Development and Optimization of a Waste Management Model for Selected Sappi Saiccor laboratories

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Oswell Matasva
B. Tech: Chemical Engineering

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Supervisor Date
Prof. K.G. Moodley (PhD: Chemistry)

ABSTRACT

The purpose of the study was to formulate a model that can improve waste minimisation, management, and remediation; with the goal of minimising risk to health of staff working in the targeted facilities and the environment of the Sappi Saiccor Laboratories.

This model was based on waste generated by the chemical laboratories of a chemicals manufacturing company, namely, Sappi Saiccor Laboratories. The study employed both quantitative and qualitative (pragmatic) methods within a case study design. The quantitative aspects of the study involved both the solid and liquid waste streams generated in the laboratories. Sampling was conducted using a simple random method, which is part of probability methods. Eleven laboratory staff (50 percent of the total laboratory staff) participated in the laboratory analysis of the waste stream at the Sappi Saiccor laboratories. For the qualitative aspects of the study, the same eleven laboratory staff members participated via completion of pre- and post- assessment questionnaires regarding the development of a new model for waste management at Sappi Saiccor Laboratories. Probability methods of sampling were used to ensure the generated results were representative of the entire population.

A pre-risk assessment questionnaire was designed, implemented and assessed to identify all gaps and areas of improvement of the current waste management system. The types of waste generated, and their current disposal or treatment methods were described in the questionnaire. The use of a piloted questionnaire before and after the implementation of the new waste management model showed an increased awareness in waste handling, treatment, and disposal on the part of the laboratory staff involved throughout the study. The results provide evidence that the creation and implementation of a waste management model at the Sappi Saiccor laboratories improved environmental awareness and personal safety of laboratory staff which lead to reduced risk on the people and the environment.

Waste characterisation was possible through perusal of documented laboratory analysis methods, highlighting the major components of hazardous waste, alkaline waste, and toxic inorganic materials with corrosive characteristics. The largest quantities of generated solid hazardous waste comprised pieces of glass, used

paper towels, and nitrile gloves impregnated with toxic hazardous substances. A labelling system was introduced and implemented, in addition to the use of colour codes to classify/categorise the generated waste. The staff from the Sappi Saiccor laboratories generating the waste recommended the treatment and recovery of chemical substances such as copper sulphate anhydrous ($CuSO_4$) and potassium chromate (K_2CrO_4), using physicochemical techniques as opposed to the current practice of discarding into effluent channels without any form of pre-treatment. These are regarded as green alternatives designed to prevent damage to human health and the environment, as opposed to discarding the substances down the sink drain, situated under a fume hood. An integrated model for minimisation, management and treatment of waste was developed and the in-depth analysis concerning prediction of daily total laboratory waste generation at the Sappi Saiccor laboratories was performed to generate a multi-variable linear regression model for prediction of total waste. A multi-variable predictive model, which is a function of three independent parameters; number of people working per laboratory (Tp), number of laboratory tests performed per laboratory (Tt) and quantity of consumed chemical solutions per day (kg) (Tc) was developed. The main outcome of the predictive model suggested that the quantity of chemicals consumed per laboratory has the greatest effect or impact on the quantity of total waste produced.

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The waste prediction methodology applied in this case study can be adapted in any other laboratory unit within Sappi Sulphite Mills or allied industries which use acid bisulfite process for the manufacture of 92-94% alpha cellulose. Indicator and/or parameter adjustments may be required to adapt this methodology prior to the organisation of waste management plans in other laboratories belonging to different companies.

DECLARATION BY CANDIDATE

I, Oswell Matasva, declare that unless otherwise indicated, this dissertation is my original work and has not been submitted for any degree at another Tertiary Institution.

O. Matasva

Student Number: 22173805

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LIST OF ACRONYMS

BMW	Biomedical waste
CED	Cupri ethyl diamine
COD	Chemical oxygen demand
COE	Centre of excellence
CS_2	Carbon disulphide
$CuSO_4$	Copper sulphate anhydrous
CWTL	Chemical waste treatment laboratories
DUT	Durban University of Technology
GM	Grey model
H_2S	Hydrogen sulphide
HCI	Hydrochloric acid
HW	Hazardous waste
HWM	Hazardous waste management
HWMS	Hazardous waste management system
ISWA	International solid waste association
LCA	Life cycle assessment
MCC	Microcrystalline cellulose
MCDA	Multi criteria decision analysis
MLR	Multi linear regression
NaOH	Sodium hydroxide
NHW	Non-hazardous waste
PPE	Personal protective equipment
RCRA	Resource conservation and recovery Act
RW	Regulated waste
SPSS	Statistical package for social sciences
TDS	Total dissolved solids
WMP	Waste management project

GLOSSARY OF TERMS

Five S (5S)	A methodology for organising, cleaning, developing and sustaining a productive work environment.
Linear regression	A regression model that estimates the relationship between one independent variable and one dependent variable using a straight line.
Questionnaire	A research instrument consisting of a series of questions for the purpose of gathering information from respondents through survey or statistical study.
Sampling	Selection of a subset of individuals from within a statistical population to estimate characteristics of the whole population.
Waste management	Is the process and actions required to manage waste from its inception to its final disposal.
Quantitative research	Is a research strategy that focuses on quantifying the collection and analysis of data.
Qualitative research	A research method that relies on researcher obtained data from first-hand observation, interviews, focus groups, and questionnaires, as well as participant-observation, recordings in natural settings, documents, and artefacts.
Pragmatic research	A research method that combines both qualitative and quantitative research approaches.
ANOVA	Analysis of variance is a collection of statistical models and their associated estimation procedures used to analyse the differences among means.
Risk assessment	Is the combined effort of identifying and analysing potential events that may negatively impact individuals, assets and or the environment.
Model	Informative representation of a person, object, or system.
Waste minimisation	A set of processes and practices intended to reduce the amount of waste produced.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Hazardous and general waste is continually generated throughout all industry categories, which can create a permanent, negative, and long-term and employee impact, affecting both the workplace and communities, as well as the macro environment, worldwide in some cases. Implementing an effective hazardous waste management system (HWMS) is thus crucial to maintain a safe operating environment (Hazardous waste management 2021b).

According to results from research Chung Ho and Shu Chen (2017) conducted at Taiwan University chemical laboratories, it was found that the continuous increase in the number of laboratories in universities and research institutes in recent years has resulted in a greater number of industrial wastes, such as solid waste, liquid waste, and effluent. This has resulted in complex waste management issues. Kandel, Neupane and Giri (2017), who examined the status of chemical laboratories in Nepal, added that chemistry laboratories can become a dangerous environment for laboratory personnel, as the use of the laboratories involves hazardous chemicals, glassware, and equipment, highlighting that waste generated from laboratory activities can become equally dangerous when not managed properly. In addition, Chung Ho and Shu Chen (2017) pointed out that several accidents and personal injuries in academic and research laboratories, were caused by improper handling of waste. Badi, Shetwan and Hemeda (2019) concur, noting laboratory waste is a problem that haunts environmental officials in Libya, in view of the many environmental and health risks it causes, as well economic losses. Analytical and research laboratories generate small amounts of a large variety of wastes, which makes their management difficult.

Historically, issues of waste management existed but were not completely solved globally. Awasthi and Wang (2018) noted environmental deterioration and health risk, due to improper waste management, has become a serious issue in India. In Brazil, universities that generate waste are obliged to manage their own waste in a safe manner, resulting in the adoption of proper waste disposal procedures to fulfil good laboratory practices and meet legal guidelines (Fatima, Pedrozo and Philipi 2006). Research conducted at Dalhousie University highlighted the growing concern of product production impacts and associated waste materials (Dalhousie University, *Waste management practices* 2011).

Managing waste can, nonetheless, be challenging for industrial, commercial, and institutional sectors, as organizations must deal with a wide variety of materials and large volumes of waste; there is no one waste management plan that will best fit the needs of all organizations. However, a strategic solid waste and hazardous chemical waste resource management planning approach will help to define solutions. Integrated waste resource management planning will enable organizations, such as Sappi Centre of Excellence (COE) laboratories, to create a comprehensive strategy for waste management.

As of 2017, laboratories in the United States of America (USA) are required by Federal and State regulations to develop and implement a waste management strategy (*Laboratory chemical waste management guidelines* 2017). In South Africa (SA), waste management has been at the centre of a debate in most environmental policy discussions, dating back to the Polokwane Declaration in 2002, where the following resolutions were taken:

- Decrease in waste generation by 50 % by 2012
- Decrease in waste disposal by 25 % by 2012
- Plan for zero waste by 2022 (Department of Forestry, Fisheries and the Environment (DFFE), RSA 2022)

All the above has placed increased pressure on government to take immediate action to ensure targets are met (DFFE, RSA 2022). Although SA is leading the waste management sector in Southern Africa, when considering the life cycle of waste management, the country still lags European and other developed countries by about 20-30 years (Averda 2022).

In recent years an increased number of non-conformances in the sector have surfaced, such as those noted at the Sappi COE laboratories, with findings related to improper waste management practices in observing and adhering to waste management protocols. These irregularities unnecessarily complicate waste management at the Sappi COE laboratories, yet have no explanations or established causes, requiring further investigation to potentially produce sustainable solutions.

1.2 PROBLEM STATEMENT

Waste management is a problem prevalent across the globe with consequences that significantly damage earth's environment and develop negative financial, social, and biological effects (Heng & Qiu 2018). Several studies have been conducted on the origins and characteristics of wastes, as well as the possible adverse impact of incorrect handling and best international practices (Amasuomo & Baird 2016). Historically, problems of waste management have been noted in several institutions that include but are not limited to analytical/research laboratory facilities and educational institutions (Fatima *et al.* 2006). Laboratory waste exposes people to potential health emergencies in the form dangerous substances that can be corrosive, carcinogenic and pose other health risks. Waste may also find its way to landfills where it may degrade the environment in diverse ways.

Due to manufacturing and laboratory activities at the Sappi Saiccor mill, situated outside the town of Umkomaas in the KwaZulu-Natal province, SA, much waste is generated. The mill is one of the world's largest producers of natural extracted cellulose from wood, using *Eucalyptus* wood as raw material to produce this product (Saiccor technical manual 2012). The mill has put various measures in place to monitor, control, and manage "waste". However, other than the mill itself generating waste, there are several laboratories within the mill that render analytical services to the different departments in the mill. Some help to monitor, control, and manage waste on site. It is important to note that while these laboratories render technical and analytical support to the mill, they also generate waste in the process. At Sappi COE laboratories, a significant quantity of waste is generated because of laboratory operations, with some of the waste generated hazardous, raising the need to develop a model for waste management.

In addition to the above sentiments, there has been an increase in the number of non-conformances and findings in recent years at the Sappi COE laboratories related to improper waste management practices, such as laboratory personnel mixing waste that should not be mixed, discarding chemical and general waste incorrectly, poor chemical compatibility and general ignorance in observing and adhering to waste management protocols. The root cause for these findings is not known and has created a need for further investigations that will lead to sustainable waste management solutions at the laboratories.

1.3 AIMS AND OBJECTIVES OF THE STUDY

1.3.1 Aim/s

The aim and objectives of the study are:

- To formulate a model that improves waste management, minimisation, and remediation at the Sappi Saiccor COE laboratories, with the goal of minimising risk to health and the environment.
- To reduce non-conformances and findings related to non-adherence to waste management protocols at the Sappi Saiccor COE laboratories with the goal of minimising risk to health and environment.

1.3.2 Objectives

- Identify the types of waste generated by the Sappi Saiccor COE laboratories.
- Categorisation of waste into hazardous and non-hazardous.
- Conduct risk assessments on chemical hazardous waste (HW) frameworks.
- Design a model to handle or manage chemical HW at the Sappi Saiccor COE laboratories.

1.3.3 Research questions

- What type of waste is generated by the Sappi Saiccor COE laboratories?
- What components are essential in a comprehensive waste management model or plan?
- What categories should waste be grouped into?

- What model of waste management should be developed at the Sappi Saiccor COE laboratories?

1.3.4 Scope and significance of the study

- The scope is based on developing waste management model based on suggestions and recommendations using pre-risk assessment findings followed by comparison with post-assessment findings.
- The research carried out is extremely necessary within a South African context; as it creates public awareness of management and disposal of waste by many industries. Due to the use of chlorinated and sulphur-containing compounds, this research will highlight the safe disposal of them.

1.4 CURRENT STATUS OF WASTE MANAGEMENT AT COE LABORATORIES

The COE laboratories under study are located in the Technology centre hub at the Sappi Saiccor mill, outside the town of Umkomaas, in the KZN province of SA and, through the Sappi Southern Africa (SSA) Technology Centre and Innovation Hub, also a COE, in Johannesburg, Gauteng Province, SA render analytical and technical support to Sappi mills around the world. Due to the nature of work at the laboratories, waste is generated.

The biggest COE laboratory at the Sappi Mill is the Viscose laboratory, with a pilot plant that mimics the viscose rayon process for the manufacture of viscose staple fibres. During the production of rayon fibres, dissolving wood pulp is immersed in metal vessels containing approximately 18.5 % caustic soda; the process is popularly known as alkalisation or steeping. The cellulose or pulp reacts with the caustic soda solution to form alkalised cellulose that is dewatered by removing excess caustic soda before being reacted with a chemical known as carbon disulphide (CS_2), which converts it to sodium cellulose xanthate that is, in turn, dissolved in caustic soda to form viscose dope under carefully controlled conditions. The other derivetisation process conducted at the Sappi Saiccor COE laboratories is the acid treatment of pulp or cellulose using hydrochloric acid (HCl) of 2.5N (normal) concentration to form microcrystalline cellulose (MCC), which is in a powder form. These processes, with other tests taking place at other Sappi COE laboratories, generate general and chemical HW. Over the years, various measures have been put in place at these laboratories to monitor, control, and manage the produced waste.

The Sappi Saiccor COE has a total of six laboratories namely the Viscose, MCC, Acetate, and Acetate technology, to an Instrumentation and General laboratory. Each laboratory has its own function. Hence, it is expected the nature of waste generated from one laboratory may differ in composition and characteristics to the waste generated in another laboratory. Common types of waste are also found in all laboratories, such as used paper towel and gloves, nonetheless, they may still contain different contaminants, since each laboratory testing differs from the other. Currently, the Sappi Saiccor COE laboratories do not operate according to a waste management model, instead, a simple generic waste management framework on how to handle and manage all forms of waste is relied on; however, it lacks detailed waste management systems, including a waste generation prediction model.

Waste prediction is a very important component of any sustainable waste management model nowadays, since it contributes to effective waste planning and management (Abassi *et al*. 2012); hence, a predictive mathematical equation or expression that can be used to estimate waste generation at the Sappi Saiccor COE laboratories will be developed. In the past years, increased findings or non-conformances related to not complying with waste management protocols have been noted. Recently, though, there have been complaints that the topic of waste management has been undermined and not given enough attention, which could explain the diminishing level of waste management compliance. The purpose now is to identify gaps within the current system, to address these gaps and improve the overall waste management system. Table1.1 shows some of the waste materials currently generated at the Sappi Saiccor COE laboratories and their treatment or disposal methods.

Table 1.1: Waste materials and Treatment disposal methods/protocols at SAPPI SAICCOR COE Laboratories

Waste material generated	Treatment/disposal method
Waste viscose dope (A product of the Viscose process for rayon fibre production)	1. Waste viscose dope is regenerated with five percent sulphuric acid. The regenerated viscose is washed with copious amounts of hot water to remove residual traces of sulphuric acid and H_2S gas and thereafter disposed in a general waste bin. 2. Waste viscose dope is extensively diluted with dilute sodium hydroxide solution and washed down the laboratory sinks to effluent with copious amounts of water to prevent precipitation of cellulose and subsequent blockages
Waste MCC powder (Microcrystalline cellulose which is a product of acid hydrolysis of pulp/cellulose)	Powder MCC is discarded into general waste bins for disposal.
Alkalised cellulose/alkcell (A product of steeping cellulose/pulp in 18.5 percent sodium hydroxide solution)	Alkcell from the Viscose Laboratory is disposed into a designated bin. Once full, the alkcell is taken to the skip, located outside the COE. Alkcell waste bins are in the Viscose and General Laboratories. From the skip, it goes to landfill.
Effluent generated from Cupri Ethyl Diamine (CED) viscosity testing of pulp	Washed into the laboratory sinks/drains processed through effluent channels
Effluent generated from acid hydrolysis of pulp	Washed into the laboratory sinks/drains processed through effluent channels
Spent 18.5 percent sodium hydroxide solution	Washed into the laboratory sinks/drains processed through effluent channels
Effluent generated from hemicellulose in steep soda test, solubilities and copper number test of pulp	Washed into the laboratory sinks/drains processed through effluent channels
Effluent generated from bleaching using Sodium hypochlorite (NaOCl)	Washed into the laboratory sinks/drains; thereafter processed through effluent channels
Used nitrile gloves	Discarded into a designated bin in each COE Laboratory. Once full, the gloves are collected by an authorised contractor for landfill disposal
Used glassware	Thoroughly rinsed glassware (without cap for bottles) is placed into the bin labelled “Clear Glass” outside the Viscose Laboratory. The glass is collected by an authorised contractor for landfill disposal.
Empty chemical containers	Plastic chemical containers/bottles are rinsed out thoroughly, punctured and placed into the bin labelled “Empty Plastic Chemical Containers” located outside of the Viscose Laboratory. This is collected by a contractor for landfill disposal.
Used paper towel	Contaminated tissue (all chemicals) is disposed of into the chemical paper bins located in all the COE laboratories and thereafter is taken to the skip. From the skip, it goes to landfill.
General waste such as boxes, plastics, and metals	Wastepaper from offices is disposed into the general waste bins. Cardboard boxes are placed into the bin which is taken for recycling by contractors
Expired chemicals	Chemicals that have expired or not been consumed during project work are removed from site by an authorised contractor for disposal to a landfill

1.5 RESEARCH METHODOLOGY

This study comprised a case study of developmental nature that involves statistical analysis, with a pragmatist paradigm, resulting in a mix of qualitative and quantitative methods and approaches that assist the researcher to best structure, investigate and provide provisional answers to research questions (Onwuegbuzie, Johnson and Collins 2009). In a pragmatist approach, surveys were thus analysed quantitatively, while qualitative analysis was applied to organisational documents and interviews. SAPPI COE laboratory staff was subjected to questionnaires voluntarily.

A case study is defined by Rule and John (2011: 4) as "a systematic and in-depth investigation of a *particular instance in its context* in order to generate knowledge", while Yin (2003, cited by Rule and John 2011:4) describes a case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". However, the definition of case study is refined by Vanwynsberghe and Khan (2007: 80) to be: "a transparadigmatic and transdisciplinary heuristic that involves the careful delineation of the phenomena for which evidence is being collected (event, concept, program, process, etc.)". Nevertheless, at its most basic, a case study is "a unit (something you study), a process (something that you do), and a product (something that you make) (Merrriam 1998 cited in Rule and John 2011: 5).

The researcher investigated the full content of circumstances at the Sappi Saiccor COE laboratories prior to design of the present study. Both pre- and post-assessment were achieved through dissemination of a questionnaire (qualitative method) to 11 laboratory personnel (half the staff), including analysts, technicians and management, who agreed to participate in the pre- and post-model risk assessment questionnaire. Sampling was conducted using a simple random method, which is part of probability sampling methods, ensuring results generated are representative of the entire population (Acharya *et al.* 2018).

A pilot study was further performed, with the questionnaire (Annexure A) completed by staff who did not participate in the study, checking for understandability, readability and accuracy; adjustments were made where needed as suggested. The pre-assessment questionnaire was used to assess the current waste management status at the Sappi Saiccor COE laboratories, with the post-model risk assessment questionnaire used to assess the new implemented waste management model at the laboratories.

Participation in the study was voluntary and all efforts were made to ensure respondent anonymity, confidentiality and protection of data.

1.6 LAYOUT OF THE RESEARCH PROJECT

The dissertation is divided into five chapters. A brief description of the contents of each chapter follows:

Chapter 1: The Introduction provided an overview of the global challenge of waste management in research, academic and manufacturing institutions. This chapter also focused on the study background, rationale behind the research, problem statement, and aims and objectives, as well as the scope of the research, in addition to the research instrument and methodology.

Chapter 2: The Literature review provides an extensive review of the existing literature on waste management; it starts with a review of waste management history. The chapter will then seek to identify the philosophies and core principles of waste management planning, followed by different institutions globally, specifically in the chemical, research, and analytical laboratories.

Chapter 3: Incorporates the design of Research and Methodology of the study, providing a description of the procedure followed and tools used in the creation of the waste management model.

Chapter 4: Results and Discussion will reveal the findings and analysis of the study. Findings are detailed and discussed to evaluate the issues of waste management at the Sappi Saiccor COE laboratories.

Chapter 5: Model Validation, Conclusions and Recommendations form the final chapter of this dissertation and provides discussions and conclusions concerning the study.

1.7 SUMMARY OF THE CHAPTER

The background and significance of the study outlined in this chapter provide evidence that the topic of waste management is a major issue, worldwide. The chapter also introduced the research instrument and methodology adopted to accomplish the research project. The next chapter will present the review of related literature and the potential research ideas used during this investigation.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will outline the theoretical background and content of waste management in academic, research, and analytical laboratories, through detailed information sources selected from peer reviewed academic journals, grey literature, relevant books, and periodicals, as well as newspaper articles, and websites. The literature review focuses on surveying information pertaining to waste management methodologies, policies, and research relevant to Sappi COE laboratories. The findings of this literature survey will aim to answer the following questions.

- What components are essential in a comprehensive waste management model?
- What types of considerations should Sappi COE laboratories contemplate in developing a waste management model?
- What is the range of options in formulating a waste management plan?

2.2 WHAT IS WASTE?

Ever since humans have inhabited the earth, they have been confronted with the problem of what to do with their waste materials; substances which are no longer of use. Waste is defined as an unwanted or unusable material or substance that is discarded after primary use, or it is worthless, defective and of no use. They may be in the form of solids, liquids or gases in a container. Waste materials may also include hazardous residues (Meyer 2018). Sakai, Sawell and Chandler (1996) noted that waste management strategies and definitions of waste differ significantly between countries and waste management remains a prominent issue with common methods of achieving goals and objectives. With increasing support for improving economic, environmental, and social impacts of human activities, material efficiency and waste management have been a primary objective of much research. In SA, waste management is a function amongst all spheres of government and as the custodian for environmental management, the department of environmental affairs is mandated to ensure a safe and healthy environment that is not harmful to the well-being of the citizens of the country (DFFE RSA 2022).

As an alternative to managing the disposal of waste, some companies have been formed to recycle waste or to convert combustible waste into energy or into marketable products. One example of such a company is COWI. It is a northern European industry that converts combustible solid municipal, industrial, scrap tyres and bulk waste to heat and power energy. Prior to this venture, COWI has been engaged in preparing integrated waste management plans for several companies all over the world: focussing on a coherent approach to high energy efficiency and sustainable waste management involving saving of natural resources. The European Union landfill ban policy has encouraged member states to find alternative ways for waste disposal. Germany, for example, enjoyed a recycling rate of around 66 percent by 2010, while 32 percent of its waste was sent for energy recovery (Waste management world magazine 2010).

In 2017, SA generated an estimated 55.6 million tonnes of general waste (non-toxic material that cannot be recycled) and 52 million tonnes of HW (Averda 2022). Of this number, only 34.5 percent of general waste and 6.6 percent of HW was recycled or recovered. The remaining hazardous and general waste was disposed in landfill sites (Averda 2022).

2.3 COMPONENTS OF WASTE MANAGEMENT SYSTEMS

Chemical agents, which include chemicals, radiation, and biological agents, produce waste, and are widely and continuously used in industry. Waste produced from these agents may have detrimental effects. These may have immediate as well as long term impact on employees handling these agents, the workplace, communities, and the macro environment on a global level. As with all categories of risk, the impacts of waste from chemical agents will ultimately have an impact on the environment and health (Hazardous chemical substance management 2021a). According to the International Solid Waste Association (ISWA) (2010), prehistoric discoveries prove the problem of waste disposal and efforts to find solutions have existed since people began to live in settlements. All over the world, there have been several developments in how people, organizations and governments manage waste (ISWA 2010).

Problems in waste management have become ever more complex. The increasing volumes of waste produced and social environmental consciousness present prominent drivers for environmental managers towards the achievement of a sustainable waste management scheme (Achillas *et al*. 2013). Waste management is a pressing issue prevalent across the globe, with significant damage caused to the environment, with negative effects developing in social, financial, and biological spheres as a result (Heng & Qiu 2018). Human activities produce a significant amount of waste (Brunner and Rechberger 2014). Despite this, the production and management of wastes remain a source of concern (Chandler *et al*. 1997).

In the last 15 years, the degree and load of waste generation has been on the increase year on year by 2.5%. As the quantity of wastes spikes, so also does the diversity of the waste increases (Vergara and Tchobanoglous 2012). Problems of waste management have been noted in several institutions such as academic, research and manufacturing. As example, three accidents occurred in east China's Jiangsu Province in March and April 2019, which sounded the safety alarm for effective HWM. The root cause analysis showed HWMS failed to take full account of safety and environmental protection, leading to many potential risks (Yang *et al*. 2020).

