Life Cycle Assessment (LCA) of hazardous waste generated by Crime Scene Laboratories (CSL) in Mpumalanga, South Africa.

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Declaration

I, Vuyo Maqutu do hereby declare that the work submitted as research report, apart from the contribution mentioned under acknowledgements is my own work. I fully acknowledge the rules of the University this regard and will abide by the consequences of being in breach of the rules and regulations with regards to plagiarism.

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Signature of Candidate

19th **day of** September **20**17 **in** Wits (Gauteng)

Abstract
Mismanagement of hazardous waste has been witnessed in many part of the world including South Africa, and it has costed the environment too much pollution. This study aimed to analyse Life Cycle Assessment (LCA) methodology of Crime Scene Laboratory waste. To this aim, aspects analysed included assessment of potential environmental impacts evaluated with each stage of waste management, such as waste generation stage, processing, collection, transportation and disposal. Results showed that crime scene laboratories were only addressing the cost associated with collection and transportation of their waste for disposal, and no assessment of environmental impacts by means of LCA was practiced. This study also investigated how hazardous waste generation is managed. Data was collected from six laboratories (Witbank, Secunda, Ermelo, Nelspruit, Acornhoek and Lydenburg) for the period of eight months. Aspects analysed included suitability of temporary waste storage which should be able to prevent release of waste, use of waste registers which are used to determine how much time is taken for waste to be disposed, regular inspection of waste bins for monitoring of leakages and overfilling, and the competency of people managing waste. Findings showed that CSL's have poor waste storage facilities and waste is temporary stored inside the laboratories and building passages when the space inside the laboratories is a challenge due to delayed waste collection by contracted service provider. Results also showed that no waste minimisation strategies were established to reuse generated waste for secondary products to reduce quantity aimed for disposal. Furthermore, production of waste per site, nature of waste, months, and waste type was compared, and Statsoft statistics analysis technique for this purpose was used to analyse these differences which summarized variation across the sites. The level of variation was estimated at significant level of 0.05.Results showed that Ermelo produced significantly more non-anatomic biological waste, Witbank produced significantly more heavy metals and Lydenburg more Inorganic and organic acids and bases different to other locations. Non-anatomic biological waste was significantly produced more in January, May, June and August different to other months. Statistics results on the nature of waste showed that chemical, biological and miscellaneous waste was significantly produced more in February and May different to other months. Non –chlorinated waste was significantly produced more in January. Statistics results on waste types showed that all types of waste were significantly produced more in

February different to other months, also in March all waste types were significantly produced, except non-anatomic biological waste, which was significantly produced more in April, July and August.

The study makes recommendations on adoption of LCA, waste separation methods, storage and minimisation methods and training of waste handlers as an important aspect of environmental protection. The study also recommends an adoption of the Environmental Management system, ISO 14000 by the CSL's. The standard according to the literature encourages and gives guidance in achieving cleaner productions including waste separations and minimisations in order to avoid pollution of natural resources by mismanagement wastes.

Dedication

I dedicate this work to my wife (Virginia Radebe) for her support and understanding when I had to be away for academic commitments. I also dedicate this work to my friends (Tseliso Mahoa, Irene) for their words of encouragements throughout this study.

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Table of contents

List of figures

List of tables

Definitions

Hazardous Chemical Substances	Any toxic, harmful, corrosive, irritant or asphyxiant substance, or a mixture of such substances for which an occupational exposure limit is prescribed or an occupational exposure limit is not prescribed, but which creates a hazard to health (Yilmaz, Kara & Yetis, 2016).
Material Safety Data Sheet (MSDS)	Is an important component of product stewardship and occupational safety and health. It is intended to provide works and emergency personnel with procedures for handling or working with that substance in a safe manner, and includes information such as physical data (melting point, boiling point, flash point, etc.), toxicity, health effects, first aid, reactivity, storage, disposal, protective equipment, and spill-handling procedures. MSDS formats can vary from source to source within a country depending on national requirements (Singh, Oats, Plant & Voulvoulis, 2015)
Waste	Any material, substance, or by-product eliminated or discarded as no longer useful or required after the completion of a process (Godfrey, 2007)
Hazardous Waste	Waste that has the potential, even in low concentrations, to have a significant adverse effect on public health and the environment because of its inherent toxicological, chemical and physical characteristics (Yilmaz, Kara & Yetis, 2016).

