy the bottom part of the waste management hierarchy. Disposal approaches cause air, soil, water contamination, visual pollution, outbreak of veld fires, and affecting flora and fauna negatively. Occupational health risks associated with management of hospital solid waste encompass pricks, cuts, contacting infectious waste, inhaling noxious odours, musculoskeletal disorders, and being exposed to radiation from waste combustion.

In light of the findings, various recommendations were made, for instance, there is a need for rural hospital authority to provide adequate PPE/C to those involved in solid waste management. EHTs must carry out training focusing on enlightening health workers on aspects

related to hospital solid waste management. EMA officers should carry out workshops where they inform health workers on policies, guidelines, and legislation applied in hospital solid waste management. ZMoHCC should channel enough financial resources to hospital solid waste management aspects at rural hospitals. Collaboration of ZMoHCC and NSSA among other stakeholders in mapping out approaches to minimize occupational health risks associated with solid waste generated at rural hospitals is required. Rural district authorities must assist rural hospitals in dealing with solid waste, since rural hospitals generate solid waste with similar characteristics to urban health facilities. There is a need to uphold the use of current technology like GIS and RS in management of hospital solid waste. Application of GIS and RS facilitates determination of solid waste collection routes, location of disposal sites, and determining environmental attributes which are vulnerable to pollutants from hospital disposal sites. In order to attain sustainability and CE, rural hospitals should adopt and try to utilize the proposed framework (Fig. 13). The proposed framework supports solid waste recycling, reuse, recovery, and repair of materials; therefore, facilitating reduction of solid waste disposed into the environment. The framework upheld involvement of all stakeholders, conformity to national and international legal frameworks, continuous improvement of the waste management system, and reduced cost in managing waste while protecting the environment; hence, narrowing the gap to reach SDGs, AA 2063, and ZV 2030. SIHSWM (Fig. 13) urges hospitals to consider raw disposal of hospital as a waste of resources; therefore, by adopting this framework, hospital solid waste can be utilized as a resource to catalyse economic growth. SIHSWM direct government and rural hospitals to craft policies support circular economy activities like recycling, recovery and reuse.

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Chapter 6

Research synthesis, Conclusion and Recommendations

6.1 Introduction

The chapter summarises the research by synthesising research results. In this chapter, study verdicts are discussed in the context of existing literature in order to derive meaning and implications of the findings. Furthermore, the chapter presents conclusions and recommendations based on the research results.

6.2 Overall research synthesis

6.2.1 Hospital solid waste characteristics, management strategies and environmental health implications

This study found out that ST Theresa and Holy Cross rural hospitals generated diverse solid waste consisting of hazardous and non-hazardous waste. A large proportion of solid waste was non-hazardous regarded as general waste while a minor proportion encompassed hazardous materials (figure 5 in Chapter 3 and figure 3 in Chapter 4). These types of solid waste produced at these hospitals was comparable to that produced at rural hospitals in other developing countries such as Uganda, South Africa, India and developed countries like United Kingdom and Germany where hazardous waste like infectious, pharmaceutical, chemical and sharp waste and general waste namely non contaminated plastics and papers were produced (Kwikiriza *et al.*, 2019; Olaniyi *et al.*, 2019; Chisholm *et al.*, 2021). These solid waste categories are common across developed and developing nations due to similarities of activities namely patient caring and procedures conducted at hospitals (Ahmad *et al.*, 2019). However, what differs markedly are the waste volumes and management strategies applied in developed and developing countries due to differences in material and financial resources as well as technical expertise amongst the key stakeholders. Despite a minor proportion of hazardous solid waste generated at these rural hospitals, more attention must be directed to it because it usually has various pathogens namely viruses, bacteria and fungi with potential to cause various intestinal,

infectious and respiratory ailments among people if not properly managed. Although it depends on the nature of waste, individuals exposed, duration of exposure and availability of interventions for those exposed, solid waste affects health and it is one of the “major reasons its management is a top environmental and public health issue” (Ziraba *et al.* 2016:2). Inappropriate handling of hospital sharp waste can result in pricks, cuts and injuries, causing tetanus, tuberculosis, hepatitis, HIV and AIDS among involved health workers making appropriate management of healthcare waste a prerequisite for delivery of healthcare services that ensure safety and good health of medical personnel and members of the public (Oyekale and Oyekale, 2017). This also resonates with Shabani and Jerie (2023) and Shabani *et al.*, (2024)’s view that injuries that emanate from health institutions’ sharp waste are associated with a wide range of infectious diseases derived from the patients they would have been in contact with since they are sometimes disposed of unsterilised. Furthermore, despite being less hazardous, general hospital solid waste also requires attention since there is risk of general environmental pollution and compliance with governing statutory instruments, policies and standards (Das *et al.*, 2021; Chisholm *et al.*, 2021). Rural hospitals must pay attention to increasing general solid waste to minimise vulnerability of the public and healthcare workers to health problems and maintain integrity of the rural environment.

Major drivers of hospital solid waste escalation were an increase of patients who seek medical services coupled by high use of disposable PPE/C (Figure 4 in Chapter 3). The study established that there is a direct proportional relationship between quantity of solid waste generated and number of patients served at the study institutions. Therefore, since the district’s population is increasing at 1.2% per year (ZIMSTAT, 2022), people who seek health services at Holy Cross and ST Theresa continue to increase, translating to an increase in solid waste generated (Sangkham, 2020; Das *et al.*, 2021). This amplifies the quantity of hazardous and non-hazardous solid waste generated at these hospitals, hence the need to either increase the frequency of emptying available receptacles or the use of larger receptacles. Both responses have implications on disposal space, number of waste management personnel, required personal protective equipment among other demands in the backdrop of already financially, materially and logistically incapacitated rural hospitals to sustainably manage their waste. The situation is exacerbated by the Rural District Councils Act, Chapter 29: 13 that is ambiguous about management of solid waste from rural institutions and the noncommittal approach by the Environmental Management Agency to guide these institutions on how they can effectively

manage their waste. This scenario emerging from this study requires a rethink of a solid waste management model in the context of what is prevailing on the ground and future prospects.