Fatima *et al.* (2006) highlighted that academic, analytical and research laboratories generate different types of wastes, and this makes their management difficult. In addition, Yekkalar *et al*. (2015) noted that, due to particular characteristics, laboratory wastes are characterised by complex and heterogeneous matrices, making it difficult to standardise treatment procedures, which results in their integrated management presenting a challenge. Leoneti *et al*. (2019) considered the wide variety of wastes treated in chemical waste treatment laboratories (CWTLs) and noted the characterisation and grouping of these wastes are essential. However, it was further mentioned that chemical inventory and data recording are fundamental practices for implementing the waste management framework in CWTLs. Yekkalar *et al*. (2015) additionally explained that most chemical wastes generated in laboratories have toxic and hazardous characteristics; being flammable, corrosive, highly reactive, and mutagenic, as well as teratogenic, and carcinogenic.

Badi *et al.* (2019) suggested laboratory waste is a problem that troubles environmental officials, because of the diverse risks to the environment and employee health, along with economic losses. In many cases, the most efficient way to manage waste is to not have to deal with it, at all. Therefore, waste diversion and waste minimisation are often a primary focus for most integrated waste management plans. A common misconception is that environmental protection and sustainable initiatives must come at the expense of economic development (El-Haggar 2007). However, the best strategy for managing laboratory waste aims to maximize safety and minimise environmental impact, considering these objectives from the purchase time of the chemicals (National Research Council (US) Committee 2011).

Chitre (2010: 31) stated another way of improving waste management in a laboratory, is by introducing good housekeeping, which can be achieved using a 5S process, defined as: “a component of Lean manufacturing that is a methodology for organizing a shared workspace with the intention of improving efficiency, eliminating waste and reducing process unevenness”. Managing laboratory waste can be divided into three steps, namely, reuse, recycle and recovery (*Laboratory chemical waste management guidelines 2017*). An important question for planning within the laboratory, is whether a waste is regulated as a HW, because regulated HW must be handled and disposed of in specific ways. A HW can be a solid, liquid, or gaseous material that displays either a “hazardous characteristic” or is “listed” by name as a HW (*Laboratory chemical waste management guidelines* 2017).

According to Nagpal e*t a*l. (2019), the problems of waste are also significant in the medical laboratory field in India. The authors mentioned that because of key developments in the medical sector in India in the past 20 years, the rate of waste generation has increased tremendously. Subramanian *et al*. (2021) noted that biomedical waste (BMW) is an emerging occupational and environmental health hazard in the healthcare sector. These waste products, which are infectious, hazardous, and sometimes radioactive, and are generated during the various medical related activities, such as diagnosis, treatment, and immunisation. Today, BMW management has become a major issue of concern in countries such as India, considering its rate of population growth and rapid urbanisation (Nagpal e*t a*l. 2019). BMW is distinct from normal trash or general waste as medical facilities also generate hazardous chemicals and radioactive materials, as such wastes are normally not infectious. However, these materials do require proper disposal, creating an environmental concern, since many medical wastes are classified as infectious and could potentially lead to the spread of infectious diseases. To protect the environment, public and workers, especially healthcare and sanitation workers at risk of exposure to BMW as an occupational hazard, it must be properly managed and disposed of. Steps in the management of BMW include generation, accumulation, handling, and storage, as well as treatment, transport, and disposal.

2.4 WASTE MINIMISATION

In support of waste minimisation, Goh, Wong & Ong (2019) stated that chemical waste should be reduced to minimise environmental pollution, which includes the amount of waste in chemistry laboratories; to reduce the negative environmental impact, as well as disposal costs. Moreover, the authors also mention several ways to minimise chemistry laboratory generated waste, namely, elimination or reduction of the pollution source, recycling and reuse of the chemicals, treatment of waste to minimise its hazards, and the use of micro scale chemistry, in addition to better management of chemical inventories in the laboratories.

Waste from laboratories and research facilities are divided into special categories, some of which require particular attention and disposal (Meyer 2018), as waste legislation distinguishes between non-hazardous and HW. Non-hazardous waste (NHW) comprises communal waste, all solid waste apart from infectious, chemical, or radioactive wastes. This waste stream can include items such as packaging materials and office supplies. Generally, it can be discarded of in a communal landfill or other such arrangement. Segregation of materials that can be reused or recycled greatly reduces the impact burden of this waste stream. Types of waste include:

Hazardous waste that is also infectious waste, consists of discarded material from chemical laboratories, medical or veterinary activities with the potential to transmit infectious agents to humans. This class of waste comprises discarded objects or equipment from the diagnosis, treatment, and prevention of disease (such as assessment of health status or identification purposes) that have been in contact with blood and its derivatives (tissues, tissue fluids or excreta) or wastes from quarantine wards. Sharp items such as syringe needles, scalpels, infusion sets, knives, blades, and broken glass, should be considered as a subgroup of infectious healthcare waste, irrespective of whether contaminated or not.

Pharmaceutical waste is the type of waste that includes pharmaceuticals or materials containing pharmaceuticals (including expired medications) and items with or contaminated with pharmaceuticals (bottles, boxes, containers, and packaging). Biological and microbiological waste includes types of HW containing substances with infectious properties from laboratories, including contaminated bottles and equipment.

Chemical waste consists of or contains chemical substances, including laboratory chemicals, film developers, disinfectants (expired or no longer in use), and solvents, as well as cleaning agents and other types. Radioactive waste comprises and includes unused liquids from radiotherapy or laboratory research, along with contaminated glassware, or packages (Meyer 2018).

2.5 WASTE CHARACTERISATION

In 2008, the University of Northern British Columbia, Prince George Campus (Canada), developed a waste characterisation study to determine the amount and composition of waste produced. To minimise the extent of solid waste, a general classification method was adopted, based on recyclable, compostable, non-recyclable, hazardous, and electronic waste (Smyth, Freedeen and Booth 2010). Lara *et al*. (2017) noted that numerous materials and products used in chemistry laboratories have the latent possibility to become HW. The authors also noted that the Autonomous University of Nuevo Leon School of Chemistry in Mexico had initiated a HW classification programme in 1994. Later, in 2003, a new comprehensive programme for hazardous waste management (HWM) emerged.

This provided a systematic programme of collection and classification of HW generated in laboratories; for the purpose of confining and reducing the amount of HW produced by the institution. Lara *et al*. (2017) described the scope of this comprehensive programme for HW and explained how it had impacted the Chemistry School and the University community from 2009 to 2013.

Classification of HW by type was found to be useful and quickly adopted by the student community, as well as academic and non-academic staff, with Lara *et al*. (2017) finding the largest quantities of generated HW consisted of liquid acid waste and toxic inorganic materials with corrosive characteristics, while generated solid HW mostly comprised pieces of glass impregnated with toxic hazardous substances. In conclusion, the authors pointed out that the most important result of this comprehensive HWM programme was the legacy of environmental care imparted to the student community.

Beigl, Lebersorger and Salhofer (2008) reviewed several methods used for predicting solid waste quantities, which could be categorised into seven groups namely, correlation analysis, group comparison, single regression analysis, and multiple regression analysis, as well as time-series analysis, input–output analysis, and system dynamics. Among these methods, regression analysis is widely used to forecast solid waste generation due to its mature theory and simple algorithms (Xu *et al*.2013).

2.6 WASTE MANAGEMENT MODELS

Morrissey and Browne (2003) noted developments of waste management models over the last number of decades, revealing that the first waste management models were optimisation models that dealt with specific aspects of the problem. It was further observed that more recent models were compromising models, focused on integrated waste management, with the concept of sustainable waste management becoming central to these models. Furthermore, three main categories of models were identified, namely: cost benefit analysis, life cycle inventory, and multi-criteria models.

Christensen *et al*. (2020) observed waste management is challenged by the increasing complexity of the waste entering the system and the demand for affordable sustainable solutions that protect the climate and contribute to a circular economy. To mitigate this complexity, models such as the Life Cycle Assessment (LCA) assess the potential environmental impacts and resources used in a waste management system. This covers all waste types of interest and considers an integrated system that starts with waste generation and includes transport, treatment and disposal of the various fractions and residues, and exchanges of materials and energy with the surrounding society. Christensen *et al*. (2020) further stated the strength of using LCA in waste management is that it provides a comprehensive, consistent, and transparent overview of flows in the waste management systems, while also providing quantification of the environmental profile of the waste management system. LCA also offers insights for selected parts of the system, with Christensen *et al*. (2020). claiming there was no other tool that provides the same level of quantitative information.

Morrissey and Browne (2003) stated that modelling is one approach used to systematically identify solutions to a given problem. Furthermore, the authors observed that mathematical modelling had been used for waste management since the 1970s, and the first models were used to optimise costs within limited scopes of both time and type of waste management system. However, waste management models have gradually improved and become more sophisticated; and their system boundaries have expanded.

According to Xi *et al*. (2021) the prediction of HW production can provide a basis for establishing a waste-disposal scale and proposing counter-measures for optimal waste management in a region. The authors also state that use of a quantitative prediction model for waste is mainly based on socio-economic characteristics and statistical methods (for example, the grey model (GM), regression analysis, and time-series models).

Pourzamani *et al*. (2019) formulated a method or model for quantitative and qualitative evaluation of HW in laboratories of Isfahan University of Medical Sciences (IUMS), Iran. They identified laboratories that generated the highest amount of HW and thereafter collected data in the selected laboratories. The required information was gathered through completion of the questionnaire, and reference to available documents. The principle behind this model was based on deriving generalised multiple-variable regression models to predict each of three experimentally measured hospital solid waste (HSW) components in kg day−1; general solid hospital waste generation (WG), hazardous solid hospital waste (WH), and total solid hospital waste (WT) as a function of three parameters. The first parameter was the number of inpatients (Tin). The two other parameters are the number of total patients (Tp) and number of beds (Tbed).

A questionnaire designed by Hassanvand *et al*. (2011) was employed in the IUMS research, the survey comprised five sections: (1) Quantity of HW generation, (2) Separation, packaging, and labelling of HW, (3) temporary storage method of HW, (4) Discharge or collection frequency of HW, and (5) treatment and final disposal method of HW. To determine the total amount of hazard waste at IUMS, liquids, semi-solid and solid hazard wastes were considered. The assumption was that, "1 litre of hazard waste is almost equivalent to 1 kg" and the total amount of HW was expressed in mass units (Hassanvand *et al.* 2011: 1636-1642).

Julia, Ramm and Carla (2018) reported on a waste management programme undertaken in a technical chemistry laboratory. The general objective of this study was to analyse the development and implementation process of a waste management project (WMP), offered to students taking the Chemistry Technician's course at a public school in the city of Porto Alegre, in the state of Rio Grande do Sul, Brazil. To this end, an initial diagnostic analysis of the commonly produced waste from the practical classes was carried out, and a waste management programme developed to meet the needs of the technical course to minimise the waste produced during experimental activities and provide instructions for its adequate disposal. Additionally, teachers and students attended training courses for guidance on waste separation and identification procedures. The use of a questionnaire before and after implementation of the WMP and training courses showed an increased individual level of awareness of those involved throughout the study.

Coelho, Lange and Coelho (2017) describe waste management as a complex domain involving the interaction of several dimensions; thus, its analysis and control impose continuous challenges for decision makers. The authors also observed that multi-criteria decision-making models had become important and convenient supporting tools for waste management, because they can handle problems involving multiple dimensions and conflicting criteria. However, selection of the multi-criteria decision-making method is difficult, with several approaches to this method, each with many variants, whose applicability depends on information availability and the study aim. The most popular, sustainable decision-making models are life-cycle assessment, as well as cost-benefit, and multi-criteria analyses.

Life cycle analysis calculates the environmental impact of all waste treatment processes, from "cradle-to-grave", whereas cost-benefit analysis considers the monetary dimension, while multi-criteria decision analysis compares social, economic, and environmental criteria (Morrissey and Browne 2004). Ultimately, considerations of all relevant factors in solid waste management within local circumstances are vitally important, in order to determine the success or failure of the selected decision-making assessment methods (Zurbrügg *et al*. 2014). As Zacho and Mosgaard (2016) stated, to date, waste management has been characterised by end-of-pipe solutions, landfilling, incineration, and recycling. End-of-pipe solutions build on a different mind-set than life cycle-based approaches, addressing matters such as pollution control, for example, by treating or filtration of what is discharged, as opposed to changing the process causing the wastes (EEA 2022) and for this reason, local waste managers are reluctant to consider such strategies for waste prevention.

2.7 DATA COLLECTION USING QUESTIONNAIRES

To develop and promote a safety culture within academic chemistry laboratories at a public Brazilian University, a research project was conducted that analysed the potential of a training programme to raise awareness and establish environmental education and green chemistry concepts, with regard to procedures for the management and treatment of chemical waste generated in experimental classes (de Oliveira *et al*. 2021). This was a qualitative case study providing a critical perspective of environmental education. The training activity, lasting 45 minutes, was conducted with 66 students entering Chemistry courses.

Data collection at the Brazilian University was carried out using an initial questionnaire to identify students' prior knowledge, with a final questionnaire administered after the training period. The questionnaires contained open- and closed-ended questions with a Likert-type scaled response. Results showed the training activity contributed to the students' understanding of the concepts, procedures, and attitudes related to the management and treatment of chemical waste, including the interrelations among the environmental, social, and economic impacts of waste management, the importance of correct separation and storage of residues for disposal using different types of treatments, the civil liability of the academic community for the residues generated, and how the 3Rs principles (**reuse, recycle and recovery**) can favour sustainable practices in the academic context (de Oliveira *et al*. 2021).

According to Meyer (2018), the most important principles of a waste management system are, waste avoidance, reduction, reuse and disposal, where the safety of the community and the environment are concerned. Universities, laboratories, and research facilities striving to implement a waste management system are moving towards the achievement of a healthy and safe environment for their employees and communities. Meyer proposes the following steps needed to implement a waste management system in laboratories: 1) Formation of a commission from the various departments of the institution; 2) Nomination of a person responsible for the waste management system; 3) Collection of data to assess the present situation by means of a questionnaire.

Meyer further explains that, on the one hand, the questionnaire should provide information about the types of waste expected, the nature and quantity of the waste, packaging, internal transport, as well as temporary storage, and final disposal. The commission should, on the other hand, analyse the data from the questionnaire, from which to formulate recommendations concerning the replacement, where possible, of hazardous substances with products not harmful to the environment and health; thus, easier to dispose of chemicals recommended for use in a laboratory. Finally, a functioning waste management system could form the basis for an environmental management system certification, according to ISO 14001 (Meyer 2018).

Proper chemical waste management protects the health and safety of everyone and prevents or minimises pollution. All generators of chemical waste should, therefore, do their best to minimise the amounts or chemical waste they generate and recycle whenever possible (University of Delaware 2018).

2.8 WASTE HANDLING AND REMEDIATION

Academic, analytical and research laboratories generates different types of wastes, and this makes their management difficult, highlighting the importance of the adoption of proper disposal procedures to fulfil good laboratory practices and meet legal guidelines. A correct disposal procedure should include knowledge of the waste management steps and toxicological data for each of the substances handled, as well as adequate waste management training. Therefore, waste management should be mandatory for institutions where waste results from its operations. Furthermore, waste management should be based on administrative decisions, budget compatibility and a consistent educational programme. The overriding principle governing the prudent handling of laboratory/ institutional waste is that no activity should begin unless a NHW and HW disposal plan has been formulated. Application of this simple principle ensures the numerous states and or country requirements for waste handling are met and avoids unexpected difficulties, such as the generation of a form of waste (for example, chemical, radioactive, biological) the institution is not prepared to deal with (National Research Council (US) Committee 2011).

The most efficient way to manage waste is, in many cases, not having to deal with it; therefore, the National Research Council (US) Committee points out, most integrated waste management plans often primarily focus on waste diversion and waste minimisation. Specific goals and targets are defined in a plan, with consideration for prescribed federal, provincial, and municipal goals that organisations must follow in many jurisdictions.

The Committee further stated that the best strategy for managing laboratory waste aims to maximise safety and minimise negative impact on the environment by taking these objectives into account from the purchase time of the chemicals. The initial responsibility for implementing this hierarchy thus rests with trained laboratory personnel, as these individuals are in the best position to know the chemical and physical properties of the materials they have used or synthesised. They are responsible for evaluating hazards, providing information necessary to make an accurate waste determination, and assisting in the evaluation of appropriate strategies for management, minimisation, and disposal (National Research Council (US) Committee 2011).

Managing laboratory waste can be broken down into three steps namely, reuse, recycle and recovery. Reuse involves utilising already used material that is potentially deemed to have economic value. Recycling is employed when a material cannot be directly reused because of impurities or structural/physical deformation. Recovery is used when it is necessary to avoid wasting reactants or products in a system or to increase efficiency in a system (*Laboratory chemical waste management guidelines* 2017).

In SA, the introduction of an internationally best-known practise in waste management, namely, the waste hierarchy (Figure 2.1), is one of the best mechanisms that came into effect with the promulgation of the Waste Act, (Act 59 of 2008), which promotes sustainable waste planning. The Waste Act promotes the exercising of the duty of care and implementation of the waste hierarchy, while protecting the environment (DFFE RSA 2022).

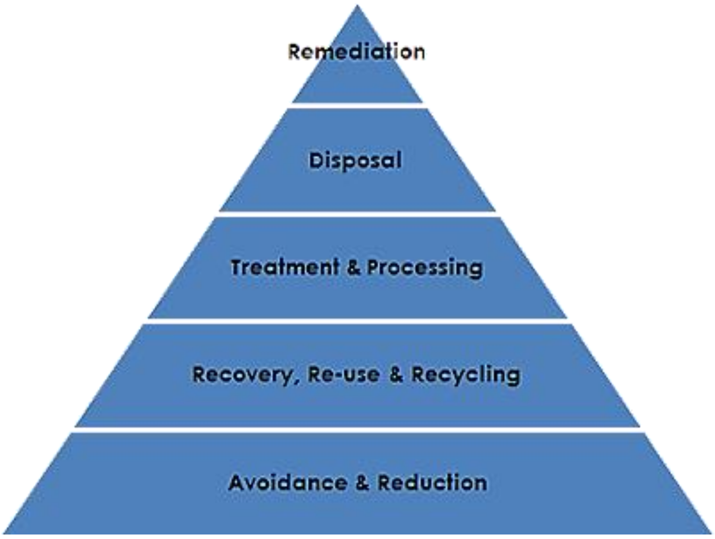

Figure 2.1: Waste Hierarchy-SA National Waste Management Strategy (DFFE RSA, 2022)

The objectives of the service delivery agreement for the national government also make provisions for the Department of Environmental affairs to deliver on specific targets related to waste management.

2.9 WASTE DISPOSAL

Remote location dumping of wastes in places such as deserts, oceans and across national boundaries is a classic example of the historic “out of sight, out of mind” mentality, now rejected by all internationally responsible organisations and industries (Adedipe, Sridhar and Baker 2005). However, the challenge of safe disposal of waste often also requires interim storage while new technologies are developed.

It is the clear responsibility of all laboratory workers to ensure the safe and correct disposal of all wastes produced in the course of their work. Improper and irresponsible disposal of chemical wastes down drains, to the local authority, refuse collection, or into the atmosphere, is forbidden by law. Due to new legislation, increasingly strict environmental controls, and the escalating costs of disposal, it is essential the appropriate disposal procedures are strictly adhered to (University of St Andrews 2022). Managing waste generated in the clinical or research laboratory facility is thus a core element of an overall laboratory safety programme. While there are numerous priorities in the modern research laboratory environment that demand director-level attention, such as inventory control, staffing to workload, and budget management, the reality is an effective laboratory waste management programme can positively impact each of these issues (Scungio, 2018).

A variety of approaches have been developed to address waste issues, as a well-designed framework can help managers attend to waste management issues in a cost-effective and timely manner. It can spur the improvements of existing plans or aid in the design of new ones (USEPA 1995). Some laboratories take meticulous management of waste as a point of professional pride; however, the fact remains that control of laboratory generated waste is regulated and controlled by several national organizations and local authorities. Gaining a comprehensive understanding of the guiding indicators and different regulatory agency standards can, nevertheless, take time, with good resources available to assist in speeding up the process. Zero waste refers to waste management and planning approaches that emphasise prevention, as opposed to ‘end-of-pipe’ waste management (Snow and Dickinson 2001; Spiegelmen, 2006). Zero waste encompasses more than eliminating waste through recycling and reuse; it focuses on restructuring production and distribution systems to reduce waste.

2.10 VALUE OF WASTE SEGREGATION

Waste management methods cannot be uniform across regions and sectors because individual waste management methods cannot deal with all potential waste materials in a sustainable manner (Staniskis 2005). Laboratories will inevitably produce HW that, when improperly managed, can lead to safety issues, damage to the environment, or even catastrophic accidents. By reducing the amount of waste generated and altering how it is managed, it can assist in preventing health and safety risks and improving the efficiency of waste management systems (*MLI Environmental* 2021).

The initial step in managing laboratory waste is to learn about and comprehend the various waste streams and educate laboratory staff in proper waste segregation. Mixing waste is sometimes done for convenience, but this straightforward approach is costly and can create needless environmental burdens. Research and clinical laboratories ordinarily generate at least three separate waste streams: Regular waste, regulated medical waste (RMW), and hazardous (chemical) waste. RMW can be further separated into biohazard waste and medical sharps (Scungio, 2018). Each of these waste streams is regulated separately, and some are overseen by multiple local and central government agencies.

Laboratory waste may be disposed of in recycling, as trash, via laboratory glassware disposal boxes, in containers for sharps, or through regulated medical waste boxes; it may need to be submitted to the Chemical waste programme (*Princeton University: EHS* 2022). Laboratory glassware, broken glassware and Pasteur pipettes and slides are disposed of in laboratory glassware disposal boxes. Laboratory glassware is often made of tempered borosilicate glass or soda lime glass and is not beneficially recycled. Laboratory glassware disposal boxes are disposed of in municipal waste landfills with trash. The boxes serve as a rigid outer container, minimizing risk of laceration or impalement to sanitation workers (*Princeton University: EHS* 2022). Training staff to properly segregate solid wastes, therefore, plays an important role in management of departmental finance and enhancing staff safety (Scungio, 2018)

2.11 NON-REGULATED WASTE

Regular, non-regulated waste is regarded as non-contaminated and discarded into a local community landfill. Typically, the cost-effective way to remove waste is to ensure the laboratory discards as many allowable items in this waste stream as regulations allow. The bulk of local municipalities allow the disposal of items such as gloves, disposable laboratory coats, plastic transfer pipettes, and gauze, when the items are not visibly soaked with hazardous impurities. The majority of the other laboratory waste is removed by a third-party service provider, and providers usually charge by load (Scungio, 2018).

2.12 REGULATED WASTE (RW)

This type of waste (RW) is contaminated and should be placed in labelled, biohazard-particular containers with close-fitting lids. RW bags are usually red or orange in colour, and containers for laboratory RW are available in a wide range of sizes. The treatment of RW bags varies depending on the location of the facility and state laws regarding transport and disposal. Some healthcare facilities sterilise their waste and discard it as NHW, while some RW-handlers treat the bags with a high-heat steam process that renders the contents unrecognisable. Many RW bags end up in biohazard landfills that require special assembly and maintenance and are not normally considered good for the environment (Scungio, 2018).

Medical ‘sharps’, another type of RW, include needles and glass, or other items that can easily break to create a sharp edge. Glass containers, agar plates, and wooden applicator sticks are all blueprints of items that should be discarded into a container for sharp objects, even when not broken. When placed into a plastic bag and broken during transport, these sharp objects may result in added vulnerability for someone handling the bags downstream. Most ‘sharps’ containers are removed from the laboratory and incinerated.

Placing items that do not qualify into RW bags or containers for sharps is an expensive mistake for laboratories. The added volume and weight increase disposal costs, while the use of specialised sharps containers and biohazard bags adds to the total waste management cost. Staff should thus be properly trained to segregate solid wastes as this impact departmental finance management and enhances personnel safety (Scungio, 2018).

2.13 HAZARDOUS WASTE (HW)

HW is composed of substances potentially harmful to human health or the environment, as such, they typically require special disposal techniques to eliminate or reduce the hazards they pose (Meakin 1992). Hazardous chemical waste is generated in the laboratory through standard work processes and removed from the laboratory establishment by means of drain disposal, recycling, neutralisation, or removal by a contracted vendor. Learning how and where to discard the various types of clinical and research laboratory chemical waste depends on the locality, composition, generation, and designated waste generation status of the laboratory facility (Scungio, 2018).

Liquid chemical waste discarded by means of a laboratory drain may be directed to the local sewer system or to a facility-owned chemical collection tank. These collection tanks are a beneficial feature, as chemical waste can simply be poured down specific drains with no significant restrictions. The contents tanks are then unloaded by a contracted waste disposal company. Unfortunately, these types of laboratory sinks and tanks are not common in the clinical and research settings.

Scungio (2018) adds that sinks connected to local sewer systems require more oversight, and the effluent from the facility may be monitored regularly by the local wastewater authority to ensure no improper chemicals such as corrosives or carcinogens are introduced. In some places, the wastewater agency will conduct on-site facility waste audits, therefore, knowing what wastes are being disposed via laboratory sinks is important. In addition, local authorities may request a review of laboratory waste compositions that is an evaluation of the Safety Data Sheets before allowing them to be dispensed with down the drain (Scungio 2018). HW is typically classified by product type. However, it is important to consider that materials and concentrations can impact the dangers and risks posed by certain materials (Cheremisinoff and Cheremisinoff 1995).