Waste prevention	The prevention and avoidance of the production of a waste could be by regulation (Corvellec, 2016; Ewijk & Stegeman, 201).
Waste minimisation	Reduction of the volume of waste during production by means of different processes or clean technology (Ewijk & Stegeman, 2016)
Treatment	The treatment of waste to reduce volume or hazardousness (Godfrey, 2007).
Disposal	The safe disposal of waste so that it will not pollute the environment or cause health hazards (Gouin, 2010).
Non Chlorinated waste	Waste made of Chloroform, dichloromethane,benzidene acetonitrile.
Non Anatomic Biological Waste	Waste made Ethanol, Methanol, Acetone, Hexane, Isopropanol, Ethyl Acetate, Paraffin (Hossain, Santha & Norulani, 2011; Blenkharn, 2006)
Anatomic Biological Waste	Any object contaminated with biological substance such as bone and body fluids (Hossain, Santha & Norulani, 2011; Blenkharn, 2006)
Biological substance	Human tissue, bone, bone, food, blood, contaminated glass, anybody fluid (Hossain, Santha & Norulani, 2011; Blenkharn, 2006)
Heavy metals	Mercury waste, Lead, cadnium
Sharps	A category of infectious waste which includes objects such as needles,

	scalpels, knives, blades, and broken glasses that can cause cuts, and other injuries (Hossain, Santha & Norulani, 2011; Blenkharn, 2006)
Infectious waste	Waste which may cause human diseases, and which may be suspected of harbouring human pathogenic organism and can substantially pose potential hazard to human health and damage to the environment when improperly treated, stored, transported and disposed (Hossain, Santha & Norulani, 2011; Blenkharn, 2006)
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Segregation	The systematic separation of waste into designated categories (Phuong Nguyeni, Zhu & Phang Le, 2015).
Miscellaneous	Any hazardous objects, liquid or material that is contaminated with hazardous substances (Ojeda-Benitez, de Vega, Ramı´rez-Barreto, 2003).
Storage	The placement of waste in suitable location or facility where isolation, environmental and health protection, and human control (e.g. monitoring for radioactivity, limitation of access) are provided. This is done with the intention that the waste will be subsequently retrieved for treatment and conditioning and/or disposal (Wager, Bilitewski, 2009).
Container	A bag or puncture resistant and leak container in which health-care waste is placed. Containers may be

	reusable or disposable (Wager, Bilitewski, 2009).
Site	An area where waste is generated separated, stored, for the purpose of this study it refers to crime scene laboratories (CSL).

CHAPTER 1: INTRODUCTION

Improper waste management is the biggest cause of environmental pollution, and such mismanagement is witnessed by several countries including South Africa. Due to population growth, waste production has also been discovered to increase with population rate (Ho *et al*., 2016). Unsound waste management, especially hazardous waste has been practiced by developing countries where poor landfilling has been witnessed (Ho *et al*., 2016). Sources of waste should develop effective treatment and disposal methods to minimise negative impacts to receiving environments (Gu *et al*., 2014). Nature becomes vulnerable to great amounts of waste due to production of hazardous products by industries and humans (Gu *et al*., 2014). When such type of waste is mishandled, unpredicted negative impacts may result from points where such waste is produced, collected, during transportation, and at the disposal stage, with potential impacts on public health and nature in general (Gu *et al*., 2014).

Sustainable waste management is identified as the key synergy concept of economically affordable, socially acceptable and environmentally friendly way for waste management (Ho *et al*., 2016; Silva, Rosano, Stocker & Gorissen, 2016 & Oyedele *et al*., 2016). Recovery of resources from waste which decreases the depletion of non-renewable resource is identified as the key strategy for sustainable waste management (Ho *et al*., 2016; Silva, Rosano, Stocker & Gorissen, 2016 & Oyedele *et al*., 2016). Sustainable waste management may also contribute to reduction in GHG (Green House Gases) emissions and dependency to landfilling. Waste management policies are increasingly moving on from the reduction of waste to more sustainable materials policies which are focusing on recognising waste as a resource than a by-product for disposal (Silva, Rosano, Stocker & Gorissen, 2016). This has brought light to policy directions, governance frameworks and conditions propelling waste management towards resource and materials systems thinking encompassed in waste sustainability (Silva, Rosano, Stocker & Gorissen, 2016).

Hazardous waste can be described as any product that has corrosive, toxic, ignitable, reactive, and/or flammable properties (Inglezakis & Moustakas, 2014; Gu *et al*., 2014). Such waste may be potentially harmful to the environment, and can also increase hazardous properties of municipal solid waste when improperly handled. Hence understanding hazardous waste disposal is important for environmental protection and prevention of degradation (Inglezakis & Moustakas, 2014; Gu *et al*., 2014).

Hazardous waste constitutes a small fraction of municipal waste, however the knowledge of and risk associated with mismanagement must be transparent to citizens and handlers (Inglezakis & Moustakas, 2014). Hazardous waste must be treated with care and efficiency to avoid degradation of nature by accidental release of hazardous material to the environment (Inglezakis & Moustakas, 2014). Producers of waste should be aware of the consequences of unsound management of waste which places environment and health of humans to risk, and make effort to improve their methods of treatment and disposal (Gu *et al*., 2014). Nature becomes vulnerable to great amounts of waste due to the production of hazardous products by industries such as hospitals, laboratories, construction, manufacturing, agriculture etc. (Gu *et al*., 2014). Hazardous waste accidents and spillages from those industries have the potential to seep into and contaminate groundwater and sewer systems, affecting the whole management system, and possibly resulting in explosions in water pipes (Gu *et al*., 2014).