Shortage of financial resources loomed very large among the problems hampering adoption of proper waste management strategies at the two study hospitals. In Kenya as well as in Zimbabwe, limited financial resources at most rural hospitals leads to prioritisation of patient diagnosis and treatment activities at the expense of proper solid waste management aspects (Odongo, 2022; Jerie *et al.*, 2024). Findings at ST Theresa and Holy Cross hospitals confirm the existence of this challenge hindering the application of solid waste reduction measures, recycling and reuse activities. This is the case despite the fact that improper waste management increases the disease burden of a society and therefore further strains its health institutions. No wonder why, holding other factors constant, developing countries are saddled with a high disease burden with implications on the attainment of the SDGs by the year 2030 (Hannan *et al.*, 2020; Elsheekh *et al.*, 2021). This suggests that the Zimbabwe Ministry of Health and Child Care must increase its allocation of financial resources to rural hospitals since they are facing an increasing disease burden whilst they are also supposed to manage their own waste. However, the likelihood of this happening in light of a very limited fiscal space due to a non-performing economy is very slim hence the need to think outside the box and produce a framework that is cost effective, efficient and environmentally friendly (Wassie *et al.*, 2022; Jerie *et al.*, 2024).

In terms of hospital solid waste storage, pedal operated bins and sharp containers were highly utilised as illustrated by Figure 4 in Chapter 4. High utilisation of pedal operated bins reduces vulnerability of health workers, patients and visitors to pathogens from bins since they open and close the bins using their feet. Utilisation of foot-operated bins limits exposure of hospital staff and non-hospital staff to infectious diseases such as tuberculosis and pneumonia among others, a scenario also observed by Jumaah and Rashaan (2021). In order to minimise impacts of stored solid waste on patients, visitors and health workers, storage receptacles were transported to disposal sites through manual handling and use of wheelbarrows. Although these transportation approaches are rudimentary and less efficient considering aspects of occupational health and safety, these rural hospitals resorted to them because they are less expensive, easy to maintain, create employment opportunities for less skilled labour and little

expertise is required to carry out the job, characteristics that make them relevant for developing countries particularly those in Africa (Kwikiriza *et al.*, 2019; Niyongabo *et al.*, 2019). However, manual handling of heavy solid waste receptacles, awkward lifting postures and pushing of wheelbarrows expose involved health workers to musculoskeletal disorders such as hand, back and shoulder pain (Chireshe *et al.*, 2023). Exposure to musculoskeletal disorders during solid waste management is determined by weight and size of storage receptacles, consciousness about proper lifting techniques, frequency and duration of handling the containers and physical fitness of the personnel (Uddin *et al.*, 2021; Chireshe *et al.*, 2023). Transportation of solid waste to disposal or storage sites at hospitals need to be carried using automated, wheeled containers with lids and push bars to uphold safety and health of involved personnel. Despite presenting good qualities, relevance of automated wheeled containers at these rural hospitals remain very low due to their high cost, need for skilled workers and most of the routes which link disposal sites are not paved. Therefore, in order to achieve proper transportation of hospital solid waste more financial resources are required and infrastructure needs to be improved.

Solid waste receptacles were commonly emptied on a daily basis (Figure 6 in Chapter 5), although a minor proportion of them develop moulds while releasing noxious odours. Noxious odour was generated from containers with infectious waste like blood and fluid stained linen and receptacles with pathological waste like human tissues. Availability of micro-organisms intensifies putrefaction of infectious and pathological waste, although it is also determined by temperature, frequency of disposal and moisture content (Kalogiannidou *et al.*, 2018; Thakre, 2019). Noxious odours cause nose and throat irritation as well as breathing problems among health workers, visitors and patients. In order to minimise health problems, health workers must be enlightened on the importance of emptying all solid waste containers on a daily basis. According to Omran and Mohammed (2020) and Hossain *et al.*, (2021) hospital infectious waste's storage period should not exceed 48 hours during cool season and 24 hours during hot season in areas with warm climate. Therefore, considering the climate of Zimbabwe characterised by hot rainy summers and cool dry winters, infectious and pathological waste receptacles warrant daily emptying, but achievement of this require number of waste workers to be increased since the activity is done manually. Moreover, sharp containers which are leak and puncture resistant were mostly used to store sharp waste at these rural hospitals in line with WHO and ZMoHCC hospital solid waste management guidelines. Sharp waste containers were

manually handled to disposal sites, thus exposing health workers to sharp injuries namely cuts, pricks and incision while increasing their vulnerability to infectious diseases such as HIV and AIDS and hepatitis, a similar scenario revealed by studies in Malawi (Katusiime, 2018) and South Africa (Motlatla and Maluleke, 2021). This implies the significance of raising awareness of people involved in handling of sharp waste through trainings, posters and videos while equipping them with appropriate PPE/C like needle stick resistant gloves. Provision of proper PPE/C has the potential to minimise occurrence of occupational risks among health workers.