Some laboratories participate in recycling HW, for example, certain formaldehyde solutions, xylenes, and ethanol can be distilled for reuse. This recycling requires extra labour and equipment upkeep, but also reduces chemical purchases and minimises overall laboratory HW output. Another chemical waste treatment that decreases waste is neutralisation or sterilisation. Many histology laboratories neutralise formaldehyde liquids, a process that renders the waste safe for drain disposal (Scungio, 2018).

2.14 ADDITIONAL WASTE STREAM CONSIDERATIONS

Universal waste can be defined in several different ways. The United States Environmental Protection Agency (USEPA) defines universal waste as a set of hazardous materials generated in a wide variety of settings, by a vast community, and that which is present in significant volumes in NHW systems (USEPA 1995). The USEPA restricts the definition to four classes of materials: batteries, mercury-containing equipment, pesticides, and lamps.

Other waste streams may be created in highly regulated healthcare, analytical and research laboratories that are costly to manage but not commonly handled by clinical or chemical research laboratories. In this regard, radioactive wastes should be handled in conjunction with a professional radiation safety officer (RSO) (Scungio 2018). Universal waste, such as batteries, mercury-containing equipment, and light bulbs or lamps, is controlled by the Environmental Protection Agency (EPA) and often managed through the facilities department. Mixed waste may accommodate both radioactive and HW. Handling this waste is very complex and is overseen in the USA by multiple federal and regulatory agencies. Again, it is necessary to work with the RSO to ensure safety during handling and disposal (Scungio 2018).

2.15 WASTE AUDITS

The EPA and its state agencies have expanded hospital and chemical laboratory waste oversight in recent years and require an inspection once every five years of any facility registered as a Large Quantity Waste Generator, that is, when it creates over 1 000 kg of HW per month (EPA 2018). Many areas now include all hospitals and chemical laboratories of research institutions in these inspections, regardless of generator status. Although this decision was largely driven by changes in pharmaceutical waste regulations, the audits include laboratory departments, as well as any other area where waste is generated. In the laboratory, auditors review the storage, labelling, and movement of waste in and out of the laboratory and will check for correct waste handling in satellite and central waste accumulation areas. Proof of staff training and documentation are details likely to be audited (EPA 2018).

Performing internal waste programme inspections can assist to prepare the laboratory for regulatory inspections and should be a part of the overall laboratory management programme. These audits should include a physical walk-through of the laboratory and associated waste storage areas, a review of documentation including policies and waste manifest records, and development of an action plan to correct any non-conformity discovered during the audit. Internal audits should be conducted at least annually or whenever there are major changes to laboratory waste types or volumes (Scungio 2018).

2.16 STATUS OF LABORATORY WASTE GUIDELINES

One beneficial resource that details best practice waste management information is the Clinical and Chemical Laboratory Waste Management guidance document

(Scungio, 2018). The most recent version was published in 2011, and while that may seem like a distant past, there have not been any significant changes to laboratory waste processes or regulations to warrant an update. However, new technologies are emerging swiftly, and some applications generate new waste for certain laboratories; though, these have not yet had a significant effect on laboratory waste handling or treatment. DNA sequencing in genomic testing is an expanding technology as well, however, the waste produced is easily managed with other HW streams. Additional, new molecular testing in microbiology and other laboratory areas is also creating new waste, but these, too, tend to fall under established hazardous or non-regulated waste streams.

Although newer laboratory technologies have not created major waste practice changes, the EPA has been reviewing its HW generator regulatory programme and is making some changes. The original Resource Conservation and Recovery Act (RCRA) regulations were published in 1980, and after a few formal evaluations, the agency decided to make changes to increase clarity, consistency, and flexibility for waste generators and handlers. After these edits, a proposed rule was published in the Federal Register in 2015, and the final rule became effective in May of 2017 at national level. As from 2016, those States that run their own HW programme had one year to implement the new final rule (United States Federal Register 2016).

The changes in the new regulations are complex and cover several different aspects of the waste management programme. First, some regulations will be reorganised for clarity and improved organization. Other edits provide methods for waste generators to comply with regulations more easily. There are edits to the regulations that improve environmental protection, including emergency response procedures and updated container labelling requirements (Scungio 2018). Ultimately, additional changes allow generators to maintain their status despite rare monthly waste volume increases, and waste movement from certain facilities is allowed. For example, a site designated as a Very Small Quantity Generator is now allowed to move HW to a separate Large Quantity Generator facility under the control of the same person or business. This new provision to the regulations can help laboratories save money by consolidating waste clearance to one location (Scungio 2018).

2.17 LABORATORY WASTE PROGRAMME MANAGEMENT

Before a laboratory or a firm can design a waste management framework, certain conditions must be met, with resources in place to undertake the design and implementation efforts of the strategy, including human resources and capital. A commitment from management to support the policy is another component crucial to successful implementation. In addition, an understanding of current waste management practices is also required. Moreover, the responsibility of ensuring the waste management plan is implemented and monitored is crucial (CCME 1996; RRF 2008).

Waste collection is a critical component to waste management. The economic and environmental performance of the entire system can be impacted by the way materials are collected and sorted. In many instances, the collection point will be an interface where generators and waste collectors find common ground that must be carefully managed for the system to be effective (McDougall *et al*. 2001). Regardless of regulatory agency, all laboratory generated waste is considered the responsibility of the laboratory until its final disposition. When problems occur in the storage, handling, or disposal process, people may be injured, the environment may be endangered, and expensive fines can be levied (Scungio 2018). Thus, a comprehensive laboratory waste management plan is vital to the laboratory safety programme, and when effectively operated, it should prevent such issues.

Since laboratory waste is overseen by many regulatory agencies, it can be useful to understand and utilise several available resources to aid in programme management. Communication with the contracted HW removers for the facility is essential and recommended, as they are often willing to answer questions or even provide training. Many agencies are, likewise, willing to aid with waste issues and may provide on-site compliance audits.

A complete waste programme should include procedures current with the country's regulations, while staff training should occur for all waste processes, where providing regular updates and competencies will help staff remain compliant. Regular waste audits will also help with programme continuity and a successful waste management programme will provide the necessary cradle-to-grave oversight to instil safety in the laboratory and beyond (Scungio 2018).

2.18 LEGISLATIVE FRAMEWORK

Over the years, wastes and waste management responses such as policies, legal, financial, and institutional instruments, for example, cradle-to-cradle or cradle-to-grave technological options and socio-cultural practices have impacted ecosystem health and human well-being (Adedipe *et al*. 2005). Nonetheless, command and control strategies such as legislation and enforcement create a set standard and minimum guideline for all to follow, with international, national, provincial, and municipal regulations, which define how materials and waste should be handled, diverted and transported (*Waste Management Practices* 2011).

The Constitution of the RSA, under Chapter 2 of the Bill of Rights, stipulates that; everyone has the constitutional right to have an environment not harmful to his or her health and to have the environment protected for the benefit of present and future generations through reasonable legislative and other measures that prevent pollution and ecological degradation. Waste in SA is currently governed by means of several pieces of legislation (DFFE RSA 2022). In recognition of this Constitutional obligation, the DFFE promulgated the national environmental management: Waste Act 59 of 2008 (Waste Act) and in 2010 developed the National Waste Management Strategy (NWMS).

According to Thompson (2022), companies in the USA could be fined a civil penalty up to $81,540 per violation, per day, for HW violations of the RCRA. However, the monetary cost is small, when compared to the costs associated with injuries or environmental incidents from ineffectively handling HW. Zorpas (2020) noted a need to develop strategies in the framework of waste management to reach targets. These strategies aim to increase quality of life and change the way that citizens react in the great debates. These strategies should reduce the impact several processes have on the environment through product, processes, and corporate policies using green applicable and sustainable resources and environmental management systems (such as ISO 14001, EMAS), as well as several activities; measuring the impact on society at the same time.

Proper chemical waste management is necessary to protect the health and safety of research institutions, Universities and surrounding communities, and the environment (University of Delaware 2018). The USA has federal and state regulations that require all generators of chemical waste to receive training and follow proper waste management and disposal procedures; In USA these regulations have severe associated monetary and civil penalties. Between 1990 and 2004, over 12 million dollars in fines have been levied against research and academic institutions for HW and other environmental violations, leading the environment protecting agencies to question waste management at educational institutions (University of Delaware 2018).

2.19 WASTE MANAGEMENT SYSTEMS

It is important to consider the components needed for successful implementation of a waste management system, which would include collection and storage of material, equipment, signage, and human resources, including contracts with external waste providers, transportation, materials processing, and material use (CCME 1996).

Behavioural instruments play a role in waste management strategies through initiatives that inform and educate. Examples of these types of initiatives include waste audits, school programmes, advertising, and training (CEF Consultants 1994). However, education has been shown to be a critical component in encouraging participation in recycling programmes (Bolaane 2006). Signage is also a critical component to waste management systems, as it helps inform the public about which materials are acceptable for recycling and which are not and can also encourage participation in recycling programmes (*Waste Management Practices* 2011).

Larger organizations often require services from external waste service providers, with these companies required to ensure the bins they provide to customers meet local area requirements. Commercial waste service providers must, in addition, be able to provide customers with a range of potential options to suit their needs. Hiring an external waste service provider will typically require commitment to a contract, allowing for different factors that can be negotiated, including collection frequency, the equipment being used, fees, volumes collected, and rates for different streams (CCME 1996).

2.20 SUMMARY OF THE CHAPTER

From the literature, it is evident which elements should be included in developing a sustainable waste management model. This chapter outlined the main determinants of effective waste management planning and model development, followed by the critical success factors for achieving integrated waste handling and treatment techniques. It also dealt with various author perspectives on each of the determinants presented. The concluding remarks reveal that the development of an effective waste management model requires proper and detailed waste planning. The next chapter will outline the design of the research and the methodology used during this study.

This study was underpinned by a multi criteria decision analysis (MCDA) waste management model (Morrissey & Browne 2003), which focuses on the objective or goal of the decision that generates the criteria related to the goal and possible alternatives., Unlike the majority of waste management models, MCDA considers economic, environmental and social aspects. For a waste management system to be sustainable, it needs to be environmentally effective, economically affordable, and socially acceptable (Nilsson, Djerf and McDougall 2000).

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

This chapter illustrates the research tools, design and methodology followed in this project, presenting the techniques available to conduct research and demonstrating those selected for this study. It includes details of the questionnaire design, data collection techniques, target population group, and sample size, as well as credibility.

3.2 RESEARCH DESIGN

Babbie and Mouton (2001) suggested the research paradigm, aim of the investigation, techniques used to conduct research, and the manner within which the observation takes place, are the four important research design aspects. Viewed from this perspective, the researcher analysed the full content of the circumstances at the organisation (SAPPI COE laboratories) before designing the present study.

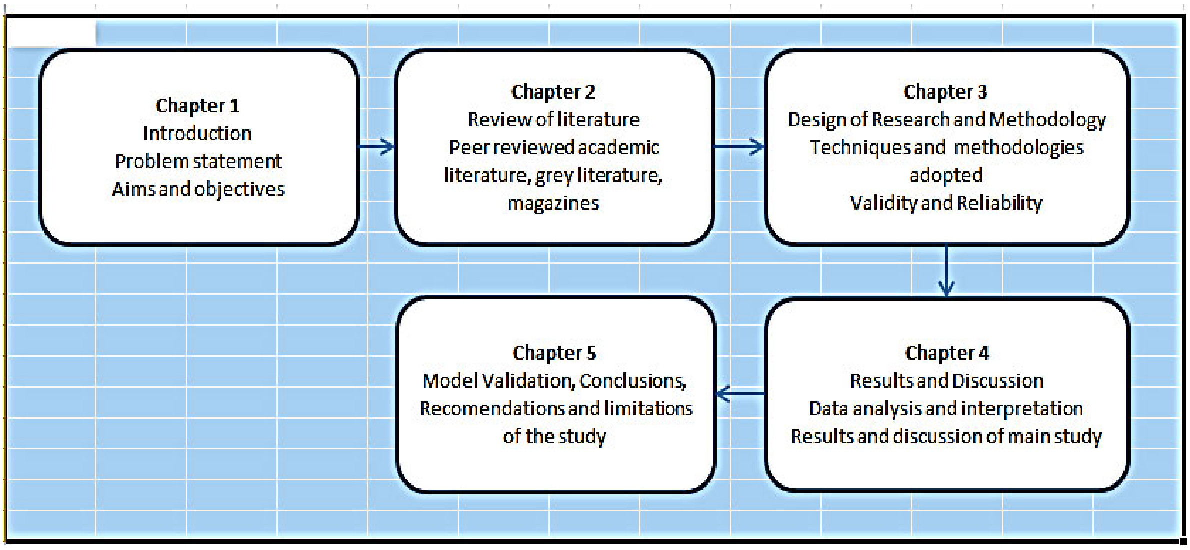

Figure 3.1: Research Design of this study

As can be seen in the graphical representation (Figure 3.1), the research starts by identifying the problem, followed by a detailed literature survey, thereafter, appropriate methodology is adopted and the results and discussions presented, followed finally, by conclusions, recommendations, and limitations of the study.

3.3 RESEARCH PARADIGM

Terre Blanche, Durrheim and Painter (2006) define methodology as the study of procedures or methods used in research to create new knowledge, with Sekaran (2006) and Cooper and Schindler (2006) suggesting qualitative and quantitative techniques are commonly used to conduct research. Cooper and Schindler (2006) indicate quantitative research is mostly employed for testing a theory and focuses on describing, explaining, and predicting data with the use of statistical and mathematical methods. The most distinguishing feature, based on the opinion of Terre Blanche *et al*. (2006), is that the researcher generally knows the important variables in advance, prior to designing a quantitative study. In essence, quantitative research is mostly encountered as part of formal or conclusive research and the aim of this research method, is to determine the relationship between an independent variable and a dependent or outcome variable in a population.

Qualitative research is frequently aimed at understanding and interpreting data, while providing a detailed explanation of events, situations and interaction between people and things, thus providing depth and detail. The views of Terre Blanche *et al*. (2006) and Babbie and Mouton (2001) agree with those of Cooper and Schindler (2006), in that qualitative research aims to study human interaction from the insider's perspective, as they identify, examine, and reflect on perceptions. In summary, qualitative techniques are used to study phenomena that do not fit into theories.

Welman and Kruger (2001), moreover, point out that the two common types of quantitative research designs are characterised as non-experimental (descriptive) or experimental. A pragmatist paradigm, which is a mix of qualitative and quantitative methods, was the research paradigm employed for this case study. The pragmatist paradigm assists the researcher to optimally frame, examine and provide tentative answers to research questions by mixing approaches and methods (Onwuegbuzie *et al*. 2009). Doolen *et al*. (2008) employed both quantitative and qualitative method techniques to conduct their field study, wherein quantitative analysis was used for surveys, while qualitative analysis was used for interviews and organisational documents.

3.4 RESEARCH APPROACH

The research approach undertaken in this project is a mixed method (qualitative and quantitative) case study of a developmental nature that involves statistical analysis. Case studies, according to Cooper and Schindler (2014: 128), afford added prominence to a complete "contextual analysis of fewer events or conditions and their interrelations". The authors highlight that even though case studies often use hypotheses, relying on qualitative data means support or rejection is made that much more difficult. In addition, a case study approach was deemed appropriate for this research project, because: "An emphasis on detail provides valuable insight for problem solving, evaluation, and strategy. This detail is secured from multiple sources of information. It allows evidence to be verified and avoids missing data" (Cooper and Schindler 2014: 128).

The objective of a case study approach in research, as Cooper and Schindler (2014: 165) explain, "is to obtain multiple perspectives of a single organization, situation, event, or process at a point in time or over a period. It can be used to understand particular processes".

The research approach used in this project was based on collecting pre-model data through the use of questionnaire to ascertain how Sappi COE employees perceive waste management effectiveness in their laboratories. A brainstorming session was held to discuss major weaknesses of the current COE waste management framework based on the feedback received from the pre-model questionnaire. Recommendations from the brainstorming session were integrated into the waste management framework to close any gaps that were uncovered by the pre-model assessment. A post-model assessment was administered to evaluate the effectiveness of the corrective measures put into place.

3.5 RESEARCH BACKGROUND

To develop a sustainable waste management system, a variety of procedures must be conducted efficiently, including sampling, surveying to address the problem and obtain waste information, modelling and simulation, as well as calculation of economic and environmental impacts of potential management options, and implementation of the decision-making process (Giang 2017). Firstly, planning, design, and operation of a sustainable waste management system require an understanding of waste stream characteristics (Abu Qdais, Hamoda, and Newham 1997; Chang and Pires 2015). For integrated waste planning, accurate and reliable data on the waste constituency and generation are needed for evaluation of optimal treatment options. Data describing the actual waste flow are basic input in discussions on any waste management aspects, such as technical design of the collection system, environmental objectives, operating costs, types of recycling material, economic incentives, and information strategies (Giang 2017).

According to Petersen *et al.* (2004), the quality of waste composition data is highly affected by the sampling procedure and method applied. There are basically two approaches for analysing waste stream composition: the material flow and the output approach. The material flow approach considers the production and the life cycle of the product to estimate the solid waste stream composition. The output approach, in contrast, focuses on components of the waste stream and can provide information regarding the waste composition prior to separation or disposal (McCauley-Bell *et al*. 1997).

3.6 WASTE CHARACTERISATION

Following identification of waste samples/streams, sampling will be conducted using a target sampling method, which is part of probability sampling methods. Probability methods of sampling ensure results that are generated are representative of the entire population (Acharya *et al*. 2013). Waste characterisation will assist in gaining a better understanding of appropriate waste classification, treatment, or disposal methods. According to the National Research Council (US) Committee (2011), waste must be categorised as to its identity, constituents, and hazards so it can be safely handled and managed. The *Laboratory chemical waste management guidelines* (2017) state that the properties of chemical waste that pose hazards are ignitability, corrosivity, reactivity and toxicity.

The following laboratory data were collected on waste generated at the Sappi Saiccor COE laboratories:

- pH of all liquid effluent/s, viscose dope
- Moisture content of used tissue paper towels, viscose dope, MCC powder

- Conductivity of all liquid effluents
- Temperature of all liquid and solid waste streams
- Chemical oxygen demand (COD)
- Total Dissolved solids (TDS)

In addition to the laboratory tests, the toxicity data, chemical and physical properties of the synthesised materials from which the waste emanates were evaluated and included in waste characterisation. Following characterisation, HW was either categorised as chemical, radioactive and or biological waste. For the quantitative aspect of the analysis, the study population will be composed of various solid and liquid waste streams generated in the laboratories, with sampling conducted using a random sampling method, which is part of probability methods.

3.7 PILOT STUDY

As Wright and So (2018) explained, pilot testing is used to test the accuracy of the research measurement instrument on a small number of participants, before the questionnaire is distributed to the entire population. To reduce risk and refine the questionnaire, pilot testing was undertaken with five laboratory staff who did not participate in the study, assessing whether the questionnaire (Annexure A) was understandable, readable, and accurate, with suggestions considered where ambiguity was encountered, and changes made where needed (Sekaran and Bougie 2010).

A pilot study was undertaken in this project. Five participants volunteered to partake in the pilot study. These five participants did not participate in the main study. The purpose of the pilot study was to assess the suitability of the pre- and post-model questionnaire in terms of time taken to complete it, relevance of the questionnaire to the laboratory team, and ease completion. Detailed results obtained from the pilot testing were not included in the main study. However, the feedback received from the pilot study showed that the participants were comfortable with it and were generally happy with the contents and structure of the questionnaire. The current waste management status at Sappi Saiccor COE laboratories was assessed with a pre-assessment questionnaire, while the proposed new Sappi laboratories waste management model was assessed through a post-model risk assessment questionnaire.

3.8 PRE-RISK ASSESSMENT QUESTIONNAIRE TO ASSESS CURRENT WASTE MANAGEMENT STATUS AT SAPPI SAICCOR COE LABORATORIES

Rathilall (2011) noted three focus areas the researcher should concentrate on while developing a measuring instrument or with questionnaire design. These include the actual wording of the questionnaire, the planning of categorising and coding the response variables, and the general appearance of the questionnaire. Cooper and Schindler (2006) share a similar view as Rathilall (2011) on the importance of the actual wording of a questionnaire; however, they indicate the questionnaire content and response strategy choice are also important.

The objective of a measuring instrument is to gather data that represent quantities of what is being measured. Cooper and Schindler (2006) point out that measurement in research consists of assigning numbers to empirical events, objects, or properties, with a set of rules that incorporates a three-part process. This process includes selecting the empirical events, followed by developing mapping rules of assigning numbers that represent what is being measured, and finally, applying the mapping rules to each measured event.

Due to the importance of information gathered through data, Sekaran (2006) proposes the following methods for collecting data, namely, interviews, questionnaires, observation, and projective tests. The data collection method applicable in this survey study entails the administering of a questionnaire. The reason for selecting this method is the advantage questionnaires have in obtaining data more efficiently in terms of researcher time, energy, and costs. Cooper and Schindler (2006) postulate that the validity of the questionnaire determines how well the measuring instrument assists the researcher in solving the research problem. This means the questionnaire should measure what it set out to achieve.

Chung Ho and Shu Chen (2017) noted several faults in the recycling, including storage, clearance, and delivery procedures of chemical laboratory waste disposal.

Therefore, this study examined current recycling, storage, waste removal/clearance, and management of laboratory wastes as factors that can be incorporated into the proposed waste management model of Sappi Saiccor COE laboratories. Annexure B (appendices section) is a risk assessment questionnaire that shows potential factors that could contribute to the establishment of a waste management model at Sappi Saiccor COE laboratories. The risk assessment questionnaire was adapted from the potential factors of the chemical laboratory default waste management model table by Chung Ho and Shu Chen (2017). According to World support resources (2019), a rule of thumb is that, for small populations (<500) at least 50 percent of the sample population should be selected. For large populations (>5000) at least 17-27 percent of the sample population should be selected.

For the pre-risk questionnaire study (qualitative method), 11 laboratory personnel (which represents 50 percent of the total population) including the analysts, technicians and management who agreed to participate in the pre-risk assessment questionnaire. Table 3.1 shows the list of these selected personnel.

Table 3.1: Details of the 11 selected personnel

Employment level	Technicians	Analysts	Scientists
Number of participants	3	6	2
Location	Based in the technician office-COE	Based in COE laboratories	Scientist office-COE
Department	COE laboratories	COE laboratories	COE laboratories

Sampling was conducted using a simple random probability method; probability methods of sampling ensure results generated are representative of the whole population (Cooper and Schindler 2014: 219).

3.8 STATISTICAL DATA ANALYSIS TOOLS AND WASTE MANAGEMENT MODELLING OF SAPPI SAICCOR COE LABORATORIES

Predicting waste generation is increasingly essential in waste collection planning, as well as waste treatment strategies, and establishing waste policies toward a sustainable waste management system (Abbasi *et al*. 2012). Various modelling techniques were applied to the development of waste generation predictive models. According to Beigl *et al*. (2008), multivariate methods, such as 36-system dynamics and input-output analyses, are very complex due to the numerous interactions between parameters. The main problem of these methods is the difficulty in achieving model validations. Linear regression analysis, on the other hand, is more popular in the application of waste generation estimation (Ghinea *et al*. 2016).

Linear models can handle simple datasets and can easily be expanded and modified to handle complex datasets. However, linear regression analysis is useful in empirical investigations and prediction, rather than for studying the theoretical relationship between variables, which are better done by non-linear regression analysis (Faraway 2005). Based on the above views, a multi-variate linear regression analysis method, using the statistical package for social sciences software (SPSS), was employed in developing a waste management model of Sappi Saiccor COE laboratories. The purpose of the model was to predict the amount of waste per day each laboratory can generate. The independent or predictor variables used were the number of people working in each laboratory per day, the number of laboratory tests conducted in each laboratory and the quantity of chemical solutions consumed per laboratory per day.

3.9 RELIABILITY AND VALIDITY OF METHODS USED IN WASTE MANAGEMENT

In general, the primary objective of research is to investigate a problem area and present findings based on data collected. To be effective, Cooper and Schindler (2006) claim the characteristics of good measurement are the validity, reliability, and practicality of the measurement tool. Thus, achieving the three outputs determines how well the data will be collected and analysed to achieve sound measurement. According to Al-Salem and Al-Dhafeeri (2018), statistical analysis was used to confirm the reliability of regression models developed. The mean and standard error results indicated that predications were highly accurate for the multiple regression predictive models. The multiple variable regression models developed showed mean standard errors ranging between 0.125% and 1.09%.

Developed regression models can be used to predict individual waste components that could be used by decision makers when devising measures for long-term waste management strategies. Multi linear regression (MLR) was successfully used in predicting waste generation in the municipalities of CCS, Chiapas State, Mexico (Aguilar-Araiza, Valencia & Aguilar-Vera 2019). A triangulation method and statistical analysis (calculation of mean standard errors) will be used to confirm validity and reliability of the regressions models developed in waste management systems at the Sappi Saiccor COE laboratories.