Mismanagement of such waste at generation and collection points or during transportation (such as ignitable chemicals) may also lead to serious incidents, including fire outbreaks or spillages, which can destroy equipment and is dangerous to employees handling it (Gu, *et al*., 2014). Environmental sustainability can be achieved when hazardous waste is reduced from generation points through proper strategies and/or diverting waste from disposal to recycling (Nahman & Godfrey, 2009).

In the past there has been stable growth in the global economy, including in economies of individual countries and increase in technology. Yet, the global environment has also experienced contamination of the earth's ecosystems (Marshall & Farahbakhsh, 2013; Hu, Hipel & Fang, 2009). Among other concerns of degradation, the international mismanagement of hazardous waste has become a major problem to environmental health, and it has created concerns over environmental protection all over the world (Hu, Hipel & Fang, 2009). Technology development has also resulted in new industries producing a variety of products from different sources, hence significantly increasing production of different waste products (Hu, Hipel & Fang, 2009).

The cost of hazardous waste disposal in many countries including South Africa had to increase to enforce waste management compliance, such as proper dumping or disposal of dangerous waste products (Hu, Hipel & Fang, 2009). Due to profit maximisation, industries sought ways to reduce disposal costs of toxic waste by exporting their waste to under-developed countries, and similarly weakly governed areas gradually became targets for toxic waste dumping (Hu, Hipel & Fang, 2009). Many countries stood up to protect their habitats due these practices by developing countries, and it was then when United Nations came up with programs such as UNEP to combat against such practices (Hu, Hipel & Fang, 2009).

Many parts of the world publicised environmentally friendly strategies to make public and industries aware of environmental degradations posed by waste mismanagement (Hu, Hipel & Fang, 2009). Making communities appreciate healthy and uncontaminated environments promotes environmentally sound and better ways of managing hazardous material including waste (Hu, Hipel & Fang, 2009). Laws and regulations are set for legal purposes and prohibition of transportation of hazardous waste, and to provide practical means of managing trans- boundary movement between countries in order to protect areas which can be victims of such movements (Hu, Hipel & Fang, 2009).

Safe and secure management of hazardous waste from producing industries such as laboratories can be better managed where adoption of waste management practices become organisation's part of managing processes and workflows (Manga *et al.*, 2011). Therefore waste management practices must be part of employees' routine training, awareness, education, and evaluation processes to assess compliance. Most countries in the world are characterised by a variety of health care facilities, and other similar industries producing hazardous waste, both private and government sectors which need documented waste management approaches for continual improvement (Manga *et al.*, 2011).

Crime Scene laboratories (CSL) also known as Forensic Science Laboratories (FSL), use the application of scientific methods in the investigation of crime (Alves-Girelli, 2016), and specifically the exhibit material (any material collected from the crime scene for finger print identification). CSL receives collected exhibits from the crime scene attendants known as investigators and process them for fingerprint identification to build evidence (Raymond, Van Oorschot, Walsh & Roux, 2008). A variety of material including organic and inorganic matter is analysed (Virkler & Lednev, 2009). Collection of exhibits includes plastics, synthetic fibres, clothes, fuels (Virkler & Lednev, 2009). Inorganic matter includes soils, gold, metals, prime residues etc. Scientific methods of analysis include use of chemicals, DNA analysis, chemistry and ballistics (Virkler & Lednev, 2009; Mapes, Kloosterman, de Poot, & van Marion, 2016). During analysis of these materials, CSL laboratories generate a variety of hazardous waste. A range of waste categories of approximately 0.165-0.95 kg/L is generated by each laboratory per month comprising of non-chlorinated waste produced from chemicals such as DFO, Ninhydrin, Basic yellow, Rhodomine 6G, Cyanobloom, and Polycyano, non-anatomic biological waste (Alves-Girelli, 2016), anatomic biological waste produced from used Personal Protective Equipment (PPE) contaminated with human body parts including blood and bones, heavy metals such as mercury and lead, and miscellaneous waste, including any hazardous objects, liquid or material that is contaminated with hazardous substances (Montpetit, Fitch & O'Donnell, 2005).

According to Papu-Zamxaka, Harphan and Mathee (2010) since 1994, South Africa has embarked on international agreements to prohibit movement of hazardous waste and maintain clean and uncontaminated environments through the development of waste regulations, such as the National Environmental Management Waste Act (No. 59 of 2008). The Act was introduced to provide a legislation framework which give guidance on how to properly manage waste including its sound disposal to avoid destruction or pollution of natural resources (Papu-Zamxaka, Harphan & Mathee, 2010). The Act particularly governs the local movement or management of waste. Section 16(1) of this Act states that waste which may result in environmental pollution should be avoided, reduced, reused, recycled, and where these options are not practical, waste must be disposed of in an environmentally responsible and friendly manner (Papu-Zamxaka, Harphan & Mathee, 2010). According to this Act (Papu-Zamxaka, Harphan & Mathee, 2010), waste generators must take reasonable measures to ensure that their waste does not result in environment destruction or ill-health by means of exposure. The Act also places responsibility on waste generators to ensure that risk assessment of their waste is conducted and mitigation measure in place in order to effectively protect the environment from pollution (Papu-Zamxaka, Harphan & Mathee, 2010).