Increase of solid waste coupled by shortage of finance causes difficulties to achieve appropriate storage of waste due to shortage of storage receptacles. Inadequacy of appropriate storage containers was worsened by under prioritisation of waste management in favour of fulfilling the hospitals' main objective of treating people with various ailments. Wassie *et al.*, (2022) argued that although low priority is given to solid waste at hospitals, its inappropriate management is exacerbated by national policies which overlook the importance of proper management of solid waste, including those in rural areas. Indiscriminate storage translates to disposal of non-segregated solid waste in incinerators, on dumpsites and in open pits, exacerbating health problems associated with waste management and challenges in managing disposal sites. Incineration of combustible and non-combustible materials triggers occurrence of incomplete combustion which generate toxic gases, particulate matter and heavy metals. The pollutants increase occurrence and severity of respiratory and neurological diseases as well as health problems like cancer among people. Dioxins and furans from incineration of medical waste are carcinogenic, however their potential to cause cancer depends on duration of exposure (Tait *et al.*, 2020; Gul *et al.*, 2021). Problems that emanate from incineration of solid waste at hospitals under study illustrated the significance of integrated waste management approach which supports appropriate segregation of waste and construction of incinerators equipped with scrubbers. Incinerator scrubbers have potential to trap heavy metals, toxic acid gases and particulate matter generated during incineration, thus reducing air contamination and health problems (Wang *et al.*, 2020). Inappropriately managed hospital disposal sites acted as breeding sites for vectors which facilitate spread of pathogens which cause outbreak of cholera, typhoid and malaria particularly among people who reside in proximity to the dumpsite.

Disposal sites encompassing open dumps and open pits used by rural hospitals provide breeding sites for vermin such as cockroaches (*Dictyoptera*), two winged flies (*Diptera*), common house flies (*Musca domestica*) and rats (*Rattus*) if improperly monitored (Krystosik *et al.*, 2020; Jerie *et al.*, 2024). To minimise breeding and multiplication of vermin as well as reducing access by scavenging animals and birds on dumpsites, disposed hospital solid waste must be compacted and covered by soils (Berruti, 2021). Moreover, people who reside in close proximity to the dumpsite are highly exposed to pollutants (Figure 13 and 17 in Chapter 4). Similarly, severity of waste related diseases like respiratory, cholera, typhoid, malaria among others was higher among the population close to solid waste disposal sites in Lagos state, Nigeria (Oyedele and Oyedele, 2017) and in Beitbridge, Zimbabwe (Munyai and Nunu, 2020). Environmental attributes encompassing residential areas located at areas which are less than 500 metres from dumpsites are at high risk of being impacted by pollutants from dumpsites (Jerie and Zulu, 2017; US EPA, 2020; Shabani *et al.*, 2024). Minimisation of environmental health impacts requires the Environmental Impact Assessment process to be carried out before locating dumpsites at rural hospitals, but the process needs to be supported by integration of technology like Global Positioning System and Geographic Information Systems. Therefore, in the Zimbabwean context solid waste management policies must put enough attention to application of technology in management of solid waste from rural hospitals. Decomposing hospital solid waste generates contaminants encompassing heavy metals which affect water quality (Table 4 in Chapter 4) and soil quality (Table 7 in Chapter 4). Heavy metals affect lives and breeding of marine creatures negatively while increasing risk of cancer, kidney damage and ulcers among people who consume edible marine creatures and contaminated water (Sonone *et al.*, 2020 and Kimani, 2021). This suggests that among other routes of exposure, human beings are exposed to pollutants from hospital solid waste through the ingestion route.

Contaminated soil affects human beings such as pregnant mothers who are interested in geophagy to obtain nutrients and minerals such as iron critical during this condition. Heavy metals namely lead, mercury and cadmium from rural hospitals dumpsites increase the risk of reproductive disorder, miscarriage among pregnant mothers while causing neurological and growth disorders to unborn babies. At ST Theresa and Holy Cross pregnant mothers may be more vulnerable since maternity waiting facilities as well as hospital dumpsites are located within the hospital fence. Disposed pharmaceutical products, electronic waste and ashes produced during incineration increase generation of arsenic, copper, mercury and cadmium

from hospital dumpsites (Tait *et al.*, 2020; Jiang *et al.*, 2022). Children are mostly vulnerable to health problems that emanate from soil contaminated by these heavy metals due to their unlimited hand-to-mouth behaviour. As a result, these children are susceptible to respiratory problems, kidney problems, neurological disorders and cancer since heavy metals are carcinogenic. Results of the study, are supported by Aendo *et al.*, (2022) and Shabani *et al.*, (2024) that children are largely affected by pollutants in soil due to their pica habits coupled by susceptible socio-behavioural activities. Furthermore, soil contaminated with pollutants including heavy metals from hospital dumpsites support growth of invasive vegetation species (Table 9 in Chapter 4). This suppresses growth and diversity of indigenous vegetation species, thus disturbing the integrity of the ecosystem while limiting its ability to provide services like food and natural medicine to people. Vaverkova *et al.*, (2019) buttress these results by considering dumpsites among epicentres for invasive vegetation species which diminish quality of provisional services obtained from the forest.