3.10 POST MODEL RISK ASSESSMENT

Following the completion of the waste management model, a safety risk assessment questionnaire was administered using the same checklist to the one used in the pre-risk assessment, to ascertain how laboratory personnel feel about the new waste management model. The aim was to highlight whether there were any improvements from the previous assessment checklist feedback and would also gauge or highlight the level of social acceptability of the model. A total of 11 laboratory personnel, including the analysts, technicians, and management, participated in the post-risk assessment questionnaire.

3.11 INCLUSION AND EXCLUSION CRITERIA

Establishing inclusion and exclusion criteria for study participants is a standard, required practice when designing high quality research protocols (Patino and Ferreira 2018). Inclusion criteria are defined as the key features of the target population that the investigators will use to answer their research question (Connelly 2020).

Inclusion criteria, which are thus the characteristics a potential participant in this study should possess, include the following.

- Educational background: A suitable participant should have a Chemistry background or at least two years of working in a laboratory facility, with an understanding of laboratory waste management systems.
- Type of occupation: Should be working in a chemical laboratory environment.

- Medical condition: Should have no mental or psychological conditions and should not be physically handicapped.

In contrast, exclusion criteria are defined as features of the potential study participants who meet the inclusion criteria but present with additional characteristics that could interfere with the success of the study or increase the risk for an unfavourable outcome (Patino and Ferreira 2018). Exclusion criteria that make the potential participant not suitable to participate in this study include the following:

- Increased risk for adverse events.
- Presence of mental conditions.
- Presence of comorbidities that can bias results of the study.

The above established criteria were based on the criteria used in previous studies of similar nature to the present study.

3.12 QUESTIONNAIRE OR INTERVIEW RECRUITMENT PROCESS

The process involved the following:

- Verbal discussion with potential participants was initiated to inform them of an intention to administer a questionnaire to them.
- Questionnaire letter was handed to potential participants by hand.
- A letter of consent was handed to and discussed with potential participants to ensure any decision to participate was voluntary and not coerced.
- Those interested in participating were urged to attend the Viscose laboratory on a selected date to complete the questionnaire.

3.13 ANONYMITY AND CONFIDENTIALITY

Any information provided by participants was kept anonymous. The researcher did not use personal participant information for any purposes outside of this research project. Further to this, the researcher did not include participant names or other information that could identify them in the study reports. Data will be kept secure by password protection and data encryption, secured for a period of at least five years, as required by the university.

3.14 SUMMARY OF THE CHAPTER

This chapter outlined the research design of the present study through detailed information sources and explanations of existing research philosophies and methodologies. The research was both a quantitative and qualitative study that used a questionnaire as measurement instrument to conduct the investigation and laboratory testing of waste stream samples. Furthermore, the questionnaire was piloted and standardised prior to being administered. The main objective of the questionnaire was to assist in finding gaps within the current waste management system at Sappi Saiccor COE laboratories and determine ways to improve the overall safety of waste handling and management procedures. At least 11 employees from these laboratories would be subjected to questionnaire administration, accompanied by the researcher. Inclusion and exclusion criteria of potential participants in the study were discussed, as were anonymity and confidentiality rights of participants, with the aim of protecting personal participant information.

CHAPTER 4

PRE-MODEL RISK ASSESSMENT

4.1 INTRODUCTION

This chapter will present the results of the pre-model risk assessment, via collection of data from the participants and analysis thereof using Microsoft Excel 2019, with results presented in the form of bar graphs and interpreted. A schematic waste management model of the Sappi Saiccor COE laboratories will be developed, using multi-variate linear regression to estimate the amount of waste generated per day in each of the laboratories. Total waste generated will be taken as the dependent variable, while the independent variables will be the number of participants working in a laboratory, the number of laboratory tests per given laboratory, and the amount of chemicals consumed per given laboratory. IBM SPSS version 17.0 will be the software used to analyse data and predict total waste/day produced per laboratory.

4.2 PRE QUISTIONNAIRRE RISK ASSESSMENT FINDINGS

A questionnaire that focussed on current methods and techniques of (A) recycling, (B) storage, (C) waste removal/clearance, and (D) management of laboratory waste from an administrative view, was handed to Sappi COE laboratory personnel. During the questionnaire administration, a discussion was held with the potential participants regarding the content of the questionnaire. They were all happy with the terminology and simplicity of the questionnaire structure. However, the majority complained saying the questionnaire was too long. A total of 11 participants, representing a population sample of 50 percent, volunteered to participate in completing the questionnaire. Of the 11, three are technicians, two are scientists and six are laboratory analysts. Information received from the questionnaire was processed into graphs using Microsoft Excel© 2019. Figures 4.1-4.4 show the percentage of participants whose responses suggested a risk was present in a particular task.

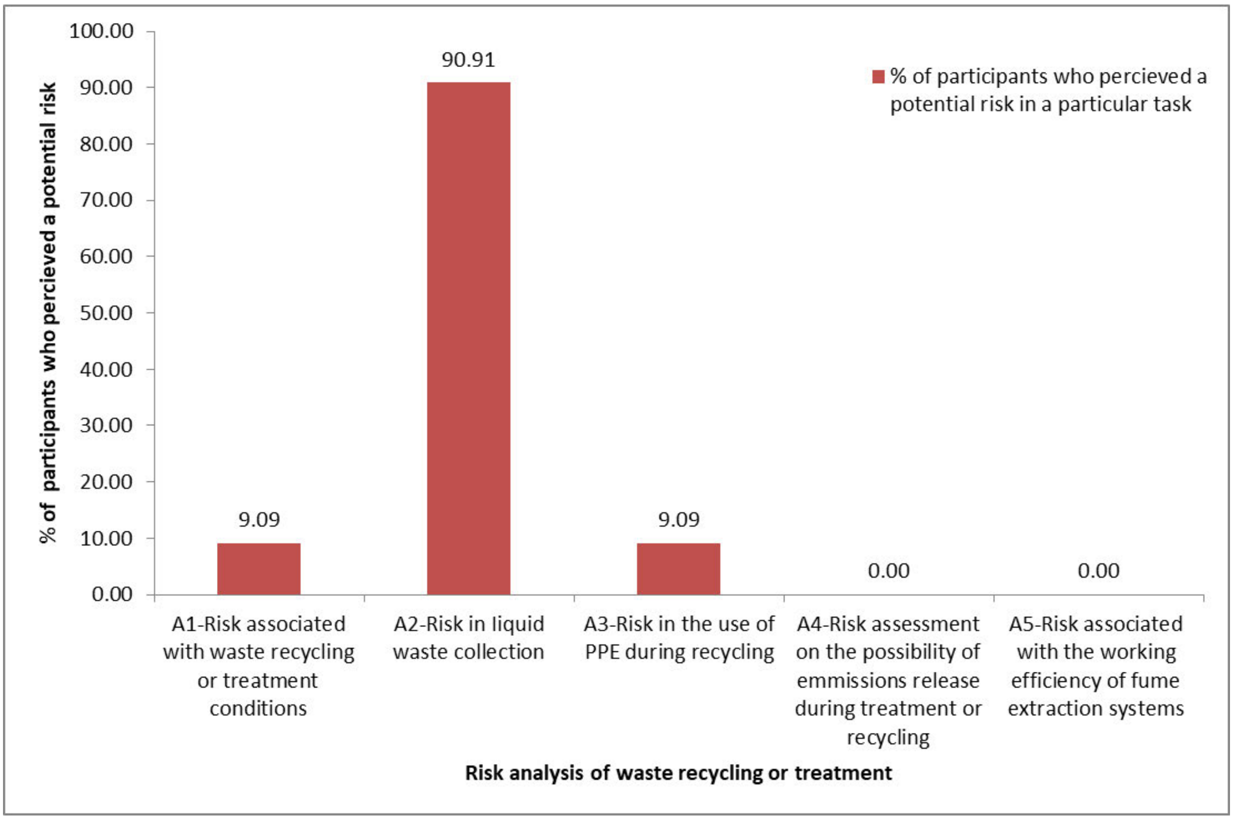

Figure 4.1: Initial risk assessment of waste treatment and recycling

Response concerning risks surrounding waste treatment and recycling suggested 90 % of participants perceived a risk existed as shown in figure 4.1 and believed there was room for improvement in the way liquid waste was handled or collected, with or without a funnel or a drain-pan spill-over (A2). Overall, most participants thought there was minimum to no risk at all in other areas included in this category, such as the use of personal protective equipment during recycling or treatment of liquid waste.

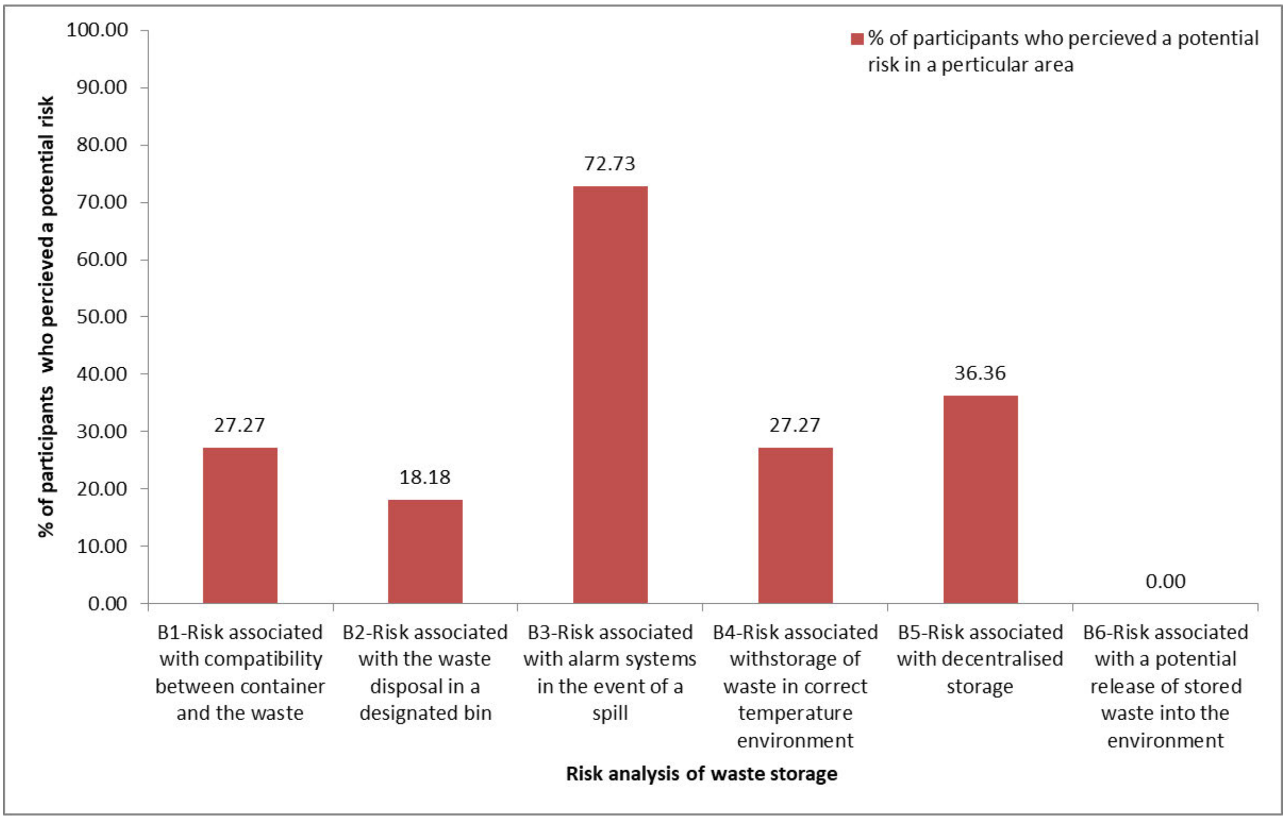

Figure 4.2: Initial risk assessment of waste storage

Response concerning risks surrounding waste storage suggested more than 70 % of the participants perceived a risk as shown in figure 4.2, based on the lack of an early warning system or device at Sappi Saiccor COE laboratories in the event of a spill (B3). Less than 40 % of participants as shown in figure 4.2 thought there were some risks in chemical compatibility between container and waste stored in it, and whether waste was stored in a correct temperature environment. On a positive note, all participants unanimously agreed there was no potential release of stored waste into the environment.

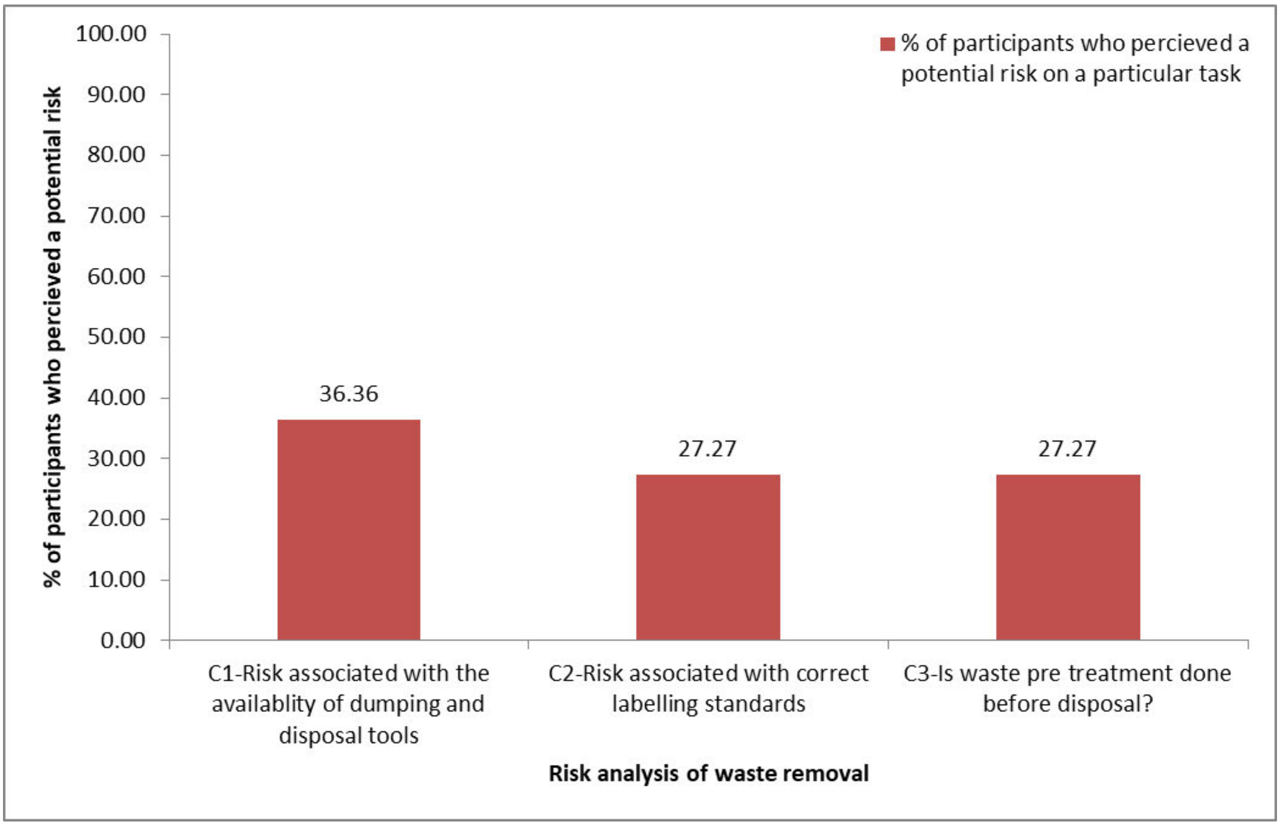

Figure 4.3: Initial risk assessment of waste removal

Responses concerning risks surrounding waste removal suggest the majority of participants felt this section had the least risk to their health and the environment. Less than 37 % of the participants as shown in figure 4.3 thought there were not enough dumping, disposal, or treatment tools available (C1). Less than 27 % indicated the laboratory does not practice correct labelling standards and did not believe waste was pre-treated prior to removal or disposal. Nonetheless, most participants thought the laboratory complied with good labelling standards and waste pre-treatment procedures before waste removal.

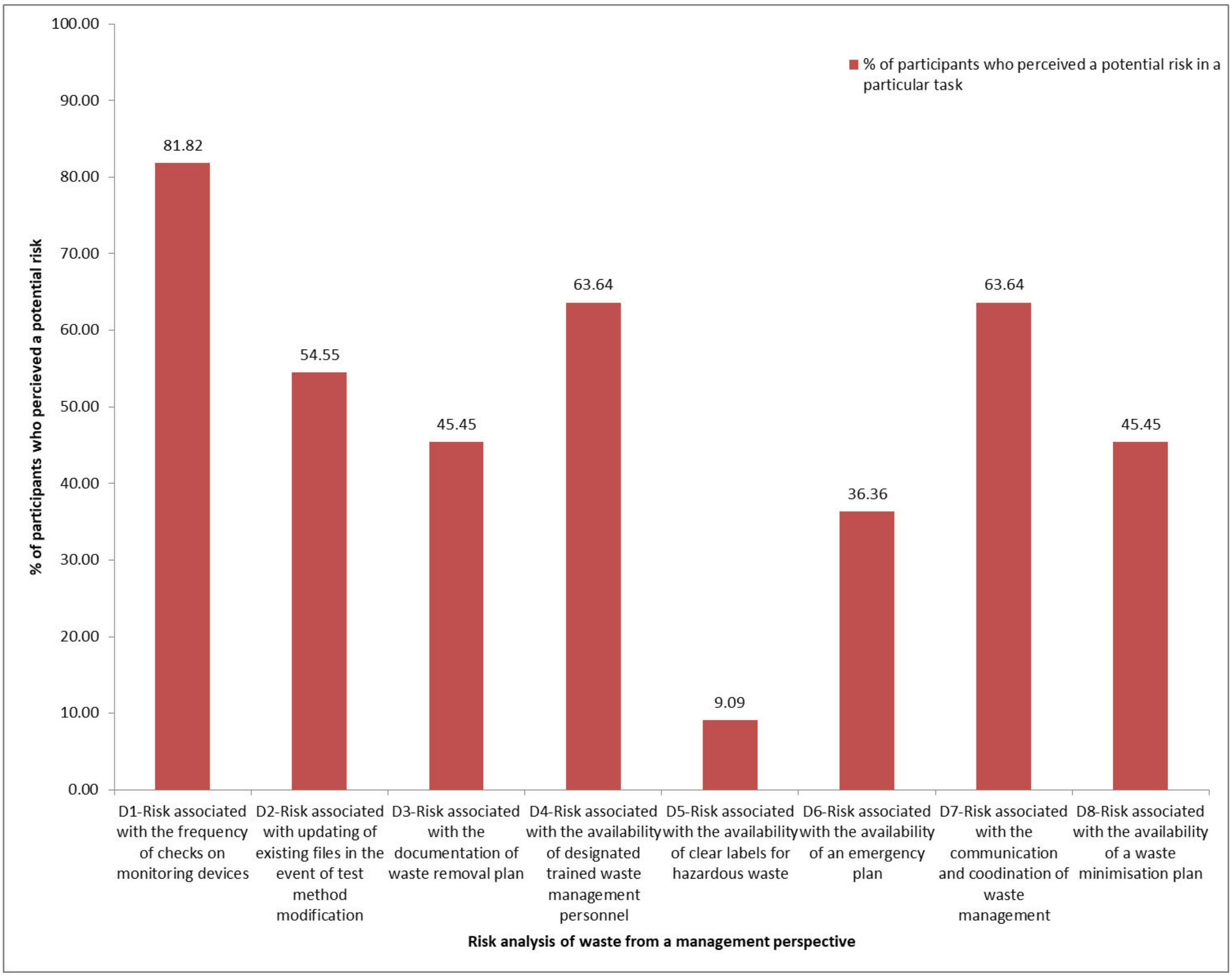

Figure 4.4: Initial risk assessment from an administrative and management point of view

Response concerning risks surrounding waste management from an administrative and management perspective suggested more than 80 % of the participants as shown in figure 4.4 did not know whether any checks were performed on the safety alarm and other monitoring devices (D1). More than 60 % of the participants as shown in figure 4.4 thought there were no special or designated waste-management-trained personnel at the Sappi COE facility (D4). More than 60 % as shown in figure 4.4 also thought the communication and coordination of waste management at the laboratory was not effective at all (D7). Disagreement was expressed by 54 % of participants that did not think waste files where being updated in the event a new test, using different chemicals, is introduced (D2). Overall, the results of this section suggest more is needed, from a management perspective, to improve waste management awareness at the Sappi Saiccor COE laboratories.

4.3 GAPS WITHIN CURRENT WASTE MANAGEMENT METHODS AT SAPPI SAICCOR COE LABORATORIES

Chemical waste reduction practices of the Sappi Saiccor COE laboratories were examined using a checklist or questionnaire to evaluate current practices. Although there are existing practices that reduce the amount of chemicals used and waste generated, the team unanimously agreed more effort could be made to further improve the situation. A team, made up of management, technicians, and analysts, met to discuss ways to improve waste management at the laboratories. Responses from the pre-model risk assessment questionnaire were vital in the discussion, as most gaps and recommendations how waste management can be improved came from those responses, with some of these gaps highlighted below:

- Recyclable material, such as used nitrile gloves, paper towelling, and broken glassware, is disposed at landfill.
- Mix up of waste in the large disposal bin called the “skip”.
- No waste treatment facilities on-site.
- No funnel used in decanting or collecting liquid waste.
- Poor communication and coordination of waste management.
- No warning devices in the event of a major chemical spill.
- No special or designated waste-management-trained personnel in the department.

4.4 RECOMMENDATIONS BY THE COE TEAM TO IMPROVE LABORATORY WASTE MANAGEMENT

- Practicing concept of source reduction by simply ordering the minimum quantity of chemical material required to complete work for a given period.
- Substituting hazardous chemicals with non-hazardous chemicals whenever possible.
- Reducing the scale of laboratory experiments to reduce the volume of waste being produced whenever possible.

- Installation of engineering controls and early warning systems such as alarms and sensors that can detect leak vapours or chemical spills.
- Sharing surplus chemicals with other departments or laboratories.
- Keeping waste containers closed.
- Prioritising departmental waste management training requirements.
- Improving and encouraging waste management communication within the department.
- Keeping an inventory of chemicals within each laboratory.
- A labelling system that includes pictograms for each substance, to provide information on its toxic, reactive, and explosive or inflammable characteristics was suggested. In addition, colour codes were recommended to identify the category in which the waste was generated.
- Another important suggestion/recommendation was the potential treatment and recovery of chemical substances such as copper sulphate anhydrous ($CuSO_4$) and potassium chromate (K_2CrO_4), using physicochemical techniques. This was touted as a green alternative designed to prevent damage to human health and the environment (Benavides, Andrade-Vivas & Ortiz-Sarria 2007).

4.5 CLASSIFICATION OF WASTE

Waste was classified into general solid waste, effluent waste, and chemical HW. The table below shows categories in which waste generated at the Sappi Saiccor COE laboratories was grouped.

Table 4.1: Waste classification in COE laboratories

Chemical waste	Effluent waste
Viscose dope (Contain CS_2 a toxic, explosive, and flammable chemical)	Effluent generated from Cupri ethylenediamine (CED) viscosity testing
Spent 18.5% sodium hydroxide solution ($NaOH_{aq}$)	Effluent generated from acid hydrolysis
Used or contaminated paper towel	Effluent generated from hemicellulose in steep soda test
Used or contaminated nitrile gloves	Effluent waste generated from plant bleaching section
Alkalised cellulose	Effluent generated from other laboratory tests

4.6 WASTE CHARACTERISATION RESULTS

Waste characterisation studies and waste audits are critical to the process of designing and implementing a waste management plan and to gain insight as to where diversion efforts should be focussed (Armijo de Vega, Benitez and Ramirez 2008; Smyth *et al*. 2010). The results of waste characterisation studies and waste audits can play a central role in educational campaigns used to foster support and motivation for waste diversion initiatives.

To gain a better understanding of appropriate waste classification, treatment, or disposal methods, waste characterisation was done on chemical, effluent, and general solid waste emanating from Sappi Saiccor. Tables 4.3 to 4.5 illustrate characterisation of HW, effluent waste, and general solid waste, respectively.

Saiccor mill must comply with the National water Act (36 of 1998). Under this act, the mill is granted a water use licence to extract water from the Umkomaas river and discharge wastewater into the river. Failure to comply with licence conditions may result in fines, prosecution, withdrawal of the current licence, and refusal to issue subsequent licences. The licence for disposing of waste containing water (effluent) to an estuary (river) requires the mill to adhere to quality and quantity limits for effluent to the river (Sheq Safety Bulletin 2021).