1. 1.2 Aims and Objectives of the study

Crime Scene Laboratories generate a variety of hazardous waste ranging from chemical to biological waste, additionally there is a service provider contracted for waste collection and disposal. The intention of the study was to analyse methods used by Forensic Science Laboratories to manage their generated hazardous waste to achieve environmental sustainability.

In order to achieve this aim, the following objectives were set:

- to determine if there are differences in volumes on waste types being produced by CSL laboratories and how much time is being taken to get the waste collected and disposed of;
- to analyse waste management methods used by these laboratories;
- to assess monitoring knowledge or manpower at the production level as a guide to oversee the service provider contracted during collection and disposal of such waste;
- to learn from Life cycle Assessment (LCA) about sound waste management systems that promote environmental sustainability.

1.1.3 Problem statement

Improper management of hazardous waste generated by industries has become a major social and environmental concern globally due to practices which led to substantial negative environmental impacts such as pollution of air, soil and water, and health and safety problems associated with different forms of pollution (Yay, 2015). Common practices of unsound waste management practices include irregular collection and disposal of waste, poor segregation, inadequate resources to management generated waste, poor storages, and lack of knowledge of best practices by those management waste. The current situation of the crime scene laboratories is that, waste management is practiced at a minimum level of best practices. Such practices might not be adequate to achieve effective waste management which contributes to the protection of natural resources. At these laboratories, it is estimated that 2.74 tons of hazardous waste is generated monthly. The intention of the study seeks to establish the cause of substandard waste management practices by answering the following questions:

- what type of is being produced
- what separation methods are in place
- what type of storage facilities
- disposal methods and the time taken for generated waste to be disposed
- what level of knowledge is available regarding best waste management practices for those involved in managing waste
- what resources are available to properly management generated waste
- tools that are in place in decision making to identify best management practices

CHAPTER 2: LITERATURE REVIEW

2.1 Hazardous waste management

Industrialisation has resulted in the generation of high quantities of complex hazardous industrial wastes (Ho *et al*., 2016). Waste produced by these industrial activities and manufacturing processes poses a threat to the receiving environment as natural resources are degraded (Ho *et al*., 2016). Improper waste management has contributed to negative impacts to the environment, such as pollution of air, soil, and groundwater; in addition it reduces valuable land space due to creation of space for disposal (landfilling) or dumping (Ho *et al*., 2016). Landfilling has its own major consequences of generating methane (CH4) gas from the decomposition of solid waste (Ho *et al*., 2016), which contributes to global greenhouse gasses (GHG). Another consequence of landfills is that it forces government and municipalities to identify better solutions for waste management which has financial implications (Ho *et al*., 2016), when landfills become full due to too much waste being disposed (Ho *et al*., 2016).

Apart from disposal, waste can produce secondary useful products through recycling, energy recovery, and biological recovery actions as suggested in the hierarchy of waste management (Silva, Rosano, Stocker & Gorissen, 2016). Reprocessing of waste material to secondary raw materials leads to conservation of resources and reduced costs (Wittmaier, Langer & Sawilla, 2009). Energy recovery from generated waste has a potential to reduce greenhouse gas emissions (Wittmaier, Langer & Sawilla, 2009). Waste management with recycling objectives may reduce the amount of waste aimed for disposal, while reducing the cost of managing such waste and landfilling (Wittmaier, Langer & Sawilla, 2009; Yilmaz, Anctil & Karanfil, 2014). Some of the techniques for reducing the release of hazardous substances to prevent environmental harm include material substitution, technology innovation, process improvements, and in-process recycling (Kluczek, 2014). Kluczek (2014) also mentions that laws, regulations, and government environmental standards are increasingly emphasising the need for improved waste processes which are environmentally and economically sustainable.

In order for waste producing companies to limit their waste productions, they need to change production processes or employ waste management strategies, such as avoiding or minimising waste production, recovering or recycling materials, and consider disposal of waste as a last and unfavourable step when all steps become impossible (a process known as waste management hierarchy), to lessen pollution caused by waste (Kluczek, 2014). The waste management hierarchy is the key to waste reduction, however reviewing realistic strategies through a life cycle assessment (LCA) can increase the chances of pollution prevention (Yilmaz, Anctil & Karanfil, 2014).