Occurrence of environmental risks was worsened by disposing solid waste into open pits, auto-way pits, open dumping and through open burning as well as incineration (Figure 8 in Chapter 4). Over reliance on approaches which are least prioritised by the waste management hierarchy was attributed to lack of finance, expertise and awareness related to the circular economy. In developing regions encompassing Southern Africa, institutions resort to solid waste management approaches which are less environmentally friendly due to lack of resources to invest in approaches which support sustainability (Chisholm *et al.*, 2021; Motlatla and Malukele, 2021). Low application of techniques like recovery, reuse and recycle among other solid waste management practices at these rural hospitals means large volumes of generated waste was disposed. This overwhelms the capacity of existing disposal structures at ST Theresa and Holy Cross hospitals causing exhaustion of dumpsites, adding difficulties in managing disposal sites and structures while intensifying environmental health problems as established by Shabani and Jerie (2023) and Shabani *et al.*, (2024). To minimise continuous accumulation of solid waste at dumpsites, open burning is applied to degrade disposed waste into partially burnt materials and ashes. Although this approach reduces the existence of solid waste piles and attractiveness of dumpsites to vectors, it generates toxic gases which cause air contamination while increasing prevalence of respiratory diseases (Ikhlayel, 2018; Siphephisiwe, 2023). Among other disposal strategies, incinerators were highly used to dispose infectious, pharmaceutical, general waste among other types of waste at ST Theresa and Holy

Cross rural hospitals (Figure 11 Chapter 3). Incineration of solid waste from hospitals is common in developing nations such as Nigeria, Botswana and at rural health institutions in Eastern Cape, South Africa (Chisholm *et al.*, 2021).

Efficiency of the incinerators was limited by loading of non-segregated waste coupled by utilisation of incinerators with cracked combustion chambers (Plate 10 in Chapter 3). These rural hospitals are using almost substandard incinerators due to lack of resources, expertise and failure to consult accountable stakeholders. This is upheld by Katusiime (2018) and Odongo (2022)'s view that utilisation of substandard disposal infrastructure including incinerators is aggravated by negligence of national health budget policies to aspects surrounding waste generated from rural hospitals. Low standard incinerators facilitate generation of emissions like carbon dioxide, carbon monoxide, heavy metals, furans and dioxins which cause acute and chronic health problems to people (Çağrı, 2024; Ravindra *et al.*, 2024). Suppression of these diseases require construction of incinerators which facilitate complete combustion and application of recycling and reuse which limit the quantity of incinerated waste, but this may be difficult at these hospitals hence an integrated approach remains a feasible option. In addition, incinerator operators were exposed to high radiation, dioxins and furans with potential to affect the neurological and reproductive systems negatively while causing high blood pressure and skin lesions. Therefore, enough and appropriate PPE/C such as work suits, hard gloves, goggles, gas masks and safety shoes need to be provided to people involved in incineration of hospital solid waste to uphold their wellbeing (Chireshe *et al.*, 2023; Jerie *et al.*, 2024). Inefficient incinerators generate partially burned residues which are further disposed on partially fenced hospital dumpsites. As a result, fauna which considers hospital dumpsites as dietary sources are vulnerable to injuries caused by partly burnt sharps and other types of solid waste. Scavenging animals mistakenly ingest plastics and papers together with their edible materials, exposing them to intestinal blockage, laceration and throat choking leading to death, detrimental health complications as stated by Liyanage *et al.*, (2021) and Manzoor *et al.*, (2022). To minimise access of roaming animals, solid waste must be compacted, covered and rural hospitals dumpsites must be secured through fencing using a tall and sturdy fence capable of deterring break through. Fencing of solid waste disposal sites in rural Ghana managed to minimise access of animals to dumpsites (Vinti *et al.*, 2023).

Furthermore, improper management of solid waste was exacerbated by existing management approaches which are fragmented and characterised by lack of co-ordination among responsible stakeholders. This points that narrowing the gap to achieve sustainable solid waste management at rural hospitals requires an integrated approach which facilitates collaboration of numerous stakeholders and application of different techniques, an approach viewed as potentially effective by Jerie *et al.*, (2024). Figure 10 in Chapter 5 indicated that lack of knowledge among health workers was also hindering progress in the realm of solid waste management. Health workers present little knowledge regarding solid waste legislation, environmental health risks, segregation and strategies to minimise quantity of waste generated and disposed of. Owing to this situation, management of solid waste at the study hospitals was far from management strategies advocated for by WHO, ZMoHCC and EMA guidelines, causing more burden in solid waste management translating to cropping up of numerous environmental health problems. This contradicts Ranjbari *et al.*, (2022)'s studies which demonstrate that health workers have enough knowledge regarding management of hospital waste. Inappropriate management was further illustrated by the appearance of randomly placed solid waste materials at hospital corners and under trees. Existence of solid waste on illegal sites increases visual pollution while diminishing the aesthetic view of the environment in rural areas of Limpopo, South Africa (Senekane, 2024).

Primary reasons causing less conformity to existing legal framework and guidelines were less follow-ups and enforcement of solid waste management laws in rural areas as compared to urban areas. However, commitment of EMA to capacity building through training and educating health workers on aspects related to solid waste management is low since they mainly apply the instrumental approach particularly arrest and offering tickets. There is need for EMA to leave the colonial approach and adopt modern strategies which put emphasis on capacitating individuals, monitor them and apply aspects of fines and tickets where lack of compliance is due to negligence. Among other problems, mismanagement of solid waste is worsened by weaknesses associated with existing legal framework in Zimbabwe (Marange *et al.*, 2023; Shabani and Jerie, 2023). However, Zamparas *et al.*, (2019) argued that effectiveness of definitive rules and laws directed to hospital solid waste management is largely determined by behaviour of health workers. This implies the significance of applying the normative approach that focuses on changing attitudes, norms, beliefs and values and subsequently behaviour of health workers towards management of solid waste.