Table 4.2: Threshold limits of parameters of effluent stream to be disposed to the Umkomaas river

Parameter	Limit	Unit
Chemical oxygen demand (COD)	<75	mg/L
Suspended solids	<25	mg/L
Electrical conductivity (EC)	<50	mS/m
pH	7.5-8.5	-
Dissolved Oxygen (DO)	>6	mg/L
Turbidity	<10	NTU
Effluent discharge volume-daily average	3055	m^3

Table 4.3: Characterisation of Viscose laboratory hazardous waste

Hazardous waste	pH	Temperature (°C)	Conductivity-mS/m	Moisture content (%)	Chemical Oxygen demand (COD)-mg/L	Total dissolved solids (TDS)-mg/L
Viscose dope	10	22	44	80	10	20
Spent 18.5% NaOH	13	40	38	93	15	7
Used/contaminated paper towel	2-13	20	N/A	50	N/A	50
Used/contaminated nitrile gloves	2-13	23	N/A	20	N/A	80
Alkalised cellulose	12	25	20	30	16	70

Table 4.4: Characterisation of effluent waste generated from bleach plant, MCC and Viscose applications testing

Effluent waste	pH	Temperature (°C)	Conductivity-mS/m	Moisture content (%)	Chemical Oxygen demand (COD)-mg/L	Total dissolved solids (TDS)-mg/L
Effluent waste generated from bleaching section of the plant	8.0	70	40	95	70	5
Effluent generated from CED viscosity testing	7.5	25	38	93	55	7
Effluent generated from acid hydrolysis	7.5	25	35	97	60	3
Effluent generated from hemicellulose in steep soda test	12	25	46	96	72	4
Effluent generated from solubilities test	12	30	41	95	65	5

Table 4.5: Prescribed limits for items to be disposed as waste

General solid waste	pH	Temperature (°C)	Conductivity-mS/m	Moisture content (%)	Chemical Oxygen demand (COD)-mg/L	Total dissolved solids (TDS)-mg/L
Empty chemical containers	2-14	20	N/A	3	N/A	N/A
Broken glassware	2-14	18	N/A	2	N/A	N/A
MCC powder	7	25	N/A	7	N/A	93
Plastics	2-13	23	N/A	2	N/A	N/A
Boxes	4-8	25	N/A	4	N/A	N/A

N/A-Could not be measured.

4.7 TOXICITY DATA, CHEMICAL AND PHYSICAL PROPERTIES

The toxicity data, chemical and physical properties of the materials or chemicals from which the waste was generated, were evaluated as part of the chemical characterisation study. To make and analyse viscose dope, which is a product of the Rayon-making process and a major waste stream generated at the Sappi Saiccor COE laboratories, several chemicals are needed, namely, carbon disulphide ($CS_{2(l)}$), sodium hydroxide solution ($NaOH_{aq}$), sulphuric acid (H_2SO_{4aq}), and acetic acid, as well as Ammonium chloride ($AlCl_{3aq}$), hydrochloric acid (HCl_{aq}), and sodium bicarbonate solution. Other major tests conducted at the Sappi Saiccor COE laboratories, such as acid hydrolysis for the bench top production of MCC, employ chemical solutions such as ammonium hydroxide solution (NH_4OH_{aq}) and hydrochloric acid (HCl_{aq}), while other less significant laboratory tests are also conducted. These use chemical solutions similar to the aforementioned ones. A summary of toxicity and reactivity of selected chemicals that are active ingredients in most waste streams generated at the laboratories is described and discussed in sections 4.7.1 to 4.7.7.

4.7.1 Carbon disulphide (CS_2)

With a molar mass of 76.13g/mol, $CS_{2(l)}$ is a colourless liquid at room temperature and pressure. The product is chemically stable under standard ambient conditions and classified as a flammable liquid that can be toxic to reproductive organs of humans. It has the potential to reduce fertility and is suspected of damaging foetuses. Repeated use and exposure to carbon disulphide can damage parts of the human body, for example, the cardiovascular and central nervous systems, eyes, skin, and peripheral nervous system. Vapours of this substance are heavier than air and may spread along floors. It forms explosive mixtures with air at ambient temperatures. From an environmental perspective, $CS_{2(l)}$ should not be allowed to enter drains, since there is a risk of explosion. Chemical containers laden with this product should be kept tightly closed in a dry and well-ventilated place and away from heat and potentially explosive materials.

4.7.2 Hydrochloric acid (HCl_{aq})

The product has a molar mass of 36.5g/mol, is a colourless liquid at room temperature and pressure and chemically stable under standard ambient conditions. Hydrochloric acid is corrosive when in contact with metals. It forms an exothermic reaction when in contact with amines, potassium permanganate, aldehydes, and ethers. There is a risk of ignition or formation of inflammable gasses or vapours with carbides, fluorine, and lithium silicide. It generates dangerous gases or fumes in contact with aluminium, hydrides, formaldehyde, metals, strong alkalis, and sulphides. Hydrochloric acid can cause severe skin burns and eye damage on physical contact, and should it be ingested, severe burns of the mouth and throat, as well as a danger of perforation of the oesophagus and the stomach will occur; should the fumes be inhaled, mucosal irritations, cough, and shortness of breath will result. Hydrochloric acid forms corrosive mixtures with water even when diluted, has harmful effects due to pH shift, and its discharge into the environment must be avoided. Waste material containing hydrochloric acid must be disposed of in accordance with national and local regulations. No mixing with other waste is allowed.

4.7.3 Sulphuric acid (H_2SO_{4aq})

As a 98 percent solution, H_2SO_{4aq} has a molar mass of 98.08g/mol, is a colourless and odourless liquid at standard room temperature and pressure, while also chemically stable under ambient conditions. A risk of explosion and/or of toxic gas formation exists with the following substances: Water; alkali metals, compounds, and earth metals; ammonia; aldehydes; acetonitrile; as well as metals; metal alloys; oxides of phosphorus; and hydrides; in addition to halogen and halogen compounds; permanganates; carbides; and organic solvents; along with anilines, peroxides, and amines. After inhalation of its vapours, damage of the mucous membranes can occur, with severe burns with formation of scabs can happen upon skin contact. After eye contact, burns and corneal lesions can occur, while severe pain (risk of perforation), nausea, vomiting and diarrhoea can take place after swallowing the acid. H_2SO_{4aq} forms corrosive mixtures with water, even when diluted. From an ecological perspective, it is harmful to the environment due to the extreme pH shift it can cause. Further to this, sulphuric acid endangers drinking water supplies when allowed to enter soil or water, therefore, discharge of sulphuric acid into the environment must be avoided at all cost. Waste sulphuric acid material must be disposed of in accordance with the national and local regulations and should not be mixed with other waste. Uncleaned containers of H_2SO_{4aq} should be treated as the acid itself.

4.7.4 Sodium hydroxide ($NaOH_{(S)}$)

$NaOH_S$ pellets have a molar mass of 40g/mol and is a white, solid, odourless substance in pellet form at standard room temperature and pressure. This product forms violent reactions with acetone, chlorine, fluorine, and hydrogen halides, as well as acids, sulphuric acid, chloroform, water, and hydrogen peroxide, along with anhydrides, halogen-halogen based compounds, and trichloroethene. Sodium hydroxide pellets can decompose violently in contact with organic substances and hydrogen sulphide, while there is a risk of ignition or formation of inflammable gases or vapours with: powdered aluminium, ammonium salts, persulfates, sodium borohydride, phosphorus, light metals, halogenated hydrocarbon, and metals. Additional risk includes explosion/exothermic reaction with bromine, calcium, in powder form, peroxides, and organic nitro compounds, in addition to nitriles, acrylic monomers and silver nitrate. When ingested, severe burns of the mouth and throat, as well as a danger of perforation of the oesophagus and the stomach can occur. Should it be inhaled, there is a potential of mucous membrane irritation, cough, as well as shortness of breath. This product can cause harmful effects due to pH shift and forms harmful corrosive mixtures with water even when diluted. Discharge into the environment must be avoided, therefore, waste materials must be disposed of in accordance with the national and local regulations.

4.7.5 Sodium hydrogen carbonate ($NaHCO_{3aq}$)

With a molar mass of 84.01g/mol, sodium hydrogen carbonate ($NaHCO_{3aq}$) is a white, odourless powder when stored under standard temperature and pressure. The product is chemically stable under standard ambient conditions. In case of skin contact, the victim should immediately take off all contaminated clothing and wash the affected part with excess water. In the event of eye contact, the victim should rinse the affected part with plenty of water (removal of contact lenses during eye rinsing is recommended). In the event of swallowing, ensure the victim drinks water (two glasses at most) and should contact the doctor if feeling unwell. This product is relatively unsafe. When handled appropriately, hazardous effects are unlikely to occur, however, sodium hydrogen carbonate should be handled in accordance with good industrial hygiene and safety practice, with discharge of this chemical into the environment avoided.

4.7.6 Acetic acid (CH_3COOH_{aq})

Acetic acid (glacial) (CH_3COOH_{aq}) 100 percent has a molar mass of 60.05g/mol. It is a colourless liquid with a stinking odour when stored under standard temperature and pressure. The product is chemically stable under standard ambient conditions. This chemical has a risk of explosion if in contact with peroxi compounds, perchloric acid, fuming sulphuric acid, and phosphorus halides, as well as hydrogen peroxide, chromium (VI) oxide, potassium permanganate, and peroxides, along with strong oxidising agents. There is a risk of ignition of inflammable gases or vapours when in contact with metals, iron, zinc, and magnesium, as well as mild steel. When ingested, severe burns of the mouth and throat, as well as a danger of perforation of the oesophagus and the stomach can occur. Should acetic acid be inhaled, mucosal irritations, cough, shortness of breath, and damage of the respiratory tract could occur. In the event of eye contact, there is a risk of blindness and serious eye damage. From an ecological perspective, this product has a harmful effect on the environment due to pH shift. It is caustic, even in diluted form, and discharge into the environment must be avoided.

4.7.7 Ammonium chloride ($NH4Cl_s$)

The product has a molar mass of 53.49g/mol, is a crystalline, white, odourless powder when stored under standard temperature and pressure, holding a risk of violent reaction when in contact with alkali hydroxides and acids. There is also the risk of ignition or formation of inflammable gases or vapours when in contact with halogen-halogen compounds, alkaline substances and a risk of explosion when in contact with nitrates, chlorates, heavy metal salts, and nitrites, as well as hydrogen cyanide, chlorine, silver salt, and strong oxidising agents. Ammonium chloride ($NH4Cl_s$) is incompatible with aluminium, lead, copper, and copper compounds. Should the product be ingested, it can cause irritations of mucous membranes in the mouth, pharynx, oesophagus and gastrointestinal tract. When in contact with eyes, it can cause serious eye irritation. Waste material must thus be disposed of in accordance with the national and local regulations, with discharge into the environment avoided.

4.8 DESIGN OF THE WASTE MANAGEMENT MODEL AT SAPPI SAICCOR COE LABORATORIES

The MCDA team - a commission of laboratory personnel from the various Sappi Saiccor COE laboratories - discussed the findings or outcomes from the initial questionnaire. From a design perspective, some of the suggestions coming out of that meeting were as follows,

- Nomination of a person responsible for the waste management system,
- The replacement, where possible, of hazardous substances with products not harmful to the environment and health and, thus, easier to dispose of,
- Developing special safety guidelines for the laboratory,
- Sensitivity to waste and training of all employees working with these chemicals,
- Regular environmental checks concerning all waste identification and classification according to the relevant internal directives,
- Constant documentation of all processes and tests taking place in the laboratory.

Following discussions with the MCDA team, the HWM approach at the Sappi Saiccor COE laboratories was reviewed and systemised into three sections, explained as follows:

4.8.1 COE laboratories Hazardous Waste Classification

The HW from laboratory tests will regularly be managed by laboratory analysts, technicians and research scientists and placed in special containers located in the demarcated storage areas. Waste will be classified according to chemical and physical characteristics and incompatibility, collected in containers and bins, depending on the needs of each laboratory.

4.8.2 Collection of Solid Waste

All laboratory personnel who wish to begin a new laboratory test will be required to undergo training. The trainer is expected to explain classification and the security and safety measures, as well as the procedures for handling and decanting liquid and solid waste into containers. To reduce accidents to a minimum, a group of trained laboratory analysts or technicians would visit each laboratory to verify and monitor the level in each disposal container in the laboratories. When the container is nearly full, it will be transported to a designated waste site where the handling or disposal contractor will treat or dispose it safely. The HW will be identified and labelled as shown in Table 4.6.

Table 4.6: Waste labelling in Sappi Saiccor COE laboratories

Container ID	Type of hazardous waste
A	Acid waste
B	Inorganic waste
C	Non halogenated solvents
E_o	Organic solvents
F	Metals
G	Organic solids
D	Contaminated plastics
V	Contaminated glass

The waste should not be kept for longer than six months. Full personal protective equipment (PPE) should be used when handling waste containers.

4.8.3 Final disposal systems

When full, the bins or containers located in the temporary designated waste storage or handling area will be transported by a certified and specialised HW disposal company. A subset of the HW can be recovered via chemical-physical treatments. Other materials are incinerated, encapsulated, and finally, landfilled by the company. The activities associated with control, labelling and general management of HW at the Sappi Saiccor COE laboratories are performed by highly trained employees who undertake this as a full-time job.

4.8.4 Schematic model of waste management at Sappi Saiccor COE laboratories

Figure 4.5 is a schematic representation of the suggested waste management model of Sappi Saiccor COE laboratories. The model was created by the COE team of scientists, technicians and analyst based on the findings and feedback from the initial pre-risk assessment questionnaire, with the aim to provide mitigation measures that will contribute to the well-being and safety of laboratory users, as well as reducing the damaging environmental impact.

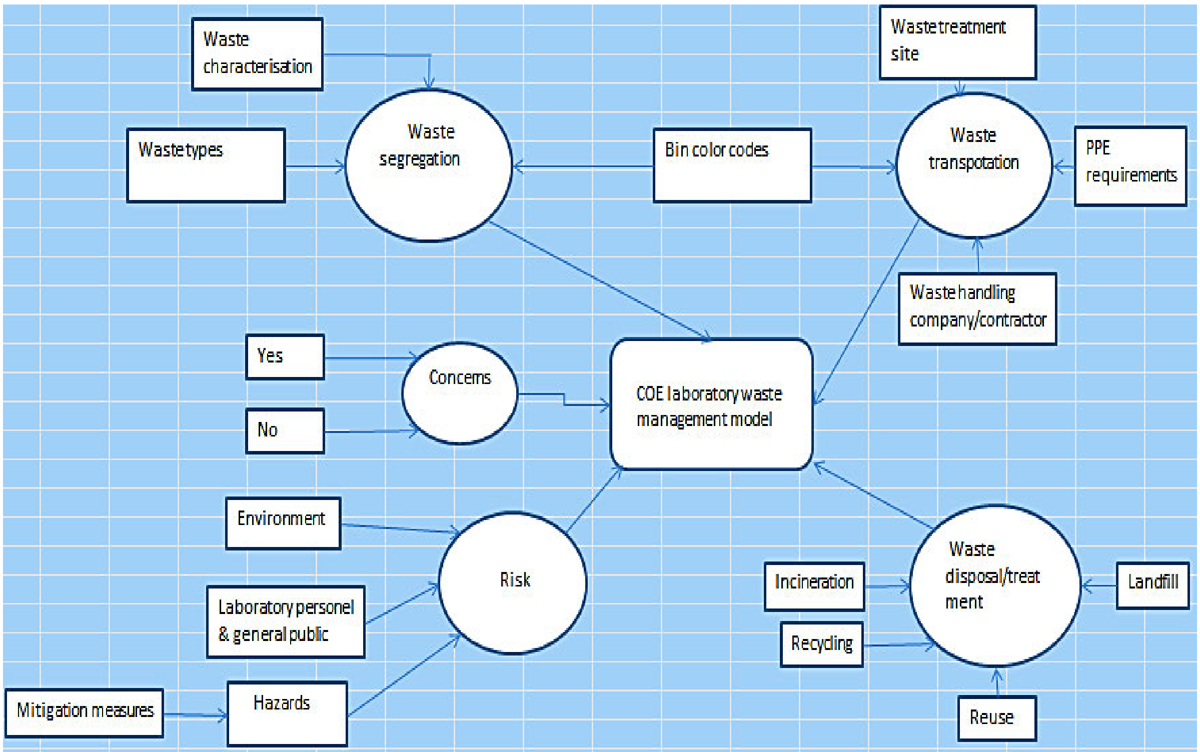

Figure 4.5: Schematic representation of the Sappi Saiccor COE laboratories waste management model

The waste management model was developed based on the need to address the gaps or shortcomings of the current waste management framework. Four key aspects were considered in building the model;

- Risk analysis of waste recycling or treatment
- Risk analysis of waste storage
- Risk analysis of waste removal
- Risk analysis of waste from a management perspective.

In each of the aforementioned aspects, mitigation measures to minimise the hazards or shortcomings were in corporated into the model.

4.8.5 Feedback of initial risk assessment questionnaire findings to Sappi Saiccor COE laboratories team

Following the meeting with the selected COE team of scientists, technicians and analyst, another meeting with the entire Sappi Saiccor COE laboratories department was scheduled and held to share the results, findings, and suggestions from the initial pre-risk assessment questionnaire. This was deemed necessary since the laboratory personnel were participants in the questionnaire. The team agreed with the findings and suggestions and were pleased their concerns were taken onboard. A post-risk assessment questionnaire was scheduled to assess, measure, and verify whether the suggestions, recommendations, and some corrective actions taken to mitigate the challenges highlighted by the initial feedback, have improved confidence in the new waste management model.

CHAPTER 5

POST MODEL RISK FINDINGS, MODEL VALIDATION, CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter will present an overview of the investigation accomplished through the theoretical and the empirical study. The post-model risk findings, model validation, findings, and conclusions are based on theories studied to ascertain the contributions of effective waste management models on the health and safety of the laboratory users. This chapter summarises the theoretical and empirical study, followed by discussions on significant findings highlighted in the previous chapter. Thereafter, the chapter sets out the conclusions to validate the research objectives.

5.2 EVALUATIONS OF PRE- AND POST-MODEL ASSESSMENTS AND CONCLUSIONS

A total of 11 participants (which represents 50 percent of the total population at Sappi Saiccor COE laboratories) participated in the pre- and post-model risk assessment. Of the 11, three are technicians, two are scientists and six are analysts. Graphs below (Fig. 5.1-5.4) show the percentage of people whose responses suggested there was a risk in a particular task.

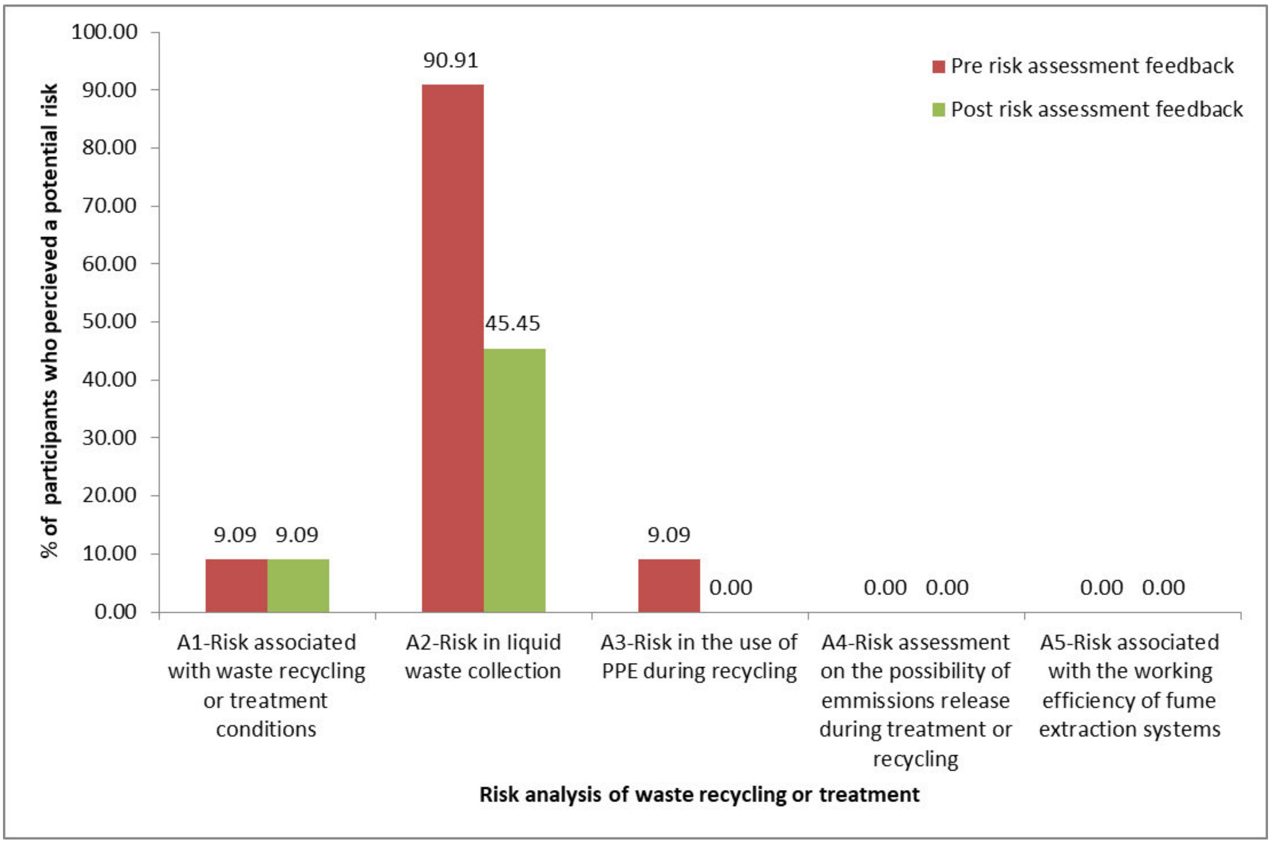

Figure 5.1: Pre- and post-risk assessment findings for waste treatment

The graph above compares pre versus post-risk assessment findings of waste treatment. Results show that the risk perception with regards to liquid waste collection had decreased by 50%. The 50% decrease was achieved as a result of COE management assigning training to the laboratory staff, regarding handling of liquid waste. Risk in the use of PPE during recycling decreased by 100% and this was possible due to the COE management investing more training in this area. Risk associated with waste recycling conditions for substances was minimised by ensuring recycling of substances which release vapours is being done under fume extraction systems. Pre and post assessment results suggests that COE staff have confidence in the working efficiency of the fume extraction systems as indicated with zero or low risk perception on A1, A4 and A5. Waste management awareness programmes that took place following the findings from the pre-assessment risk assessment may have assisted in improving waste management awareness in the COE leading to better responses in the post questionnaire risk assessment. Based on the aforementioned findings, it can be concluded that education and training of staff at COE are key in ensuring proper waste handling during recycling and treatment.

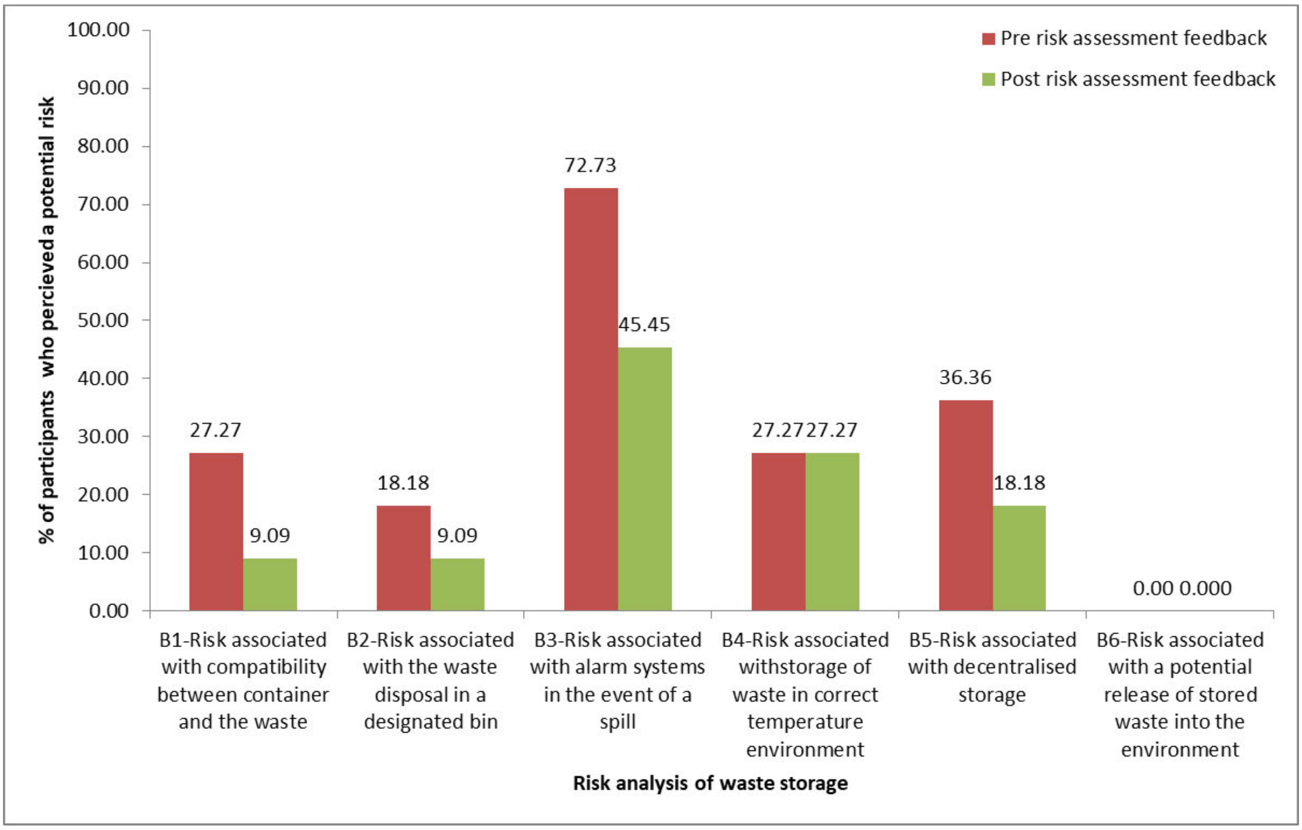

Figure 5.2: Pre- and post-model risk assessment findings for waste storage

The graph above compares pre versus post-risk assessment findings of waste waste storage. Results show that the risk perception, with regards to compatibility between container and the waste, has decreased by 75%. The 75% decrease was achieved as a result of COE management assigning online chemical compatibility training to the laboratory staff in order to familiarise the staff with chemical compatibility safe practices. Risk associated with waste disposal in a designated waste bin decreased by 50% and this was possible due to the COE management‘s programme and campaign of increasing correct waste disposal awareness in its Safety, Healty and Quality (SHEQ) meetings which are held once a month. Risk associated with the state of alarm systems in the event of a spill decreased by 38%. The 38% decrease was achieved by installation of more alarm systems in the labs that initially didn’t have them. Pre and post assessment results suggest that COE staff stored waste at the correct temperature environment and that they didn’t perceive any risk in this area. Training and waste management awareness programmes that took place following the findings from the pre-assessment risk assessment appear to have improved waste management awareness in the COE leading to better responses in the post questionnaire risk assessment. Based on the above findings, it is recommended that waste management education and training of staff at COE be prioritised for current and new employees.