Proper waste separation at point of source is considered a fundamental condition in reversing environmental impacts of waste, and in establishing a less impactful waste management system (Nguyeni, Zhu & Le, 2015). However, for the strategy to work, it is important for waste producers and handlers to understand the nature of waste they are producing, in order to make informed decisions on which waste cannot mix, and the type of landfill to be disposed (Nguyeni, Zhu & Le, 2015). In addition waste separation may also involve recovery of products that can be reused before final disposal (Nguyeni, Zhu & Le, 2015).

Nowadays landfill waste management is the most common and cheapest method to eliminate municipal solid, industrial and clinical wastes, and is a common practice in many organisations in the world (Haque, 2016), yet it also raises many concerns because it is the potential source of greenhouse gas emissions, heavy metals and toxic waste intrusion into the food chain through the soil and groundwater body percolation causing water contamination (Haque, 2016). Release of toxic waste material from landfills poses a potential hazard to both surrounding ecosystems and nearby human populations (Haque, 2016; Samadder, Prabhakar, Khana, Kishan & Chauhanb, 2016). Post-closure management is another aspect most of the landfills lack, monitoring of developing impacts after the landfill site has stopped operating should be implemented to identify risks that might be associated with such landfills (Haque, 2016; Samadder, Prabhakar, Khana, Kishan & Chauhanb, 2016).

Proper separation of waste can be attributed by proper labelling waste based on waste incompatibilities (Inglezakis & Moustaka, 2014). Waste material can be collected separately, and handled effectively with care to prevent improperly separated materials from reaching a landfill (Inglezakis & Moustaka, 2014). When waste has been produced and separated according to its compatible characteristics, it must as well be temporary stored in sound waste temporary storage where incidents such as accidental releases, seepage to ground water, emissions cannot be experienced in order to protect the environment from pollution (Albulfaras, Samman & Kamal, 1994). Waste material which is not stored correctly can easily affect human health, and the environment at large (Albulfaras, Samman & Kamal, 1994). Therefore a process of temporary storage must be carried out completely under proven safety conditions, and strict monitoring to avoid unnecessary and accidental release of hazardous material (Abulfaras, 2013). Some of the specifications for waste storage facilities include proper ventilation, proper size, concrete floors, bund walls, proper roofing, trench, sump and waterproof base, and access control (Wagnes & Bilitewski, 2009).

The Waste Act of 59 of 2008 stipulates that hazardous waste must be treated and temporary stored in an approved waste storage by local municipalities for the period not exceeding 90. According to this Act, waste producers must take reasonable steps to ensure that during storage process, containers in which waste is temporary stored are intact, not corroded, not overfilled, and leak-free to prevent accidental releases (Misra & Pandey, 2004). The Act further stipulates that nuisance such as odours which can breed vectors such as flies and other insects, pollution of the environment and harm to health must be avoided at all times (Misra & Pandey, 2004).

Education and individual knowledge contribute significantly towards waste management practices, and how employees perceive the issue, as well as how they decide on their daily behaviour particularly in solid waste management (Moh, 2017). Moh (2017) also points out that, without corporation and commitment from ground people, including employees and other stakeholders, source separation and recycling practices become a significant challenge (Kumar, Somrongthong & Ahmed, 2016). Education and training by provision of relevant information, and encouragement of compliance is essential in seeking participation and interest (Moh, 2017; Guerrera, Maas & Hohland, 2013). An appropriate training in waste management practices, including regular awareness has a potential to increase positive attitude with positive impact towards long term behaviour change on how people perceive waste (Moh, 2017), and also increases understanding capacity on the concept of waste separations, storage and transportation (Moh, 2017; Kuchibanda & Mayo, 2015). According to Moh (2017), one of the most critical challenges in gaining support to proper waste management, either by employees or public as a habit, is the lack of knowledge which results in negative or careless attitude (Kuchibanda & Mayo, 2015), and such behaviours or attitudes result to environmental consequences, such as pollution by improper disposal (Kumar, Somrongthong & Ahmed, 2016; Guerrera, Maas & Hogland, 2013).

Other authors (Scudder, & Blem, 1991) indicate that the majority of employees responsible for waste managements are unable to identify hazardous products within their generation points, and are unaware of the potential environmental effects caused by improper disposal of these products. A variety of unsafe disposal practices are common either at industries or at pubic level, and these practices are attributed by lack of waste management knowledge (Scudder & Blem, 1991; Guerrera, Maas & Hogland, 2013). In order for waste management system to perform, people need to be aware of the product contents, disposal methods, and in addition the law, policies and regulations governing waste mismanagement. Waste management have focused more on unregulated generators, and ignored the role of knowledge which significantly shape how people perceive the impact of hazardous wastes (Scudder & Blem, 1991; Kuchibanda & Mayo, 2015). Scudder and Blem (1991) also note that, it is important for organisations to measure the level of competency of waste handlers in order to improve their management system, and that can assist in assigning roles and responsibilities. Moh (2017) also points out that, pockets of non-compliances are the results of lack of awareness, lack of knowledge, more than lack of enforcement, these findings are in line with those of Kuchibanda and Mayo (2015).