Management of solid waste from rural institutions including hospitals is receiving little attention from legislation and policy makers. Owing to lack of clear legal framework directed to solid waste from rural institutions by policy makers, rural hospitals always struggle to have updated information regarding legislation. These findings are in line with Shabani and Jerie (2023) and Shabani *et al.*, (2024) that little is known about management of solid waste from rural institutions, therefore it is overlooked by policy makers. Management of solid waste is characterised by co-storage of waste, translating to disposal of mixed waste with potential to cause negative impacts on air, water and soil while threatening human health. This signifies the importance of having workshops and training programs to raise awareness of rural health workers towards solid waste management aspects including the existing legal framework. Improvement of solid waste management requires formulation of clear legislation which support proper management of solid waste from rural hospitals, indicating the role of rural district councils. This is supported by Fernando, (2019) and Tsai *et al.*, (2021)'s view that clearly formulated, implemented and enforced legislation and policies create low hanging fruits to meet demands of sustainable solid waste management. Despite gaps presented by existing legislations, application of approaches which lessen the quantity of generated solid waste while upholding the circular economy was also hindered by lack of finance at rural hospitals (Figure 19 in Chapter 4). This corresponds with Gao *et al.*, (2022) and Kozhimannil *et al.*, (2022) that most rural hospitals are operated with very limited resources particularly finance hence they put much emphasis on curative other than preventive measures such as proper waste management. Prevailing solid waste management approaches and their environmental implications necessitate the development of an integrated solid waste management system which suits these rural hospitals with limited resources.

6.2.2 Proposed integrated framework for sustainable solid waste management at rural hospitals in Chirumanzu district

The proposed framework, illustrated in figure 13 of Chapter 5, aims to reduce the burden to achieve sustainable solid waste management at rural hospitals. The framework is predominantly original except the terminology utilised which is common in the realm of solid waste management. Uniqueness is illustrated by organisation, structure and collective presentation of elements that have not been previously combined, therefore the framework provides new insights into the sustainable management of solid waste from rural hospitals. The

framework's main strength is its inclusivity of all accountable stakeholders in hospital solid waste management processes. Co-operation of responsible stakeholders promote achievement of appropriate management of solid waste (Fiksel *et al.*, 2021; Shabani and Jerie, 2023). The growing consensus regarding the need to work together to achieve sustainability in various aspects is also advocated for by SDG 17 which calls for participation of all key stakeholders to achieve sustainability. Participation of health workers improves their awareness translating to proper waste segregation hence limiting difficulties in managing solid waste. Inclusion of various experts, organisations and departments facilitates cross pollination of ideas and mobilisation of resources required to apply recycling, reuse and recovery (3Rs) techniques. The 3Rs support conversion of generated waste into useful resources, hence reducing pressure on managing solid waste from generation to disposal. Turning solid waste into resources, reduces the pressure of extracting new resources from the environment, therefore plays a pivotal role in maintaining natural environmental integrity. As a result, the framework has potential to meet the demands of SDG 15 which calls for ecosystem conservation while the aspect of recovery of energy supports targets of SDG 7 which advocates for access to affordable and reliable energy across the world.

Restructuring of disposal structures enables utilisation of incinerators with recommended chimneys, emission trapping systems and non-cracked combustion chambers which facilitate complete combustion, therefore limiting the quantity of toxic gases and particles released into the atmosphere. This minimises concentration of greenhouse gases while reducing prevalence of respiratory diseases, translating to attainment of other SDGs, particularly of good health and well-being (3) and climate action (13). Moreover, repairing of malfunctioning hospital equipment reduces the quantity of solid waste generated, thus reducing pressure on existing receptacles and disposal structures. Reduction of disposed waste lessen burden in managing disposal sites, therefore reducing environmental health risks associated with improper disposal sites. Application of reuse and repair approaches support circular economy while minimising quantity of disposed solid waste, therefore lessening its environmental implications. This suggests that application of the proposed framework in management of solid waste from rural hospitals reduces the barriers to attain SDG 11 of sustainable cities and communities. Attaining a circular economy requires countries to invest in approaches which support recycling, recovery, repairing and reuse (Ikhayel, 2018; Shabani *et al.*, 2023). In order to achieve this, rural hospitals must get higher budgetary allocations from the national fiscus complemented

by hospital solid waste management awareness programs. The framework indicates that engagement of various stakeholders is attainable through public meetings, workshops and consultation programmes. This asserts that adoption of the framework requires effective techniques since most stakeholders have different educational and socio-political backgrounds among other factors which shape their thinking and behaviour.

The framework also upholds disposal of hospital solid waste on sanitary landfills (figure 13 in Chapter 5). This is almost similar to Paul *et al.*, (2019) and Batista *et al.*, (2021)'s assertions that sanitary landfills are part of integrated solid waste management systems. Sanitary landfills are characterised by liner and methane collection systems as well as systems to collect and treat leachates. Inclusion of sanitary landfill facilitates moving towards SDG 14 which indicate targets for protecting life below water since they reduce leachates from reaching ground water as well as minimisation of emissions into the atmosphere. Hospital solid waste compaction as well as covering procedures are practiced, thus limiting potential of disposal sites to act as breeding sites for vectors which cause various human ailments. The framework has a circular structure encompassing planning, revision, adoption of plans, implementation, documentation of results and evaluation. This circular structure offers room for continuous improvement of solid waste management strategies, thus offering ST Theresa and Holy Cross hospitals opportunity to meet demands of increasing solid waste. Improving solid waste management strategies facilitates proper waste segregation, adoption of approaches which are mostly prioritised by waste management hierarchy. The circular structure assists rural hospitals to implement pro-active planning activities which enable them to respond to solid waste quality and quantity changes particularly during outbreak of diseases. This goes in line with studies which indicated that integrated solid waste management must consider prevailing and future scenarios (Bahcelioglu *et al.*, 2020; Kurniawana *et al.*, 2022). The proposed framework indicated by figure 13 in Chapter 5 encompasses the ***SHABANITT*** principle which is essential to achieve sustainable solid waste management at rural hospitals. The principle acts as a fundamental aspect that guides accountable stakeholders when dealing with issues related to solid waste from rural hospitals.