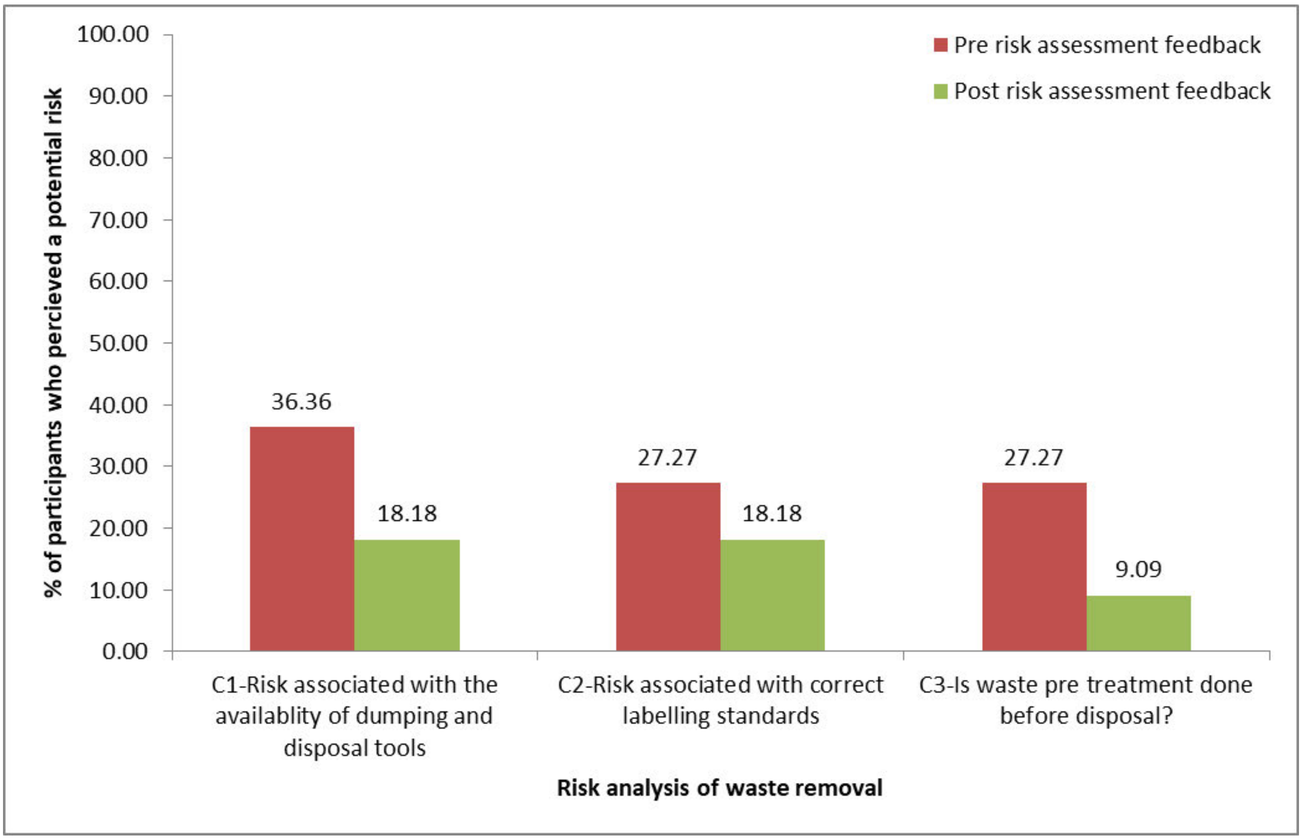

Figure 5.3: Pre- and post-model risk assessment findings for waste removal

The graph above compares pre versus post-risk assessment findings of waste waste removal. Results show that the risk perception with regards to the availability of dumping and disposal tools has decreased by 50%. The 50% decrease was achieved as a result of COE management procuring more hazardous chemical handling gloves, as well as ordering more waste disposal bins. Risk associated with the correct labelling standards and waste treatment before disposal decreased by 33% and 66% respectively. This was achieved by educating staff of correct labelling standards and the dangers associated with disposing untreated waste into bins. Based on the above findings, it is recommended that waste management education of staff at COE be prioritised for current and new employees.

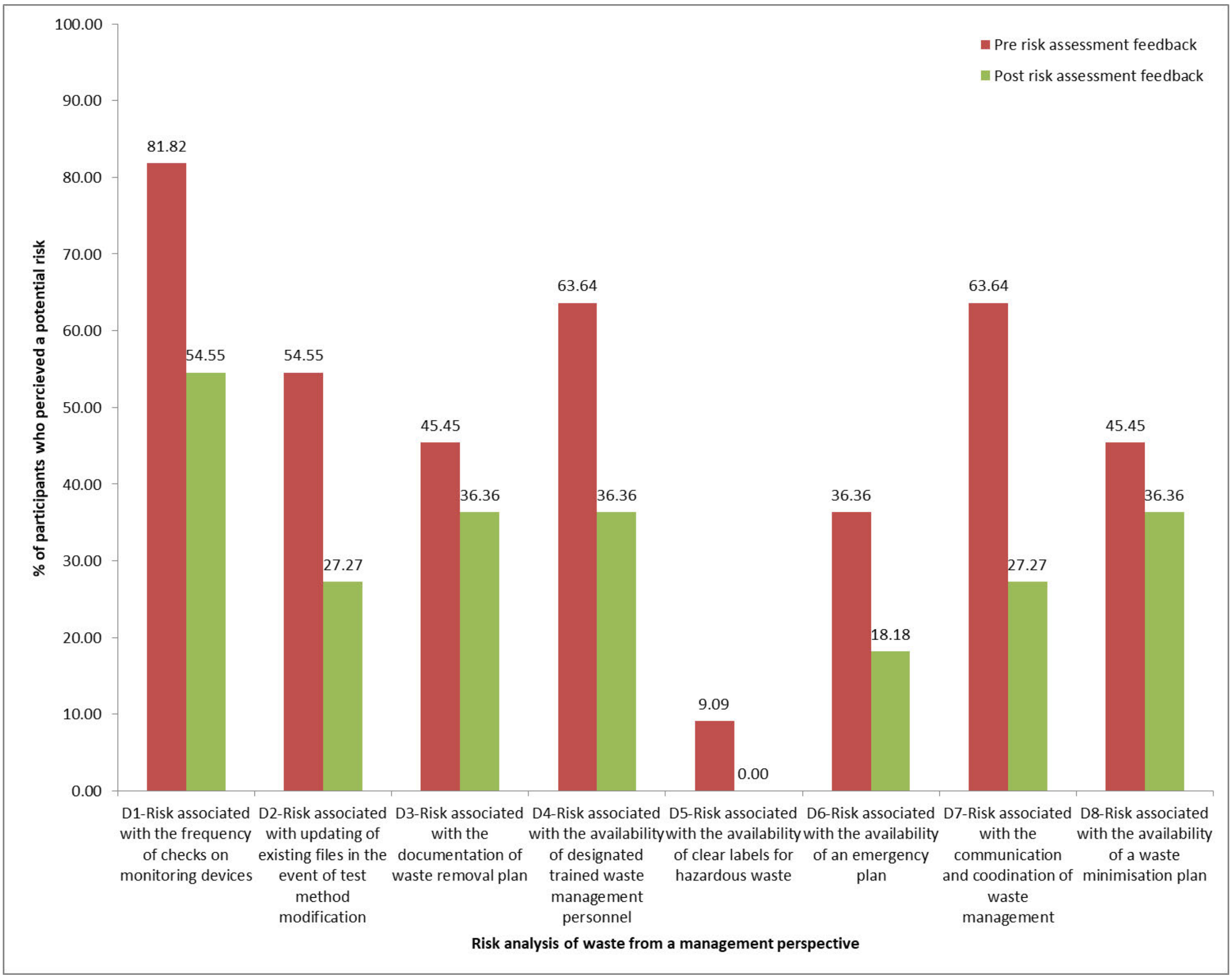

Figure 5.4: Pre- and post-risk assessment findings from an administrative view

The graph above compares pre versus post-risk assessment findings of waste management from an administrative view. Results show that the risk perception from D1 to D8 has decreased by several percentages. The 33% decrease in risk associated with the frequency of checks on monitoring devices was achieved as a result of COE management changing the checking frequency from once per month to once per week. Risk associated with the availability of clear labels for hazardous waste decreased by 100% because more hazardous waste labels were procured and thereafter placed on hazardous waste storage and disposal systems. A 42% decrease in risk associated with the availability of designated trained waste management personnel was achieved as a result of 2 staff members being nominated and trained as waste disposal ambassadors for the COE. The appointment of waste disposal ambassadors had a positive impact on the communication and coordination of waste management at the COE and as a result there was a risk drop of 57%.

5.3 MULTI-VARIABLE LINEAR REGRESSION OF COE LABORATORY WASTE PREDICTIVE MODEL RESULTS

Regression analysis was used to explain the relationship between the dependent variable (or response or output variable), and independent variables (or predictor variables). A generalised multiple-variable regression model has been derived to predict the total laboratory waste (W_G) as a function of the following three independent variables:

- Number of people working per laboratory (*Tp*)
- Number of laboratory tests performed per laboratory (*Tt*)
- Quantity of consumed chemical solutions in each laboratory per day (kg) (*Tc*)

$$W_G=\alpha+\beta_1 T_p+ \beta_2 T_t+\beta_3 T_c+\varepsilon$$

Where α is the intercept term that indicates the mean of the response variable when all predictor variables '*T*' are equal to zero, the slope of the model or β, a vector of βi, explains the average change in the dependent variable. β_1, β_2 and β_3 explain the average change in T_p, T_t and T_c respectively. The residual ε represents the difference between estimated values and observed values. ε may include measurement error, although it is often because of unincluded or unmeasured variables (Faraway 2005). This study aimed to provide a reliable model to assist the COE department decision makers and related stakeholders in predicting the quantity of laboratory generated waste.

Liquid and solid waste was collected at the Sappi Saiccor COE laboratories and measured daily for 14 consecutive days (between March and April 2022), to estimate the amount of total waste generated. Separated and deposited into different coloured and labelled plastic containers per laboratory, containers of collected waste in each laboratory were weighed every day and masses recorded. Table 5-1 shows the average measured masses of collected waste per day for each laboratory, an approximate average number of people working in each laboratory per day, as well as the number of laboratory tests conducted per laboratory, with quantities of consumed chemical solutions per day also factored in the table.

Table 5.1: Waste generation data for Sappi Saiccor COE laboratories

Laboratory name	Total Waste generated per day (kg/day)	Number of people per lab (Tp)	Number of lab tests performed per lab (Tt)	Quantity of consumed chemical solutions per day (kg) (Tc)
MCC + Acetate	5	3	3	18
Viscose	20	11	15	100
General	2	4	8	10
Instruments	5	3	6	12
Acetate technology	4	6	3	10

The above data were entered into IBM SPSS software for analysis. Descriptive indicators, such as standard deviation, R and R^2 were determined. Tables 5.2-5.4 set out the results of these descriptive indicators.

Table 5.2: Results summary of main descriptive indicators

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.993[a]	0.982	0.948	1.658

Table 5.3: Summary of regression results

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	208.051	3	69.350	25.226	.145[b]
	Residual	2.749	1	2.749		
	Total	210.800	4			

Table 5.4: Coefficients of independent variables

Coefficients[a]						
Model		Unstandardised Coefficients		Standardised Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.661	2.467		1.079	.476
	Number of people per lab (Tp)	-.054	.592	-.025	-.091	.942
	Number of lab tests performed per lab (Tt)	-.216	.356	-.148	-.608	.652
	Quantity of consumed chemical solutions per day (kg) (Tc)	.211	.065	1.144	3.245	.190

Substituting the constant and the coefficients determined by SPSS into equation 1 above, the equation reduces to:

$$W_G=2,661-0,05\ T_p-0,216T_t+0,211T_c$$

The above equation is the derived predictive regression model that can predict the total amount of waste produced in each COE laboratory per day in kilogrammes. R^2 (R-squared) is a useful property indicating the goodness of fit of the model. In this study an R^2 of 0.987 (quantity of consumed chemicals per day) was obtained which shows that the generated regression results are a true representation of the actual data entered into the SPSS programme. The standard error of estimate, tells us approximately how large the prediction errors (residuals) are for the data set in the same units as Wg. How well Wg can be predicted? The answer in this study is to within about 1.658 standard deviation above or below the line of best fit. Since it is generally preferred for forecasts and predictions to be as accurate as possible, it would be ideal to find a small value for standard error. Standard error can be interpreted as a standard deviation in the sense that if we have a normal distribution for the prediction errors, then we can expect about two-thirds of the data points to fall within a distance of the standard error either above or below the regression line. The R^2 Adj (adjusted R-squared), also indicates how well the model fits, but adjusts for the number of independent variables in a model (Giang 2017). The standard error of 1.6S indicated that the predicated values are within the 2 Sigma standard deviation which is acceptable deviation in statistical calculations. Therefore, the derived general model represented in the equation for W_G is a reliable and effective model to estimate waste generated at the COE laboratory.

According to the regression equation, the quantity of consumed chemical solutions in each laboratory per day (kg) (*Tc*) has the greatest effect on the quantity of laboratory waste generated (*Wg*) in the sense that an increase in the quantity of *Tc* will increase *Wg*. This means that when *Wg* increases, the likely cause of the increase will be coming from an increase in Tc.

5.4 PREDICTIVE MODEL REGRESSION GRAPHS

Three independent variables used in the prediction of total waste, by means of multiple regression models, were individually plotted against total waste generated per day. Line of best fit graphs was generated and compared to the plotted data points with the aim of verifying how close the plotted data points fit the graph.

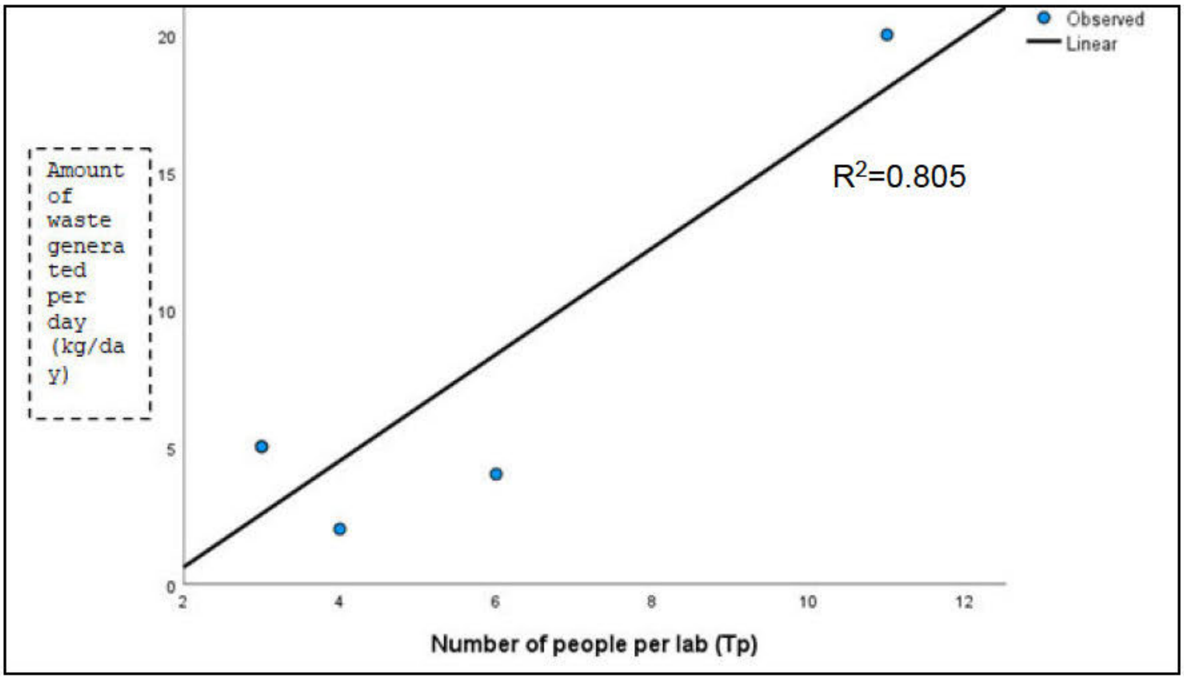

Figure 5.5: Estimation for total waste generated per number of people in the laboratories using linear regression model.

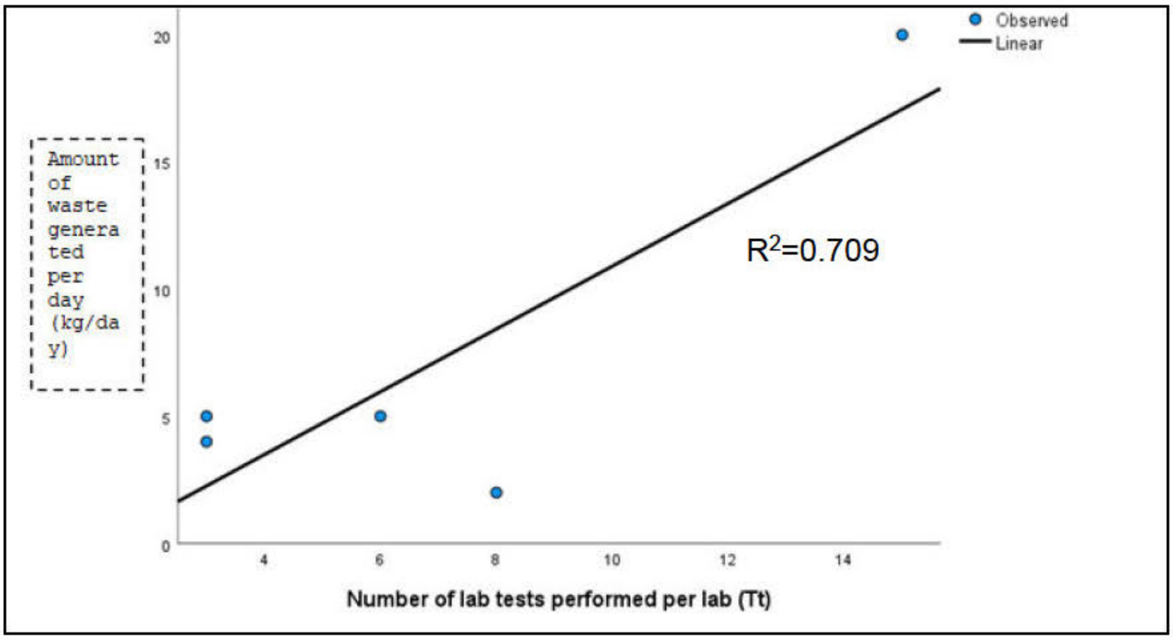

Figure 5.6: Estimation for total waste generated per number of tests performed in the laboratory using linear regression model.

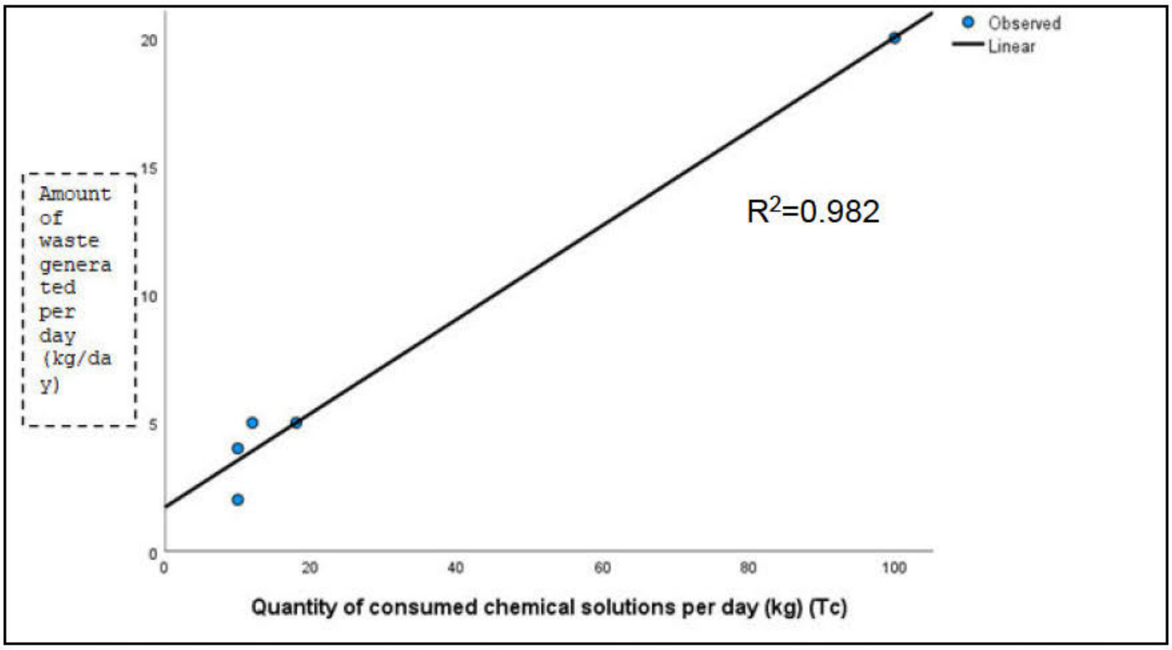

Figure 5.7: Estimation for total waste generated per quantity of consumed chemicals in the laboratory using linear regression model.

The number of people per lab and number of test per lab generated lines of best fit graphs showed that the plotted data points were not a close fit to the line graph when compared against that of quantity of chemicals used per lab suggesting weaker correlation between the independent variables and the dependent variable The R^2 values for the respective curves were 80 and 70% respectively which supported weak correlation when compared to the correlation achieved with the quantity of chemical consumed in the laboratory. The quantity of consumed chemicals per day line of best fit graph correlated well with the plotted data points suggesting good correlation between the independent variables and dependent variable. The R^2 value for the curve was 98% which supported a strong correlation. Based on these results, the quantity of chemicals used per lab best is the best Wg predictor because of how the graph correlates well with the data plotted points.

5.5 MODEL VALIDATION RESULTS

According to Giang (2017), the validity of the assumptions underlying the chosen model should be checked. The residuals ε (% error) was used to test the linear model assumptions. Formal diagnostic tests can ensure the exactitude of results but may be powerless to detect problems of an unsuspected nature, especially in data related to social and human activities.

In the above total waste predictive equation model, for a given (*Tp*), (*Tt*), and (*Tc*), the waste produced in each laboratory can be predicted with high accuracy by plugging the known values of (*Tp*), (*Tt*), and (*Tc)* into equation 1 for a given laboratory. The overall error in the prediction of the *total waste* (Error (%) can be estimated as:

$$Error\ (\%) = \frac{Total\ waste\ (measured) - Total\ waste\ (predicted)}{Total\ waste\ (measured)} \times 100 \ldots\ldots\ldots\ldots(2).$$

The % error for W_G was variable across the laboratories. General and Instruments laboratories had high % error when compared to the rest of the laboratories. This could be related to the fact that these two laboratories have fluctuating work requirements on a daily base which can make it challenging to accurately predict the waste produced on a given day. The Acetate Tech, Viscose and MCC laboratories recorded low % error because these laboratories have fixed or steady work requirements which make it more manageable to predict waste on any given day.

Table 5.5: Comparison of measured and predicted quantities of daily generated waste

Laboratory name	W_G (measured)	W_G (predicted)	% Error
MCC+ Acetate	5.000	5,661	13.22
Viscose	20.000	18,145	9.28
General	2.000	2,843	42.15
Instruments	5.000	3,747	25,06
Acetate tech	4.000	3,823	4.43

The R^2 of the model was 0.987 and 0.948 for the adjusted R^2; this means the model could explain approximately 99 and 95 percent of the daily waste generation variation rate at Sappi Saiccor COE laboratories. Other multi-variate linear regression studies had low R^2, such as 51 percent in the study of Benítez *et al.* (2008), 36 percent in the research of Grossman, Hudson & Marks (1974) and 48.7 percent in a study by Bach *et al.* (2004). The weak coefficient of determination could be explained by the fields of study, especially in the study of municipal waste generation, which attempts to predict human behaviour such as habit, lifestyle, and normally has R^2 values lower than 50 percent.