To effectively management waste, education and training should be considered a component of the management system. By building strong knowledge, people can engage in practices that protect them, general public and the environment, and their behaviour becomes sustainable thinking (Kumar, Somrongthong &Ahmed, 2016). Kumar, Somrongthong and Ahmed (2016) indicate that training on sustainability and impact are scarcely available than other trainings that are offered by organisations to their employees, and people managing waste are rarely trained, however training of workers in waste management have proven to be the most effective strategy for improving practices and behaviour than law enforcement, especially when it combined with other innovative approaches.

Waste management may also be affected by other aspects or enabling factors that facilitate the performance of the management system, example, sociocultural, technical, institution and legal (Guerrera, Maas & Hogland, 2013). Again, where organisations fail to prioritise budgets for waste management, it becomes a challenge for the system to perform effectively (Alagoz & Kocasoy, 2008). Alagoz and Kocasoy (2008) acknowledge that a significant progress has been made in managing wastes that are hazardous, however existing management practices still need a lot of modification and improvement, and some of the common challenges are, inadequate waste management, lack of awareness about the health hazard and environmental pollution, insufficient financials and human resources, as well as poor control of waste disposal, this is in agreement with the finding of other authors (Guerrera, Maas & Hogland, 2013; Moh, 2017; Kuchibanda & Mayo, 2015).

Finally, improper transportation and disposal of waste may cause serious problems, including contamination of air, surface water, ground water through seepage, fertile top soils by erosions, and biota through biological intakes and bioaccumulation processes (Misra & Pandey, 2004). In order to safeguard contamination of natural resources from waste mismanagement, it is important that waste is collected and transported in an environmentally sound manner by qualified service providers

(Misra & Pandey, 2004). Waste management system should ensure efficient collection, transportation, treatment and disposal without any environmental harm (Misra & Pandey, 2004).

2.2 Waste hierarchy

Sound waste management is regarded as an important element of avoiding environment damage as unsustainable use of raw materials are becoming a concern in nature destruction (Papargyropoulou, Lozano, Julia, Steinberger, Wright & Ujang, 2014; Van Ewijk & Stegemann, 2016). Waste management strategies, such as the waste hierarchy (reduce, re-use, recycle, recover; Figure 1) are regarded as best approaches in minimising the environmental burden caused by unsound waste practices, and can extend producer responsibilities, supported by the Polluter Pays Principle (Papargyropoulou *et al*., 2014; Rossi, Cleeve-Edwards, Lundquist, Schenker, Dubois, Humbert & Jolliet, 2015; Gharfalkar, Court, Campbell, Zulfiqur, & Hillier, 2015).

Papargyropoulou et al. (2014) note that there are occasions when the waste hierarchy is wrongly interpreted as the waste management hierarchy, however this technique was developed as a tool to assist in identifying the most appropriate ways of reducing quantities of waste aimed for disposal once waste is anticipated in production system (Papargyropoulou *et al*., 2014). The aim should be to identify the options that are most likely to result in best environmental performance with minimal waste disposal options, such as avoidance or recycle options, and disposal as the last resort (Papargyropoulou *et al*., 2014). There are five steps that must be followed on waste management hierarchy implementation; avoidance of waste generation, preparing for reuse, recycling, and recovery of secondary products (e.g. energy recovery) and disposal as a last step (Papargyropoulou *et al*., 2014).

Waste management systems without waste hierarchy are likely to lose recoverable products from the waste ready for disposal, and those products can contribute more on environmental degradation (Gharfalkar, Court, Campbell, Zulfiqur, & Hillier, 2015), and the waste hierarchy can give guide on how to address such issues. According to Gharfalkar, Court, Campbell, Zulfiqur and Hillier (2015) adequate waste hierarchy if well implemented can guarantee return of recovery of secondary products back into production system with financial benefit, and the absence of measure of recovery and reuse within the system results to waste hierarchy being ineffective as resource efficiency tool (Papargyropoulou *et al*., 2014). In order for waste producers to integrate this tool to their systems, Gharfalkar, Court, Campbell, Zulfiqur and Hillier (2015) note that there should be an understanding about the definition of waste avoidance, reduction and recovery of products, and also a clear understanding about measures that can be applied to achieve prevention, reduction and recovery of products (Gharfalkar, Court, Campbell, Zulfiqur, & Hillier, 2015). In an attempt to clarify this, other authors (Van Ewijk & Stegemann, 2016; Gharfalkar, Court, Campbell, Zulfiqur and Hillier, 2015) recommend an integration of waste hierarchy on the treatment of not only the end of life of waste but a hierarchy that is applied across all stages of waste management including after disposal. Waste hierarchy applied to all stages, according to Van Ewijk & Stegemann (2016) can develop useful measures which can be applied before or after products become waste.