Features of the principle illustrate that considering workers' safety, human well-being, environmental components, national and international policies as well as guidelines amplify

the possibility to achieve sustainability. This is because failure to conform to solid waste management legal framework causes improper waste management resulting in cropping of environmental health problems (Siphephisiwe, 2023; Jerie *et al.*, 2024). Taking into account demands of the framework's principle, health of people is safeguarded from generation to disposal while the environment is protected from pollutants generated by disposal sites. Components of the framework's principle are advocating for environmental protection while paving the route to achieve the objectives of SDG 8 such as decent work for women and men. David *et al.*, (2020) argued that proper solid waste management systems should go beyond legal framework formulation through inclusion of modern technology. Application of current technology enables rural hospitals to apply strategies which support recycling and recovery of energy from generated waste, hence limiting the quantity of disposed waste. Reduction of disposed waste maximise lifespan of disposal sites while minimising occurrence of environmental health risks emanating from discarded hospital waste. Technology particularly GIS and RS facilitate proper location of disposal sites since it assists in analysing relationships between various environmental attributes and hospital dumpsites. As a result, application of technology has potential to reduce dire consequences associated with improperly located rural hospital dumpsites. This is because GIS and RS are significant in improving solid waste management, particularly collection and siting of disposal sites (Singh, 2019; Shabani *et al.*, 2024).

The proposed framework puts into consideration the prevailing economic conditions, this entails that when responsible stakeholders are planning aspects related to hospital solid waste management they must take into account economic characteristics of rural areas. Rural hospitals are characterised by shortage of resources and are located in areas with high levels of unemployment and people with limited technical skills. Therefore, by endorsing facets of the developed framework, suggested hospital solid waste management has potential to suit rural hospitals economically while demanding less expertise and aiming to create employment for people in surrounding communities. In addition, although the framework's strengths outweigh its weaknesses, its applicability in various rural hospital settings is limited. This is attributed to the fact that other aspects used to develop the framework are context specific, yet hospital solid waste management scenarios are unique and are influenced by healthcare workers, responsible authority and existing resources. Consequently, other rural hospitals require solid waste management models that suit their context. Nevertheless, since there is general dearth of in-

depth research related to management of solid waste from rural institutions, the framework can act as a bedrock for other rural hospitals to develop their own appropriate frameworks.

6.3 Conclusion

The study focused on waste generation, management and environmental impacts, key aspects of the hospital solid waste management processes relevant for developing an integrated sustainable solid waste management framework at rural hospitals in Chirumanzu district in Zimbabwe. The dominant components of hospital solid waste generated at these were sharps, pharmaceutical, pathological, chemical, radioactive, cytotoxic, general waste, electronic and construction and demolition waste. Solid waste from these rural hospitals includes both hazardous and non-hazardous waste, although non-hazardous waste constitutes a larger percentage of the waste generated at both hospitals. In terms of solid waste generated per day ST Theresa hospital generated a larger quantity compared to Holy Cross hospital, but solid waste increase was largely attributed to increase of patients and use of disposable materials at both hospitals. Solid waste storage receptacles used at ST Theresa and Holy Cross hospitals encompass sharp containers, pedal operated bins, cardboard boxes, plastic bags as well as plastic and metal buckets. Despite utilisation of various solid waste containers at these two hospitals, sharp containers and pedal operated bins were highly used due to their puncture resistant characteristics and hygienic nature respectively. Verdicts of the study indicated that during storage, solid waste was mostly segregated into sharps and non-sharps as well as infectious and non-infectious waste at these rural hospitals. Although storage of non-separated solid waste was observed in other storage receptacles in various departments at these hospitals and was further supported by indiscriminately disposed solid waste. At ST Theresa and Holy Cross hospitals, infectious solid waste was treated through use of chlorine and autoclaving, however these processes were impeded by indiscriminate storage of waste.

In terms of solid waste disposal, open pits, auto-way pits, open dumping, open burning and incineration were used although solid waste was found at corners of the buildings and under trees within hospital yards. This signifies that solid waste was discarded through both legal and illegal approaches at ST Theresa and Holy Cross hospitals. Results illustrated that solid waste

was highly disposed of through incineration although the nature of incinerators utilised at these two rural hospitals differs. Most of the utilised disposal methods used at ST Theresa and Holy Cross hospitals are inappropriate considering the order of solid waste management hierarchy. The waste management challenges at these rural hospitals are attributed to institutional and socio-economic problems. Low budgetary allocations from the national fiscus was regarded as a major challenge impeding attainment of sustainable solid waste management at ST Theresa and Holy Cross hospitals. Inappropriate management of solid waste at ST Theresa and Holy Cross hospitals cause detrimental impacts on soil, air, water, flora and fauna. Hospital solid waste management activities expose health workers at both hospitals to musculoskeletal disorders and injuries as well as respiratory, intestinal and infectious diseases. This illustrates that hospital solid waste management at these two rural hospitals are far from acceptable standards particularly requirements of SDGS, Agenda 21 and Zimbabwe EMA, Vision 2030 and NDS 1 goals. Taking into account the existing situation at ST Theresa and Holy Cross rural hospitals, an integrated framework was proposed. The proposed framework's main goal is to lessen the burden in management of solid waste generated from these rural hospitals while averting environmental health problems associated with solid waste from these rural hospitals.