5.6 SUMMARY OF THE CHAPTER

This chapter presented the results of the study, which revealed that the creation or existence of a waste management model at the Sappi Saiccor COE laboratories improved environmental awareness and personnel safety of laboratory staff. The waste characterisation study showed that the largest quantities of generated HW consisted of liquid acid waste and toxic inorganic materials with corrosive characteristics. A multiple-variable predictive model to estimate total waste produced per laboratory on a given day was developed. The developed model is a function of three independent parameters; number of people working per laboratory (Tp), number of laboratory tests performed per laboratory (Tt) and quantity of consumed chemical solutions per day (kg) (Tc). The main indicators showed the high reliability and significance of the derived multi-variable predictive model. The objective of developing a regression model was to create a simple and reliable model to estimate waste generation, which can contribute to improving waste management. The models can provide reliable information to support current waste collection, transportation, and planning.

6 CONCLUSION

Despite being a Centre of Excellence, acts of negligence and non-compliance with safety and waste management procedures are still prevalent. This highlights the need that human intervention is key to ensure proper waste handling.

Evaluation of personal perceptions by staff within the COE laboratory facilities ensured openness and transparency on how management waste protocols were perceived and implemented. The use of a questionnaire before and after the implementation of the waste management model showed an increased level of waste handling, treatment and disposal awareness of the laboratory staff involved throughout the study suggesting that education and training of staff at COE is essential in ensuring the department achieves its comprehensive waste management goals.

Evaluation of personal perceptions results provide evidence that the creation or existence of a waste management model at the Sappi Saiccor COE laboratories improved environmental awareness and personnel safety of laboratory staff.

The predictive regression model suggested that the quantity of chemicals consumed per laboratory has the greatest effect on the quantity of total waste produced.

The waste characterisation study showed that the largest quantities of generated HW consisted of liquid acid waste and toxic inorganic materials with corrosive characteristics. The largest quantities of generated solid HW were pieces of glass, used paper towel and nitrile gloves impregnated with toxic hazardous substances.

A labelling system was introduced and implemented, which included pictograms providing information on the characteristics (toxic, reactive, and explosive or flammable for each substance. In addition, colour codes were used to identify the category in which the waste was generated.

Individual laboratories within the area of study were carefully scrutinised and investigated, hence an overall assessment was not done whereby individual toxic waste contributions by certain laboratories may not be entirely realised or reported.

6.1 RECOMMENDATIONS

Following the development and implementation of the waste management model, a monitoring programme must be put in place, since monitoring is an essential component to the continued success and growth of the model. Moreover, monitoring allows the expected strategy impacts to be measured against actual changes, which can be used as a basis for future revisions of the waste management model. Evaluation and monitoring are typically conducted through use of waste characterisation studies. Regular waste audits should be scheduled periodically and conducted whenever significant fluctuations in the waste stream occur. Results from monitoring will allow calculation of diversion rates and waste reduction, with information obtained from a regular audit can then be used as the basis in revising and evaluating waste management systems.

The waste prediction methodology applied in this case study can be adapted in any other laboratory unit within the Sulphite Dissolving Pulp Mills. Indicator and/or parameter adjustments may be required to adapt this methodology prior to using it in other laboratories of different companies. For future studies, it is recommended to repeat this analysis throughout the year, allowing for seasonal variation in the predictive data to be provided, as the seasonal variation in waste output is well-known to be linked to available laboratory project work and the number of people (laboratory personnel) taking leave days in certain periods of the year.

6.2 LIMITATIONS OF THIS STUDY

The developed regression predictive waste management model is not highly reliable in predicting waste generation in the future, but can provide reliable information to support and improve current waste management. Thus, modelling a waste generation model that can forecast the future is essential and needs to be studied.

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ANNEXURE A: PILOT STUDY QUESTIONNAIRE

Pilot study questionnaire

Voluntary questionnaire for SAPPI COE employees

A waste management model for selected Sappi Saiccor laboratory facilities

Dear Sir / Madam,

Hello, how are you. I hope I find you well. My name is Oswell Matasva. I am a master's student at Durban University of Technology's Quality management program. I am kindly requesting your participation in a master's research study that I am conducting titled: A waste management model for selected laboratory facilities at Sappi Saiccor mill aimed at reducing risk to health and environment. The intention is to formulate a model that improves waste minimization, management, and remediation at the Sappi COE laboratories with the goal of minimizing risk to health and the environment.

Note to the respondent

- I need your help to understand how effective the current waste management system at COE is and what can be done to improve it.
- Although I would like you to help me, you do not have to take part in this survey.
- If you do not want to take part, just hand in the blank questionnaire at the end of the survey session.
- What you say in this questionnaire will remain private and confidential. No one will be able to trace your opinions back to you as a person.
- Please note that there is no correct or incorrect answer and try to answer all questions even if the alternatives do not necessarily suit your opinion.

How to complete the questionnaire

- Please answer the questions as truthfully as you can. The questions are grouped into four categories.
- I am only seeking for information that you and your fellow employees should feel comfortable telling me about. The information that I need is based on everyone's personal view on waste management practices at COE laboratories.
- Your questions require a yes or no response, however where necessary an explanation may be needed.
- Please answer the questionnaire with a pen.

Research instruments

This study is based on a risk assessment questionnaire of potential factors of the default model of COE laboratory waste disposal and management procedures. The questionnaire is divided into 2 sections namely pre-risk assessment and post model risk assessment of waste management at COE laboratories.

Pilot study-Pre-risk assessment questionnaire to assess current waste management status at COE laboratories

Cause	Systematic function	Potential factors of the model	Item	Comments
Risk analysis of waste recycling or treatment	(Type) A recycling or treatment.	What waste is being recycled or treated? Under what conditions?	A1	
		Is liquid waste collected with or without a funnel or a drain pan spill over?	A2	
		Is protective tools/PPE during recycling adequate?	A3	
		Is there a possibility of evaporation and emission of toxic vapours during treatment or recycling?	A4	
		Is fume extraction system working efficiently?	A5	
Risk analysis of waste storage	(Type) B storage	What's your opinion on compatibility	B1	

		between the container and the waste		
		Is waste being put in the correct designated container?	B2	
		Is there an alarm or warming device in the event of a spill?	B3	
		Is waste stored in a correct temperature environment?	B4	
		Is there decentralized storage?	B5	
		Is there a potential for stored waste to be released into the environment?	B6	
Risk analysis of waste removal	(Type) C waste removal	Are dumping, disposal or treatment tools available?	C1	
		Does the lab practice correct labelling standards (container weight and waste composition)?	C2	
		Is there any form of waste pre-treatment before removal or disposal	C3	
Risk analysis of waste from a management perspective	(Type) D management	What’s the frequency of checks on the alarm and other monitoring devices	D1	
		Do waste files get updated in the event a new test using different chemicals has been introduced?	D2	
		Is waste removal plan documented?	D3	
		Are special/designated waste management trained personnel available?	D4	
		Are there clear labels for hazardous wastes?	D5	
		Is there an emergency plan?	D6	
		How effective is the communication and coordination of waste management?	D7	
		Is there a plan to minimize or prevent	D8	

		laboratory waste generation?		

***Pilot study-Post model risk assessment questionnaire to assess the new implemented waste management model at COE laboratories*.**

Cause	Systematic function	Potential factors of the model	Item	Comments
Risk analysis of waste recycling or treatment	(Type) A recycling or treatment.	What waste is being recycled or treated? Under what conditions?	A1	
		Is liquid waste collected with or without a funnel or a drain pan spill over?	A2	
		Is protective tools/PPE during recycling adequate?	A3	
		Is there a possibility of evaporation and emission of toxic vapours during treatment or recycling?	A4	
		Is fume extraction system working efficiently?	A5	
Risk analysis of waste storage	(Type) B storage	What’s your opinion on compatibility between the container and the waste	B1	
		Is waste being put in the correct designated container?	B2	
		Is there an alarm or warming device in the event of a spill?	B3	
		Is waste stored in a correct temperature environment?	B4	
		Is there decentralized storage?	B5	
		Is there a potential for stored waste to be released into the environment?	B6	
Risk analysis of waste removal	(Type) C waste removal	Are dumping, disposal or treatment tools available?	C1	
		Does the lab practice correct labelling standards (container	C2	

		weight and waste composition)?		
		Is there any form of waste pre-treatment before removal or disposal	C3	
Risk analysis of waste from a management perspective	(Type) D management	What's the frequency of checks on the alarm and other monitoring devices	D1	
		Do waste files get updated in the event a new test using different chemicals has been introduced?	D2	
		Is waste removal plan documented?	D3	
		Are special/designated waste management trained personnel available?	D4	
		Are there clear labels for hazardous wastes?	D5	
		Is there an emergency plan?	D6	
		How effective is the communication and coordination of waste management?	D7	
		Is there a plan to minimize or prevent laboratory waste generation?	D8	

How difficult were the survey questions?

Very difficult

Somewhat difficult

Easy

Very easy

Neither easy or difficult

Did you have any challenges navigating the questionnaire?

Yes

No

Do you think that all the questions listed are relevant to the research topic?

Yes

No

Not sure

How long did it take you to complete the survey?

10 minutes

20minutes

30minutes

30-60minutes

The questionnaire was well designed.

Yes

No

Please state any recommendations or suggestions that can help us make this survey better.

……

……

……

Did you find any of the questions offensive or degrading?

Yes No

ANNEXURE B: MAIN STUDY QUESTIONNAIRE

Voluntary questionnaire for SAPPI COE employees

A waste management model for selected Sappi Saiccor laboratory facilities

Dear Sir / Madam,

Hello, how are you. I hope I find you well. My name is Oswell Matasva. I am a master's student at Durban University of Technology's Quality management program. I am kindly requesting your participation in a master's research study that I am conducting titled: A waste management model for selected laboratory facilities at Sappi Saiccor mill aimed at reducing risk to health and environment. The intention is to formulate a model that improves waste minimization, management, and remediation at the Sappi Centre of excellence (COE) laboratories with the goal of minimizing risk to health and the environment.

Note to the respondent

- I need your help to understand how effective the current waste management system at COE is and what can be done to improve it.
- Although I would like you to help me, you do not have to take part in this survey.
- If you do not want to take part, just hand in the blank questionnaire at the end of the survey session.
- What you say in this questionnaire will remain private and confidential. No one will be able to trace your opinions back to you as a person.
- Please note that there is no correct or incorrect answer and try to answer all questions even if the alternatives do not necessarily suit your opinion.

How to complete the questionnaire

- Please answer the questions as truthfully as you can. The questions are grouped into four categories.
- I am only seeking for information that you and your fellow employees should feel comfortable telling me about. The information that I need is based on everyone’s personal view on waste management practices at COE laboratories.
- Your questions require a yes or no response, however where necessary an explanation may be needed.
- Please answer the questionnaire with a pen.

Research instruments

This study is based on a risk assessment questionnaire of potential factors of the default model of COE laboratory waste disposal and management procedures. The questionnaire is divided into 2 sections namely pre-risk assessment and post model risk assessment of waste management at COE laboratories.

***Main study-Pre-risk assessment questionnaire to assess current waste management status at COE laboratories*.**

Cause	Systematic function	Potential factors of the model	Item	Comments
Risk analysis of waste recycling or treatment	(Type) A recycling or treatment.	What waste is being recycled or treated? Under what conditions?	A1	
		Is liquid waste collected with or without a funnel or a drain pan spill over?	A2	
		Is protective tools/PPE during recycling adequate?	A3	
		Is there a possibility of evaporation and emission of toxic vapours during	A4	

		treatment or recycling?		
		Is fume extraction system working efficiently?	A5	
Risk analysis of waste storage	(Type) B storage	What's your opinion on compatibility between the container and the waste	B1	
		Is waste being put in the correct designated container?	B2	
		Is there an alarm or warming device in the event of a spill?	B3	
		Is waste stored in a correct temperature environment?	B4	
		Is there decentralized storage?	B5	
		Is there a potential for stored waste to be released into the environment?	B6	
Risk analysis of waste removal	(Type) C waste removal	Are dumping, disposal or treatment tools available?	C1	
		Does the lab practice correct labelling standards (container weight and waste composition)?	C2	
		Is there any form of waste pre-treatment before removal or disposal	C3	
Risk analysis of waste from a	(Type) D management	What's the frequency of checks on the	D1	

management perspective		alarm and other monitoring devices		
		Do waste files get updated in the event a new test using different chemicals has been introduced?	D2	
		Is waste removal plan documented?	D3	
		Are special/designated waste management trained personnel available?	D4	
		Are there clear labels for hazardous wastes?	D5	
		Is there an emergency plan?	D6	
		How effective is the communication and coordination of waste management?	D7	
		Is there a plan to minimize or prevent laboratory waste generation?	D8	

***Main study - Post-model risk assessment questionnaire to assess the new implemented waste management model at COE laboratories*.**

Cause	Systematic function	Potential factors of the model	Item	Comments
Risk analysis of waste recycling or treatment	(Type) A recycling or treatment.	What waste is being recycled or treated? Under what conditions?	A1	
		Is liquid waste collected with or	A2	

		without a funnel or a drain pan spill over?		
		Is protective tools/PPE during recycling adequate?	A3	
		Is there a possibility of evaporation and emission of toxic vapours during treatment or recycling?	A4	
		Is fume extraction system working efficiently?	A5	
Risk analysis of waste storage	(Type) B storage	What's your opinion on compatibility between the container and the waste	B1	
		Is waste being put in the correct designated container?	B2	
		Is there an alarm or warming device in the event of a spill?	B3	
		Is waste stored in a correct temperature environment?	B4	
		Is there decentralized storage?	B5	
		Is there a potential for stored waste to be released into the environment?	B6	
Risk analysis of waste removal	(Type) C waste removal	Are dumping, disposal or treatment tools available?	C1	
		Does the lab practice correct labelling	C2	

		standards (container weight and waste composition)?		
		Is there any form of waste pre-treatment before removal or disposal	C3	
Risk analysis of waste from a management perspective	(Type) D management	What's the frequency of checks on the alarm and other monitoring devices	D1	
		Do waste files get updated in the event a new test using different chemicals has been introduced?	D2	
		Is waste removal plan documented?	D3	
		Are special/designated waste management trained personnel available?	D4	
		Are there clear labels for hazardous wastes?	D5	
		Is there an emergency plan?	D6	
		How effective is the communication and coordination of waste management?	D7	
		Is there a plan to minimize or prevent laboratory waste generation?	D8	

ANNEXURE C: MODEL RESULTS USING IBM SPSS STATISTICAL SOFTWARE

```
GET DATA
  /TYPE=XLSX
  /FILE='C:\Users\oswell\Documents\Independent variables.xlsx'
  /SHEET=name 'Independent variables'
  /CELLRANGE=FULL
  /READNAMES=ON
  /DATATYPEMIN PERCENTAGE=95.0

  /HIDDEN IGNORE=YES.
EXECUTE.
DATASET NAME DataSet1 WINDOW=FRONT.

GET DATA
  /TYPE=XLSX
  /FILE='C:\Users\oswell\Documents\data-model.xlsx'
  /SHEET=name 'Independent variables'
  /CELLRANGE=FULL
  /READNAMES=ON
  /DATATYPEMIN PERCENTAGE=95.0
  /HIDDEN IGNORE=YES.
EXECUTE.
DATASET NAME DataSet3 WINDOW=FRONT.
REGRESSION
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS R ANOVA
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT TotalWastegenerated
  /METHOD=ENTER NumberofpeopleperlabTp NumberoflabtestsperformedperlabTt
    QuantityofconsumedchemicalsolutionsperdaykgTc.
```

Regression

Notes

Output Created		26-APR-2022 03:41:03
Comments		
Input	Active Dataset	DataSet3
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.

Syntax		REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT TotalWastegenerated /METHOD=ENTER NumberofpeopleperlabTp NumberoflabtestsperformedperlabTt QuantityofconsumedchemicalsolutionsperdaykgTc.
Resources	Processor Time	00:00:00.06
	Elapsed Time	00:00:00.93
	Memory Required	3584 bytes
	Additional Memory Required for Residual Plots	0 bytes

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Quantity of consumed chemical solutions per day (kg) (Tc), Number of lab tests performed per lab (Tt), Number of people per lab (Tp)[b]	.	Enter

a. Dependent Variable: Total Waste generated
b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.993[a]	.987	.948	1.658

a. Predictors: (Constant), Quantity of consumed chemical solutions per day (kg) (Tc), Number of lab tests performed per lab (Tt), Number of people per lab (Tp)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	208.051	3	69.350	25.226	.145[b]
	Residual	2.749	1	2.749		
	Total	210.800	4			

a. Dependent Variable: Total Waste generated

b. Predictors: (Constant), Quantity of consumed chemical solutions per day (kg) (Tc), Number of lab tests performed per lab (Tt), Number of people per lab (Tp)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.661	2.467		1.079	.476
	Number of people per lab (Tp)	-.054	.592	-.025	-.091	.942
	Number of lab tests performed per lab (Tt)	-.216	.356	-.148	-.608	.652
	Quantity of consumed chemical solutions per day (kg) (Tc)	.211	.065	1.144	3.245	.190

a. Dependent Variable: Total Waste generated

```
GRAPH
  /HISTOGRAM(NORMAL)=TotalWastegenerated
  /PANEL ROWVAR=NumberofpeopleperlabTp NumberoflabtestsperformedperlabTt
    QuantityofconsumedchemicalsolutionsperdaykgTc ROWOP=CROSS.
```

Graph

Notes

Output Created		26-APR-2022 04:04:00
Comments		
Input	Active Dataset	DataSet3
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Syntax		GRAPH /HISTOGRAM(NORMAL)=TotalWastegenerated /PANEL ROWVAR=NumberofpeopleperlabTp NumberoflabtestsperformedperlabTt QuantityofconsumedchemicalsolutionsperdaykgTc ROWOP=CROSS.
Resources	Processor Time	00:00:04.44
	Elapsed Time	00:00:48.02

```
DATASET ACTIVATE DataSet1.

GET DATA
  /TYPE=XLSX
  /FILE='C:\Users\oswell\Documents\data-model.xlsx'
```

```
  /SHEET=name 'Independent variables'
  /CELLRANGE=FULL
  /READNAMES=ON
  /DATATYPEMIN PERCENTAGE=95.0
  /HIDDEN IGNORE=YES.
EXECUTE.
DATASET NAME DataSet4 WINDOW=FRONT.
* Curve Estimation.
TSET NEWVAR=NONE.
CURVEFIT
  /VARIABLES=TotalWastegeneratedperdaykgday WITH NumberofpeopleperlabTp
  /CONSTANT
  /MODEL=LINEAR
  /PRINT ANOVA
  /PLOT FIT.
```

Curve Fit

Notes

Output Created		09-APR-2022 02:43:49
Comments		
Input	Active Dataset	DataSet4
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Cases with a missing value in any variable are not used in the analysis.
Syntax		CURVEFIT /VARIABLES=TotalWastegeneratedperdaykgday WITH NumberofpeopleperlabTp /CONSTANT /MODEL=LINEAR /PRINT ANOVA /PLOT FIT.
Resources	Processor Time	00:00:04.31
	Elapsed Time	00:00:48.12
Use	From	First observation
	To	Last observation
Predict	From	First Observation following the use period
	To	Last observation
Time Series Settings (TSET)	Amount of Output	PRINT = DEFAULT
	Saving New Variables	NEWVAR = NONE
	Maximum Number of Lags in Autocorrelation or Partial Autocorrelation Plots	MXAUTO = 16
	Maximum Number of Lags Per Cross-Correlation Plots	MXCROSS = 7

	Maximum Number of New Variables Generated Per Procedure	MXNEWVAR = 60
	Maximum Number of New Cases Per Procedure	MXPREDICT = 1000
	Treatment of User-Missing Values	MISSING = EXCLUDE
	Confidence Interval Percentage Value	CIN = 95
	Tolerance for Entering Variables in Regression Equations	TOLER = .0001
	Maximum Iterative Parameter Change	CNVERGE = .001
	Method of Calculating Std. Errors for Autocorrelations	ACFSE = IND
	Length of Seasonal Period	Unspecified
	Variable Whose Values Label Observations in Plots	Unspecified
	Equations Include	CONSTANT

Model Description

Model Name		MOD_1
Dependent Variable	1	Total Waste generated per day (kg/day)
Equation	1	Linear
Independent Variable		Number of people per lab (Tp)
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified

Case Processing Summary

	N
Total Cases	5
Excluded Cases[a]	0
Forecasted Cases	0
Newly Created Cases	0

a. Cases with a missing value in any variable are excluded from the analysis.

Variable Processing Summary

		Variables	
		Dependent Total Waste generated per day (kg/day)	Independent Number of people per lab (Tp)
Number of Positive Values		5	5
Number of Zeros		0	0
Number of Negative Values		0	0
Number of Missing Values	User-Missing	0	0
	System-Missing	0	0

Total Waste generated per day (kg/day)

Linear

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.897	.805	.741	3.698

The independent variable is Number of people per lab (Tp).

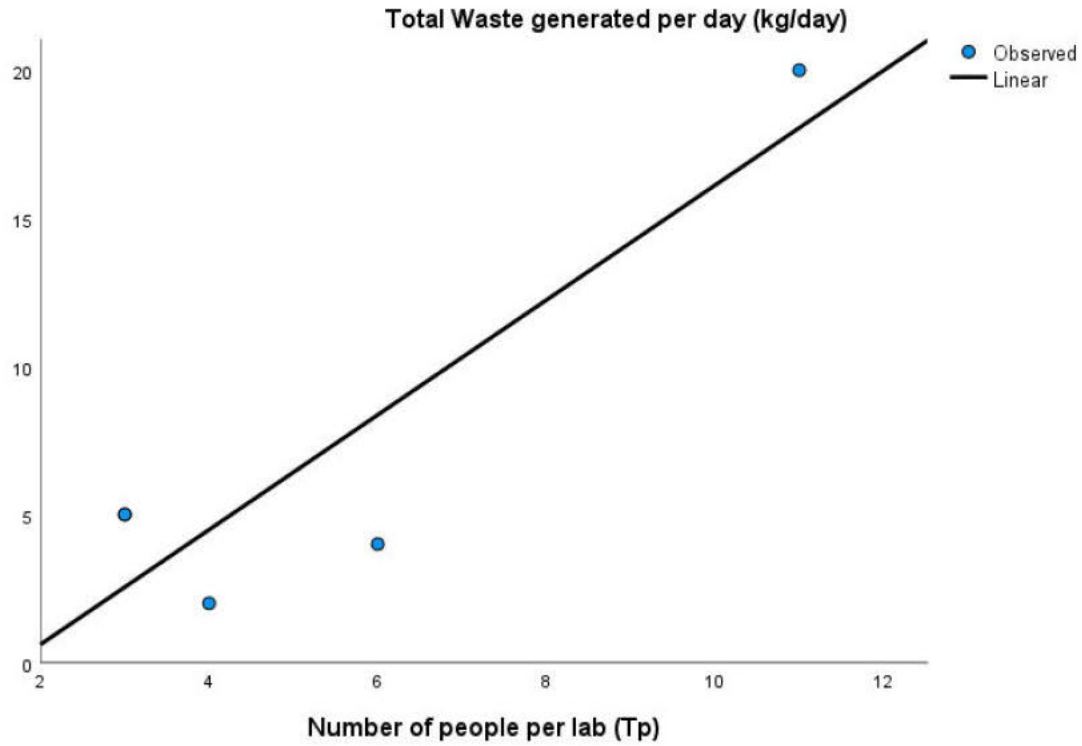
ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	169.773	1	169.773	12.414	.039
Residual	41.027	3	13.676		
Total	210.800	4			

The independent variable is Number of people per lab (Tp).