When waste is classified according to its categories (e.g. biological, chemical, organic, anatomic, chlorinated etc.) resources contained in the waste can be recovered quickly and effectively (Van Ewijk & Stegemann, 2016). The importance of focusing on waste as a resource can contribute to the growth of economy as some of the cost of disposal can be high, and can be reduced through the conversion of waste to useful products (Moh & Manaf, 2016). When waste hierarchy is implemented thoroughly in the waste management system it contributes to the reduction in consumption of virgin natural resources and to the achievement of less environmental degradation with increased resource efficiency (Moh & Manaf, 2016; Van Ewijk & Stegemann, 2016).

With growing population being recognised, land availability is becoming scarce and construction of new landfills to meet waste disposal demand is becoming a challenge (Van Ewijk & Stegemann, 2016). Moh and Manaf (2016) anticipate the possibility of landfills built near households in the future if waste minimisation strategies are not fully applied to waste management systems, hence the aim of waste hierarchy is to ensure diversion of waste from landfill (and to utilise options that result on best overall environmental and health outcomes (e.g. less need for landfills).

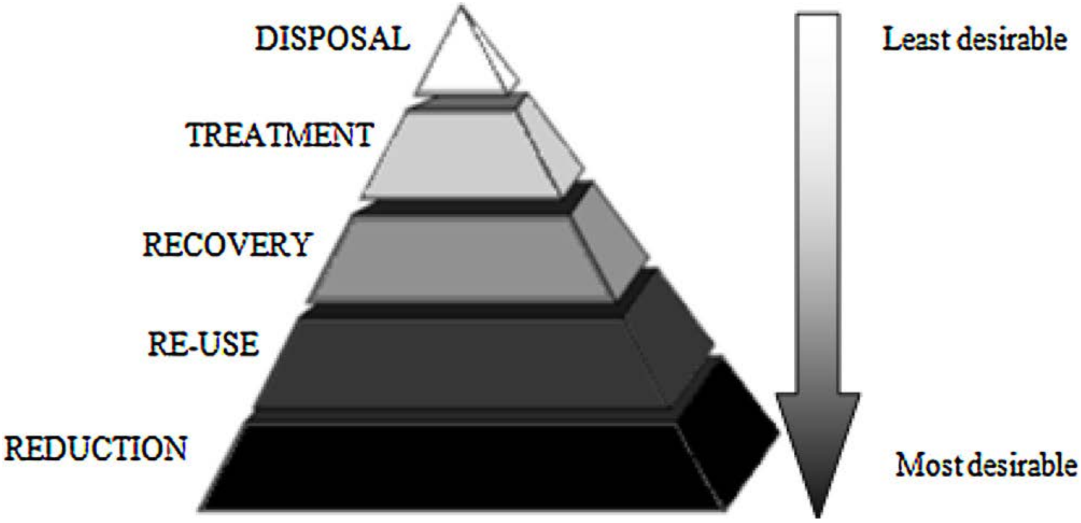

Figure 1: Waste hierarchy (taken from Moh & Manaf, 2016).

2.3 Life Cycle Assessment

Improper management of waste by many industries has contributed to the concern of environmental pollution such as pollution of air, soil and water, and health and safety problems associated with such practices (Yay, 2015). Turner, Williams and Kemp (2016) note that the waste management sector is under increasing pressure to improve its environmental performance related to their waste management practices in order to improve the quality of life and health environment, similarly other published papers (see Xiao, Zang & Yuan) emphasize the development of technologies that can result in recovering the materials from waste to environmental impacts.

Based on the increase in crime investigations (Tatolli, Tsokos, Sauter, Anagnostopoulos, Maselli, Ingravallo, Dellia & Solarino, 2014), Crime Scene Laboratories' waste generation has increased in recent years with an increase in the crime rate in South Africa (Tatolli *et a*l., 2014). CSLs produce approximately 2.895 tons of hazardous waste comprising of non-chlorinated waste, non-anatomic biological waste, anatomic biological waste, heavy methods and miscellaneous waste, including any hazardous objects, liquid or material that is contaminated with hazardous substances. The type of waste generated may lead to environmental problems due to unsustainable waste management practices, which in turn can have economic or social impact (Guereca, Torres & Juarez-Lopez, 2015). Waste generation trends require integral waste management systems with the aim of reducing environmental footprint and social acceptable treatments with disposal alternatives that ensure better environmental performance (Guereca, Torres & Juarez-Lopez, 2015).

Guereca, Torres and Juarez-Lopez (2015) note that technologically advanced strategies in sustainable waste management should help in reducing the amount of waste produced and improve management strategies without compromising the quality of receiving environments (e.g. greenhouse gas emissions from landfill sites), human and ecosystem health due to exposure to hazardous substances during waste collection and treatment and the emission of hazardous material to air, soil and water (Guereca, Torres & Juarez-Lopez, 2015; Fiorentino, Ripa, Protano, Hornsby & Ulgiati, 2015).