The attributes of the framework encompass a principle which supports safety of workers, human well-being, protection of the natural ecosystem as well as conformity to international and national policies and standards when managing hospital solid waste. This paves the way to achieve sustainable management of solid waste from rural hospitals under study, translating to attainment of various SDGS namely decent work and economic growth (SDG 8), good health and well-being (SDG 3) and clean water and sanitation (SDG 6) among other sustainable goals. The framework upholds aspects such as recycle, reuse and recovery which minimises volume of disposed hospital solid waste. Reduction of disposed hospital solid waste reduces wasting of resources while lessening cropping up of environmental health problems associated with inappropriately managed and disposed solid waste. Considering this, the proffered framework has potential to narrow the gap to achieve the targets of Zimbabwe EMA, Vision 2030 and NDS 1 objectives which advocates for environmental protection, human well-being and economic growth. Furthermore, the framework has a circular structure consisting of planning, revision, adoption of plan, implementation, documentation of results and evaluations. This gives ST Theresa and Holy Cross rural hospitals the opportunity to improve solid waste management by reviewing existing management strategies. Continuous reviewing of prevailing

solid waste management approaches offers these rural hospitals the opportunity to respond to solid waste quantity and quality changes. Among other significant aspects, the framework pointed to the need to engage all accountable stakeholders in dealing with solid waste generated from these rural hospitals. Inclusion of responsible stakeholders lessen challenges experienced in managing solid waste from rural hospitals since stakeholders share ideas while assisting each other with the required resources. Inclusion of all stakeholders is advocated for by SDG 17 which calls for partnership of various stakeholders in dealing with various problems which hinder attainment of sustainable development.

The proposed framework urges the rural hospitals under study to use sanitary landfills with leachate control systems and gas collection systems. Utilisation of sanitary landfills have potential to curb emission of landfill gases like methane into the atmosphere while reducing potential of leachates to contaminate groundwater. This clearly suggests that adoption of the proposed framework at these rural hospitals paves the way to achieve sustainable goals which calls for climate change mitigation (SDG 13 of climate action) and prevention of water contamination (SDG 14 of life below water). According to the framework, solid waste management strategies adopted by ST Theresa and Holy Cross must support economic growth while considering economic characteristics of the area where the hospitals are located. Among other significant aspects, the framework has potential to facilitate improvement of solid waste management at these rural hospitals, thus creating low hanging fruits which are essential to attain SDG 11 of sustainable cities and communities. Although the proposed framework presents various strengths if utilised at ST Theresa and Holy Cross rural hospitals, but generalisability of its applicability to other rural hospitals is limited. This is attributed to the fact that development of the framework was done utilising aspects related to ST Theresa and Holy Cross hospitals, therefore is context specific yet solid waste management strategies at rural hospitals differs. This suggests that applicability of the framework to other rural hospitals need to be tested by other researchers, so that they figure out components of the framework which require revisions. In light of these research findings, a number of recommendations were proffered.

6.4 Recommendations

Health workers at rural hospitals must be offered training related to solid waste management through workshops to enable them to understand environmental health impacts associated with hospital solid waste and their waste management responsibilities. EHTs at rural hospitals must carry out awareness programmes which put emphasis on the significance of minimising solid waste segregation. EMA Officers and hospital EHTs should disseminate knowledge of solid waste reduction, recycling, reuse, recovery and recommended management standards to people working at rural hospitals. The Environmental Management Agency should conduct solid waste management training and workshops involving rural health workers. In order to ensure conformity of health workers and rural hospitals to proper solid waste management techniques, EMA Officers must conduct inspections on a monthly basis. Involvement of EMA Officers and hospital EHTs is essential since they are among experts in terms of solid waste management legal framework and approaches to promote sustainable solid waste management. Their knowledge in waste management legal framework can equip hospital staff with essential information they require to abide to recommended standards, translating to reduction of rural hospital solid waste ecological footprint. Moreover, receiving appropriate information from EMA Officers and EHTs enabled health workers to comply with legal requirements, thus averting violations that lead to legal consequences. This reduces financial losses due to payment of fines related to environmental pollution since these rural hospitals are already experiencing financial deficit. Additionally, EHTs specialise in environmental health aspects encompassing management of hospital solid waste and their practical understanding of the concept can enlighten health workers on how to safeguard themselves when dealing with solid waste.

Zimbabwe Ministry of Health and Child Care is among the authorities responsible for monitoring recruitment, training and registration of health workers therefore it must introduce solid waste management as a core module in the nursing curriculum to lessen unawareness of newly employed health workers. This initiative could not enhance awareness of health workers at rural hospitals in Chirumanzu district only, but can significantly contribute to appropriate management of hospital solid waste across Zimbabwe. Through utilising this strategy, health workers encompassing those at rural hospitals would be equipped with vital knowledge to

minimise potential spread of ailments associated with inappropriate management of solid waste. Through enlightening future health workers on issues related to hospital solid waste management, Zimbabwe can lubricate the process of attaining local and global sustainable goals related to solid waste management. Furthermore, in collaboration with hospital EHTs, NSSA Safety Officers should educate health workers on the significance of PPE/C when dealing with hospital solid waste. Inclusion of NSSA is attributed to the fact that among other duties it is accountable for raising awareness of workers towards safety aspects as well as promoting health and safety at all workplaces and rural healthcare facilities are not spared. However, in order to minimise health workers' exposure to solid waste related injuries and diseases NSSA should carry out continuous monitoring of rural hospitals to check their compliance to recommended safety standards. Hospital Environmental Health Department is responsible for monitoring solid waste issues at the rural hospitals hence the department must carry out consistent inspections to check adherence of health workers to solid waste management requirements. Consequently, the hospital Environmental Health Department with support from workers' representatives should create solid waste management compliance code at hospital level. This enables the hospital Environmental Health Department to conduct disciplinary hearings for health workers who consider proper solid waste management aspects for granted.