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Number of people per lab (Tp)	1.938	.550	.897	3.523	.039
(Constant)	-3.265	3.400		-.961	.408




```
REGRESSION
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS R ANOVA
```

```
/CRITERIA=PIN(.05) POUT(.10)
/NOORIGIN
/DEPENDENT TotalWastegeneratedperdaykgday
/METHOD=ENTER NumberofpeopleperlabTp NumberoflabtestsperformedperlabTt
  QuantityofconsumedchemicalsolutionsperdaykgTc.
```

Regression

Notes

Output Created		09-ARL-2022 02:44:45
Comments		
Input	Active Dataset	DataSet4
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT TotalWastegeneratedperdaykgday /METHOD=ENTER NumberofpeopleperlabTp NumberoflabtestsperformedperlabTt QuantityofconsumedchemicalsolutionsperdaykgTc.
Resources	Processor Time	00:00:00.05
	Elapsed Time	00:00:00.79
	Memory Required	3584 bytes
	Additional Memory Required for Residual Plots	0 bytes

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method

1	Quantity of consumed chemical solutions per day (kg) (Tc), Number of lab tests performed per lab (Tt), Number of people per lab (Tp)[b]	.	Enter

a. Dependent Variable: Total Waste generated per day (kg/day)
b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.993[a]	.987	.948	1.658

a. Predictors: (Constant), Quantity of consumed chemical solutions per day (kg) (Tc), Number of lab tests performed per lab (Tt), Number of people per lab (Tp)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	208.051	3	69.350	25.226	.145[b]
	Residual	2.749	1	2.749		
	Total	210.800	4			

a. Dependent Variable: Total Waste generated per day (kg/day)
b. Predictors: (Constant), Quantity of consumed chemical solutions per day (kg) (Tc), Number of lab tests performed per lab (Tt), Number of people per lab (Tp)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.661	2.467		1.079	.476
	Number of people per lab (Tp)	-.054	.592	-.025	-.091	.942
	Number of lab tests performed per lab (Tt)	-.216	.356	-.148	-.608	.652
	Quantity of consumed chemical solutions per day (kg) (Tc)	.211	.065	1.144	3.245	.190

a. Dependent Variable: Total Waste generated per day (kg/day)

```
* Curve Estimation.
TSET NEWVAR=NONE.
CURVEFIT
```

```
  /VARIABLES=TotalWastegeneratedperdaykgday WITH
Numberoflabtestsperformedperlabtt
  /CONSTANT
  /MODEL=LINEAR
  /PRINT ANOVA
  /PLOT FIT.
```

Curve Fit

Notes

Output Created		09-APR-2022 02:52:25
Comments		
Input	Active Dataset	DataSet4
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Cases with a missing value in any variable are not used in the analysis.
Syntax		CURVEFIT /VARIABLES=TotalWastegeneratedperdaykgday WITH Numberoflabtestsperformedperlabtt /CONSTANT /MODEL=LINEAR /PRINT ANOVA /PLOT FIT.
Resources	Processor Time	00:00:04.98
	Elapsed Time	00:00:29.66
Use	From	First observation
	To	Last observation
Predict	From	First Observation following the use period
	To	Last observation
Time Series Settings (TSET)	Amount of Output	PRINT = DEFAULT
	Saving New Variables	NEWVAR = NONE
	Maximum Number of Lags in Autocorrelation or Partial Autocorrelation Plots	MXAUTO = 16
	Maximum Number of Lags Per Cross-Correlation Plots	MXCROSS = 7
	Maximum Number of New Variables Generated Per Procedure	MXNEWVAR = 60
	Maximum Number of New Cases Per Procedure	MXPREDICT = 1000
	Treatment of User-Missing Values	MISSING = EXCLUDE
	Confidence Interval Percentage Value	CIN = 95

	Tolerance for Entering Variables in Regression Equations	TOLER = .0001
	Maximum Iterative Parameter Change	CNVERGE = .001
	Method of Calculating Std. Errors for Autocorrelations	ACFSE = IND
	Length of Seasonal Period	Unspecified
	Variable Whose Values Label Observations in Plots	Unspecified
	Equations Include	CONSTANT

Model Description

Model Name		MOD_2
Dependent Variable	1	Total Waste generated per day (kg/day)
Equation	1	Linear
Independent Variable		Number of lab tests performed per lab (Tt)
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified

Case Processing Summary

	N
Total Cases	5
Excluded Cases[a]	0
Forecasted Cases	0
Newly Created Cases	0

a. Cases with a missing value in any variable are excluded from the analysis.

Variable Processing Summary

		Variables	
		Dependent Total Waste generated per day (kg/day)	Independent Number of lab tests performed per lab (Tt)
Number of Positive Values		5	5
Number of Zeros		0	0
Number of Negative Values		0	0
Number of Missing Values	User-Missing	0	0
	System-Missing	0	0

Total Waste generated per day (kg/day)

Linear

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.842	.709	.612	4.524

The independent variable is Number of lab tests performed per lab (Tt).

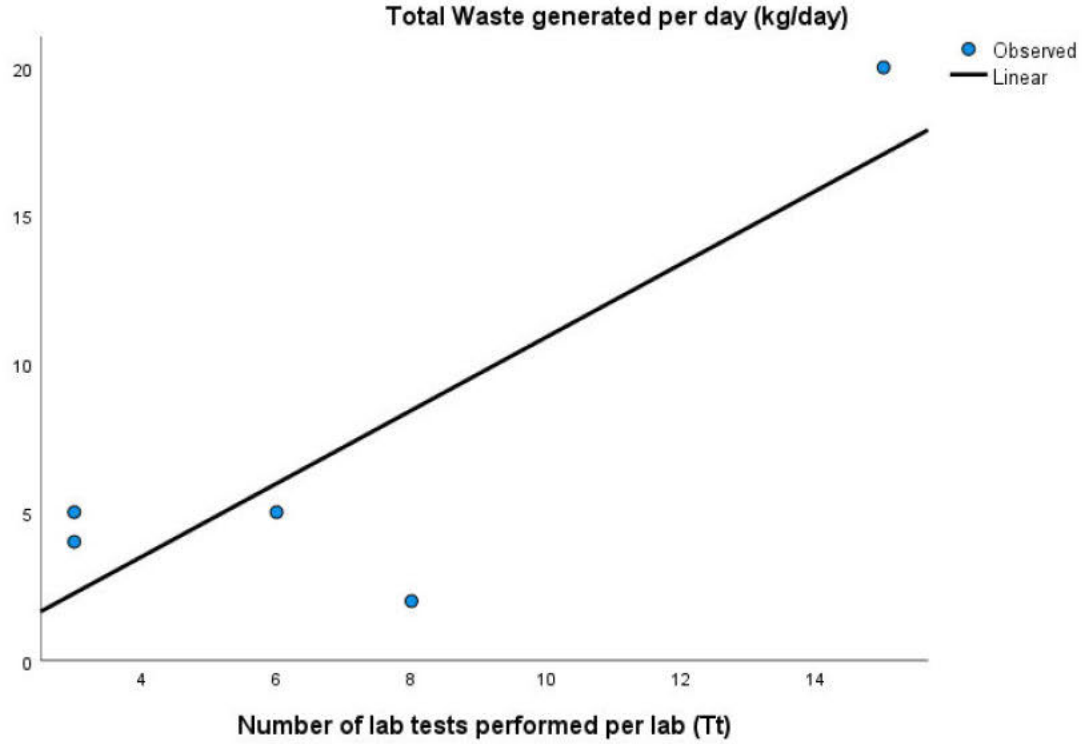
ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	149.398	1	149.398	7.299	.074
Residual	61.402	3	20.467		
Total	210.800	4			

The independent variable is Number of lab tests performed per lab (Tt).

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
Number of lab tests performed per lab (Tt)	1.235	.457	.842	2.702	.074
(Constant)	-1.443	3.785		-.381	.728




```
* Curve Estimation.
TSET NEWVAR=NONE.
CURVEFIT
  /VARIABLES=TotalWastegeneratedperdaykgday WITH
```

```
Quantityofconsumedchemicalsolutionsperdaykg Tc
  /CONSTANT
  /MODEL=LINEAR
  /PRINT ANOVA
  /PLOT FIT.
```

Curve Fit

Notes

Output Created		09-APR-2022 03:05:01
Comments		
Input	Active Dataset	DataSet4
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Cases with a missing value in any variable are not used in the analysis.
Syntax		CURVEFIT /VARIABLES=TotalWastegeneratedperdaykgday WITH Quantityofconsumedchemicalsolutionsperdaykg Tc /CONSTANT /MODEL=LINEAR /PRINT ANOVA /PLOT FIT.
Resources	Processor Time	00:00:07.95
	Elapsed Time	00:01:01.07
Use	From	First observation
	To	Last observation
Predict	From	First Observation following the use period
	To	Last observation
Time Series Settings (TSET)	Amount of Output	PRINT = DEFAULT
	Saving New Variables	NEWVAR = NONE
	Maximum Number of Lags in Autocorrelation or Partial Autocorrelation Plots	MXAUTO = 16
	Maximum Number of Lags Per Cross-Correlation Plots	MXCROSS = 7
	Maximum Number of New Variables Generated Per Procedure	MXNEWVAR = 60
	Maximum Number of New Cases Per Procedure	MXPREDICT = 1000
	Treatment of User-Missing Values	MISSING = EXCLUDE
	Confidence Interval Percentage Value	CIN = 95

	Tolerance for Entering Variables in Regression Equations	TOLER = .0001
	Maximum Iterative Parameter Change	CNVERGE = .001
	Method of Calculating Std. Errors for Autocorrelations	ACFSE = IND
	Length of Seasonal Period	Unspecified
	Variable Whose Values Label Observations in Plots	Unspecified
	Equations Include	CONSTANT

Model Description

Model Name		MOD_3
Dependent Variable	1	Total Waste generated per day (kg/day)
Equation	1	Linear
Independent Variable		Quantity of consumed chemical solutions per day (kg) (Tc)
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified

Case Processing Summary

	N
Total Cases	5
Excluded Cases[a]	0
Forecasted Cases	0
Newly Created Cases	0

a. Cases with a missing value in any variable are excluded from the analysis.

Variable Processing Summary

		Variables	
		Dependent	Independent
		Total Waste generated per day (kg/day)	Quantity of consumed chemical solutions per day (kg) (Tc)
Number of Positive Values		5	5
Number of Zeros		0	0
Number of Negative Values		0	0
Number of Missing Values	User-Missing	0	0
	System-Missing	0	0

Total Waste generated per day (kg/day)

Linear

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.991	.982	.976	1.122

The independent variable is Quantity of consumed chemical solutions per day (kg) (Tc).

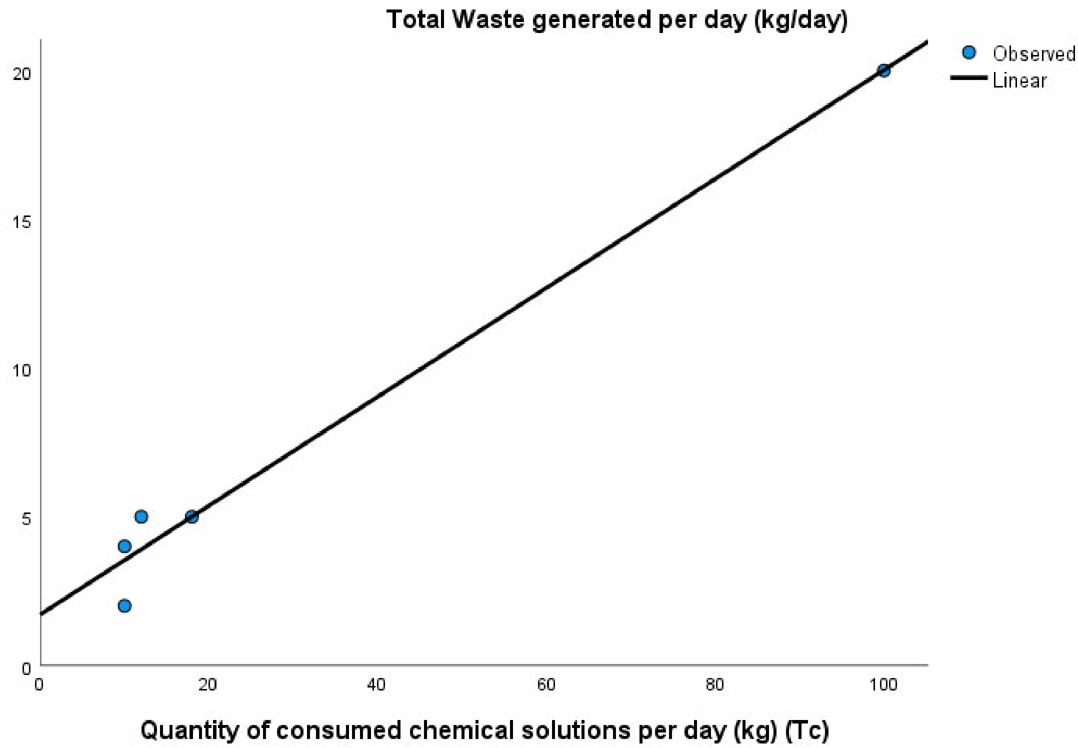
ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	207.020	1	207.020	164.306	.001
Residual	3.780	3	1.260		
Total	210.800	4			

The independent variable is Quantity of consumed chemical solutions per day (kg) (Tc).

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
Quantity of consumed chemical solutions per day (kg) (Tc)	.183	.014	.991	12.818	.001
(Constant)	1.704	.660		2.581	.082


Total Waste generated per day (kg/day)
Observed
Linear
0
5
10
15
20
0
20
40
60
80
100
Quantity of consumed chemical solutions per day (kg) (Tc)

ANNEXURE D: LETTER OF INFORMATION AND CONSENT FORM

Title of the Research Study: A waste management model for selected Sappi Saiccor laboratory facilities.

Principal Investigator/s/researcher: Oswell Matasva, Bachelor of Technology: Chemical Engineering.

Co-Investigator/s/supervisor/s: Professor K.G. Moodley.

Brief Introduction and Purpose of the Study: Due to vast laboratory and plant operations that take place at the Sappi Saiccor mill, a lot of waste is generated. Purpose of the study is to formulate a model that improves waste minimization, management, and remediation with the goal of minimizing risk to health and the environment. The model will be based on waste generated by the chemical laboratories of a chemicals manufacturing company. The types of waste generated, and their current disposal or treatment methods will be described and discussed. Possibilities for recycling of the waste or beneficiation will be considered.

Greeting: Hello, how are you. I hope I find you well. My name is Oswell Matasva. I am a master's student at Durban University of Technology's Quality management program. I am kindly requesting your participation in a master's research study that I am conducting titled: A waste management model for selected laboratory facilities at Sappi Saiccor mill aimed at reducing risk to health and environment. The intention is to formulate a model that improves waste minimization, management, and remediation at the Sappi Centre of excellence (COE) laboratories with the goal of minimizing risk to health and the environment.

Introduce yourself to the participant: I am a master's student at DUT doing research for my Master of Philosophy degree in quality management.

Invitation to the potential participant: I would like to invite you to participate in a master's research study that I am conducting titled: A waste management model for selected laboratory facilities at Sappi Saiccor mill aimed at reducing risk to health and environment.

What is Research: Research is a systematic search or enquiry for generalized new knowledge.

Outline of the Procedures: I am kindly requesting your participation in a master's research study that I am conducting titled: A waste management model for selected laboratory facilities at Sappi Saiccor mill aimed at reducing risk to health and environment. The intention is to formulate a model that improves waste minimization, management, and remediation at the Sappi Centre of excellence (COE) laboratories with the goal of minimizing risk to health and the environment. The study involves completing pre-risk assessment questionnaire to assess current waste management status at COE laboratories. A post-risk assessment questionnaire following the implementation of the waste management model will be conducted with the aim of verifying the effectiveness of the new model. Participation is completely voluntary, and you may withdraw from the study at any time. The study is completely anonymous; therefore, it does not require you to provide your name or any other identifying information. The pre risk assessments are scheduled to take place on the 23rd and 24th of September 2021 from 08H00 to 15H00. Post risk assessments dates are not yet known since they are dependent on the creation of the new waste management model; however, you will be posted as soon as the date is confirmed. If you would like to participate in the study, please read the Informed Consent letter below. To accept you need to sign the consent letter below. Your participation in the research will be of great importance to assist with identifying waste management gaps that currently exists at Sappi COE laboratories and how we can mitigate them.

Risks or Discomforts to the Participant: Being in this type of study involves some risk of the minor discomforts that can be encountered in daily life, such as fatigue, stress, and concerns the type of relationships with your service provider. Being in this study would not pose risk to your safety or wellbeing.

Explain to the participant the reasons he/she may be withdraw from the Study: The research may be terminated early in particular circumstances such as Non-compliance, illness, adverse reactions. Participation is completely voluntary, and you may withdraw from the study at any time. The study is completely anonymous; therefore, it does not require you to provide your name or any other identifying information.

Benefits: The benefits of the study include voicing your thoughts and concerns regarding the current waste management model and how we can improve it. It also promotes awareness of laboratory risks or dangers associated with waste generation and disposal.

Remuneration: This study is completely voluntary; there will be no reimbursement or payment for time.

Costs of the Study: (Participants be not be expected to cover any costs towards the study, including treatment.

Confidentiality: Any information you provide will be kept anonymous. The researcher will not use your personal information for any purposes outside of this research project. Also, the researcher will not include your name or anything else that could identify you in the study reports. Data will be kept secure by password protection and data encryption. Data will be kept for a period of at least 5 years, as required by the university.

Results: Results of the study will be shared with all participants and opportunity will be given to participants to ask all relevant questions and how the results will benefit them.

Research-related Injury: There will be compensation should there be a research related injury or adverse reaction, however the likelihood of this happening is minimal as are mitigation measures have been put in place to prevent such from happening.

Storage of all electronic and hard copies including tape recordings Data will be kept secure by password protection and data encryption. Data will be kept for a period of at least 5 years, as required by the university. Hard copies will be destroyed/shredded and electronic copies will be permanently destroyed after 5 years.

Persons to contact in the Event of Any Problems or Queries: Please contact the researcher on 0662492266, my supervisor Prof K.G. Moodley on 0724788242, or the Institutional Research Ethics Administrator on 031 373 2375. Complaints can be reported to the Director: Research and Postgraduate Support Dr L Linganiso on 031 373 2577 or researchdirector@dut.ac.za.

CONSENT

Full Title of the Study: A waste management model for selected Sappi Saiccor laboratory facilities

Names of Researcher/s: Mr Oswell Matasva

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, **Oswell Matasva**, about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: **IRE 033/22**.
- I have also received, read, and understood the above written information (Participant Letter of Information) regarding the study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerized system by the researcher.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.

  I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.
- I understand that significant new findings developed during the course of this research which may relate to my participation will be made available to me.

______________________	__/__/____	__:__	________________________
Full Name of Participant	**Date**	**Time**	**Signature/ Right Thumbprint**

I, Oswell Matasva herewith confirm that the above participant has been fully informed about the nature, conduct and risks of the above study.

O.Matasva

Oswell Matasva	__/__/____	__________________
Full Name of Researcher	**Date**	**Signature**

____________________________	__/__/____	__________________
Full Name of Witness (If applicable)	**Date**	**Signature**

____________________________	__/__/____ __________________	
Full Name of Legal Guardian (If applicable)	**Date**	**Signature**

ANNEXURE E: GATEKEEPER'S LETTER

Sappi Specialised Cellulose

Saiccor Mill

PO Box 62
4170 Umkomaas
SOUTH AFRICA
Tel +27 (0)39 973 8911
Fax +27 (0)86 686 2634

www.sappi.com

Tracy Wessels
GM Group Sustainability
Tel +27 (0)39 973 8420
Tracy.Wessels@sappi.com

Durban University of Technology
Faculty of Management Sciences
Department of Operations and Quality Management
ML Sultan Campus
1st Floor, MB1-17

11 April 2022

Dear Sir/Madam

RE: Permission to conduct study.

Please note that **Mr. Oswell Matasva**, DUT graduate student (Student number: 22173805) has the permission of Sappi Southern Africa to conduct research at our COE Technology Centre Laboratory facility for his study entitled, "***A waste management model for selected Sappi Saiccor laboratory facilities***".

On behalf of Sappi Southern Africa, I am writing to formally indicate our awareness of the research and that **Mr. Matasva** will be administering a survey to the employees. **Mr. Matasva** on site research will be concluded by 30 August 2022.

If you have any questions and concerns, please feel free to contact my office at the following numbers and email address.

Phone number: (039) 973 8420
Cell number : 083 666 6589
Email address : Tracy.Wessels@sappi.com

Sincerely

Signature……………………………………

Dr. Tracy Wessels

General Manager Group Sustainability and Research & Development
Sappi Southern Africa Pty LTD

ANNEXURE F: TURNITIN REPORT

Signed: ____________________

Date: 28 July 2022

A waste management model for Sappi Saiccor laboratory facilities

ORIGINALITY REPORT

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ANNEXURE G: EDITOR'S LETTER

Helen Richter
Advanced Editing, Proofreading
& Copywriting
feetjieding@gmail.com
+27 729538169

12 July 2022

To whom it may concern

CERTIFICATE OF EDITING & AUTHENTICATION

I have proofread and language edited the Master of Philosophy dissertation titled:

"A waste management model for selected Sappi Saiccor laboratory facilities"

by

Oswell Matasva

To the best of my knowledge, the work remains free of spelling, grammar, structural and stylistic errors and the contents are certified as the author's own work.

With thanks.

H. S. Richter

ANNEXURE H: IREC ETHICS CLEARENCE CERTIFICATE

DUT
DURBAN UNIVERSITY OF TECHNOLOGY

INSTITUTIONAL RESEARCH ETHICS COMMITTEE

Institutional Research Ethics Committee
Research and Postgraduate Support Directorate
2nd Floor, Berwyn Court
Gate 1, Steve Biko Campus
Durban University of Technology

P O Box 1334, Durban, South Africa, 4001

Tel: 031 373 2375
Email: lavishad@dut.ac.za
http://www.dut.ac.za/research/institutional_research_ethics

www.dut.ac.za

11 April 2022

Mr O Matasva
11 Persad Road
Isipingo Rail
Durban

Dear Mr Matasva

A waste management model for selected Sappi Saiccor laboratory facilities
Ethical Clearance number **IREC 033/22**

The Institutional Research Ethics Committee acknowledges receipt of your notification regarding the piloting of your data collection tool.

Kindly ensure that participants used for the pilot study are not part of the main study.

In addition, the IREC acknowledges receipt of your gatekeeper permission letter.

Please note that FULL APPROVAL is granted to your research proposal. You may proceed with data collection.

Any adverse events [serious or minor] which occur in connection with this study and/or which may alter its ethical consideration must be reported to the IREC according to the IREC SOP's.

Please note that any deviations from the approved proposal require the approval of the IREC as outlined in the IREC SOP's.

Yours Sincerely

Prof J K Adam
Chairperson: IREC

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ANNEXURE I: PROOF OF REGISTRATION 2022

DURBAN UNIVERSITY OF TECHNOLOGY

PROOF OF REGISTRATION
To Whom It May Concern

03-Aug-2022

It is hereby confirmed that the under mentioned person is a registered student at DURBAN UNIVERSITY OF TECHNOLOGY.

Surname:	MATASVA	**First Names:**	OSWELL
Student Number:	22173805	**Qualification:**	MPQMN1 MASTER OF PHILOSOPHY IN QUALITY MAN
Registration Year:	2022	**Offering Type:**	Durban Campus Part-time
Block:	POST-GRAD ANNUAL REGISTRATIONS	**Period of Study:**	Study period 2
Department:	OPERATIONS & QUALITY MANAGEMNT	**Faculty:**	FACULTY OF MANAGEMENT SCIENCES

Subject	Description	PreReq/Exp	Block	Class Group	Offering Type	Exam Year	Exam Month	Cancel	Amount
	Registration Fees/Levies P0 POST-GRAD ANNUAL REGISTRATIONS								2835.00
RSQL511	RESEARCH (1ST REGISTRATION)		P0	A	D3	2022	11	N	0.00
RSQL521	RESEARCH (2ND REGISTRATION)		P0	A	D3	2022	11	N	0.00
								Subtotal:	2835.00
								Total:	2835.00

* Subjects with Requisites will be cancelled if the requisite rules are not met in mid-year exams. Refer to Department handbook.

Outstanding Balance: 665.00

Please verify and rectify the above registration details with the Faculty Office to avoid academic and financial penalties before the dates published in the General handbook.

Faculty Officer

ANNEXURE J: SUBMISSION OF DISSERTATION FOR EXAMINATION FORM

PG 7

DURBAN UNIVERSITY OF TECHNOLOGY

Submission of Dissertation/Thesis for Examination

Faculty	Faculty of management sciences			
Department	Department of operations and quality			
Qualification for which registered				
Offering type	**Full time registration**		**Part time registration**	√
Prior qualification		B Tech Chemical Engineering		

Student Surname	Matasva		**Student No.**	22173805
First Names	Oswell		**Title (Mr, Ms)**	Mr
Postal Address	NUMBER 11 PERSADY ROAD, ISIPINGO RAIL, DURBAN, 4110			
Tel (W)	**Tel (H)**	**Cell**	**Fax**	**e-Mail**
	0389738438	0662492266		omatsva@gmail.com
Title of Dissertation/ Thesis	A waste management model for selected Sappi Saiccor laboratory facilities			**Full** / **Partial** √ / **Dissertation/Thesis**

Supervisor	Professor K.G. Moodley			
Position	**Honorary Research Professor/Researcher in Residence**		**Present Qualifications**	**PHD Chemistry**
Tel (W)	**Tel (H)**	**Cell**	**Fax**	**e-Mail**
Co-Supervisor	N/A			
Position	**N/A**		**Present Qualifications**	
Tel (W)	**Tel (H)**	**Cell**	**Fax**	**e-Mail**
I hereby grant the abovementioned student permission to submit his/her dissertation/thesis for examination.				

Signed: ______________________ **Date:** 28 July 2022 ______________ | **YES** √ | **NO** |
(Supervisor)

Signed: ______________________ **Date:** ______________________ | **YES** | **NO** |
(Co-Supervisor)

Signed: ______________________ **Date:** 3/08/22 ______________________
(HoD)

Routing	**Student**		**Supervisor**		**HoD**		**Faculty Officer**	