Moreover, all health workers should participate in solid waste management aspects at ST Theresa and Holy Cross hospitals. Healthcare workers are usually at the forefront of patient diagnosis activities and generation of solid waste at rural hospitals, hence their experience and understanding is crucial. Inclusion of every health worker facilitates sharing of ideas hence narrowing the gap to achieve appropriate solid waste management at rural hospitals. Considering research findings, partnership of EMA, hospital Environmental Health Department, ZMoHCC, health workers and community people in management of solid waste from these rural hospitals is essential. Partnership of these organisations and individuals offers a platform for various experts to engage and cross-pollinate ideas which are essential in management of hospital solid waste. Co-operation of all accountable stakeholders creates an opportunity to formulate and strengthen existing policies and legislations related to solid waste management at rural hospitals. Moreover, to limit environmental health problems emanating from hospital solid waste, EMA should transparently carry out effective law enforcement and policy follow-ups. This activity has potential to ensure that ST Theresa and Holy Cross

hospitals are operating within the endorsed waste management standards. Collaboration of EMA, ZMoHCC and hospital Environmental Health Department among other stakeholders is critical to achieve integrated solid waste management at rural hospitals in Chirumanzu district. Results indicated that impacts of generated hospital solid waste affects the natural ecosystem which supports local people with various services. Therefore, to achieve environmental justice and proper hospital solid waste management, it is essential to recognise ideas of local people.

Additionally, studied rural hospitals often struggle to manage solid waste appropriately owing to shortage of resources. Therefore, like what the municipalities in urban areas do to urban hospitals, Chirumanzu Rural District Council should assist ST Theresa and Holy Cross hospitals to manage solid waste since generated solid waste overwhelms resources available at rural hospitals. This entails that Rural District Councils Act Chapter 29:13 needs revision so that its characteristics match with Urban Councils Act Chapter 29:15 in terms of solid waste management. Clear participation of Rural District Councils has potential to assist these rural hospitals to achieve sustainable solid waste management by offering support in terms of resource allocation and infrastructure development. Hospital solid waste presents occupational health problems to those involved in handling of waste from generation to disposal. Minimisation of occupational health risks required NSSA Public Health Officers to equip rural health workers with safety information including legislation and policies which upheld their occupational safety. NSSA Public Health Officers must conduct rural hospitals inspections to check if they are offering adequate PPE/C to those dealing with solid waste while verifying conformity of workers to safety gear issues. Hospital authorities that fail to provide enough PPE/C must be susceptible to penalties. However, shortage of resources including PPE/C to utilise during hospital solid waste management was among challenges experienced at these rural hospitals. As a result, ZMoHCC and rural hospitals should budget enough finance to purchase adequate resources required in management of hospital solid waste. Availability of enough resources facilitates construction of standard solid waste disposal structures and application of approaches which support circular economy.

In addition, rural hospitals including ST Theresa and Holy Cross' Environmental Health Departments should integrate technology such as Geographic Information System (GIS) and Remote Sensing (RS) in solid waste management issues. GIS and RS assist when locating

hospital solid waste disposal sites while facilitating analysis of relationship of disposal sites with other environmental attributes. This have potential to minimise occurrence of environmental health risks triggered by improperly sited disposal sites. Rural hospitals Environmental Health Departments (EHD) should gather sufficient data related to quality as well as quantity of solid waste generated. Therefore, EHD at ST Theresa and Holy Cross should be equipped with a database where they store up to date hospital solid waste information. Information regarding quantity and quality of hospital solid waste is essential to determine solid waste characteristics, generation trend changes as well as size of disposal and treatment facilities required. Adequate data is critical at these rural hospitals since it guides hospital authorities when budgeting waste management resources while guiding EHTs on nature of required PPE/C. Rural hospitals should try to utilise the proposed framework since it supports integrated approach and circular economy, thus creating low hanging fruits to attain sustainability.

Collaboration of EMA, ZMoHCC and rural hospital EHTs who are among major stakeholders in the forefront of implementing hospital solid waste management strategies is recommended since it assists in pilot testing of the newly proposed framework. The framework is at formulation stage, therefore its applicability in management of solid waste from rural hospitals need to be unearthed through pilot testing. Therefore, ZMoHCC, EMA and rural hospital EHTs should work together and conduct a pilot testing focusing on the case studies namely ST Theresa and Holy Cross hospitals. Pilot testing process must encompass implementation of the framework and collection of data regarding its performance, challenges experienced as well as strengths and limitations of the framework. Pilot testing enables the ZMoHCC, EMA, EHTs, the initial developer and other researchers to gain insights which assist them to address gaps of the framework while enhancing implementation approaches before it is fully adopted in the rural hospital solid waste management domain. Conduction of preliminary evaluation is essential since it offers room to assess feasibility of the framework before it is implemented on a larger scale, specifically before it is deployed to other rural hospitals in Zimbabwe. Furthermore, in terms of future studies, researchers must focus on how the proposed framework can be enhanced and applied in management of solid waste from urban hospitals, since increase of solid waste from urban hospitals is also adding burden to already struggling municipalities.

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