Life Cycle Assessments (LCA) are used as a tool in decision making to identify best waste management practices (Laurent *et al*., 2013). The LCA method can provide an overview of the environmental aspects and impacts of different stages adopted by each waste generator (Wittmaier, Langer & Sawilla, 2009; Cherubini, Bargigli & Ulgiati, 2008). This methodology can be used to identify possible environmental impacts resulting from each stage of treatment and to reveal environmental impacts that might be associated with each product, process or service by determining material use (Cherubini, Bargigli & Ulgiati, 2008). The method highlights the associated environmental benefits and sustainability of the process (Cherubini, Bargigli & Ulgiati, 2008). It is an internationally recognised waste management tool used to assess environmental and public health problems associated with each wste management practice (Cherubini, Bargigli & Ulgiati, 2008). LCA methods assess environmental damage and material consumption during the lifecycle of each product from generation until disposal (Wittmaier, Langer & Sawilla, 2009).

There are a number of methods available for assessing environmental problems for the purpose of sustainable development (Wittmaier, Langer & Sawilla, 2009), such as EIAs (Environmental Impact Assessments) and SFE (Supercritical Fluid Extraction), however LCA can serve as a suitable instrument for comparing waste management in relation to their environmental impact (Wittmaier, Langer & Sawilla, 2009).

LCA has been used in many waste management systems as measure of environmental impacts, with the aim of developing better alternatives of managing waste and the identification of areas needing improvements in terms of reducing impacts (Yay, 2015). For example, it has been used by many industries to compare environmental impacts of waste practices, such as temporary storages, collection, transportation for disposal, and landfilling ((Yay, 2015; Fiorentino, Ripa, Protano, Hornsby & Ulgiati, 2015), and development of the most environmentally friendly ways of managing waste, and less impactful waste management system (Yay, 2015; Lausselet, Cherubini, Del Alamo Serrano, 2016).

The method in many studies (Fiorentino, Ripa, Protano, Hornsby &Ulgiati, 2015; Thomsen *et al*., 2016) is regarded as a powerful tool in making decisions of how waste management system performs in relation to pollution outcomes.

Fiorentino, Ripa, Protano, Hornsby and Ulgiati (2015) define LCA as a method of analysing the aspects and impacts of a system or a product by developing and compiling its inventory of inputs (raw materials and consumed energy) and outputs (e.g. impacts such as pollution to air, water, soil).

The method has been used largely on waste management systems where impacts need to be determined before environment in endangered (Fiorentino, Ripa, Protano, Hornsby &Ulgiati, 2015; Thomsen *et al*., 2016), comparing different waste management and technology systems like landfilling, reuse, composting, prevention and disposals and revealed better alternatives to current waste management processes and recommendations that support environmental sustainability (Fiorentino, Ripa, Protano, Hornsby &Ulgiati, 2015; Thomsen et al., 2016).

2.4 Environmental management systems

An environmental management system (EMS) is a standard developed to assist organisations on how to protect the environment from their products, services or any activity that might pose danger to the environment (Arimuri, Darnell, & Ganguli, 2016). ISO 14001 is a specific voluntary environmental management standard which can be adopted by organisations to guide on how to reduce environmental impacts and achieve their environmental performance targets (Arimuli, Darnell, Ganguli, 2016; Ferraudo & Sal, 2016; Tanido, Mason, Arguiari & Scipioni, 2016).

Organisations certified on the standard have a better chance to reduce or improve on their environmental impacts by following the guidance and clauses of the standard (Arimuli, Darnell, & Ganguli, 2016). Although adoption of the standard is voluntary, many organisations have opted to adopt the standard to benefit the environment (Arimuli, Darnell & Ganguli, 2016). The adoption of the standard can be driven by many reasons and can differ per industry (Arimuli, Darnell & Ganguli, 2016). Other organisations are implementing the standard in order to easily access markets, therefore it is used as a marketing strategy, whereas others adopt and implement the standard purely to have guidelines to reduce environmental footprint from their activities (Mazzi *et al*., 2016). Arimuli, Darnell and Ganguli (2016) note that organisations which are certified on the standard are more likely to have improved environmental performance of their products and services, and they usually expect their suppliers to have similar improved environmental management system, therefore certified organisation can influence other organisations it trades with (Massoud, Fayad & Kamleh, 2010).

Singh, Bruecker and Padhy (2014) define waste minimisation as key indicator in which environmental performance of an organisation can be guaranteed as this standard encourages organisations to opt for cleaner productions. Certification on the standard also forces environmental friendly practices where allocations of resources to achieve or maintain certification are provided by top management of the organisation (Oleveira *et al*., 2016). Organisations with this certification are able to plan for better environmental results by plan-do-check-act approach which is included on the standard guidelines or clauses (Oliveira *et al*., 2016). The standard, according to Oliveira et al. (2016) has step-by step approach for successful implementation, such as establishing environmental objectives and processes aimed at achieving environmental targets. Mazzi et al. (2016) also note that organisations certified organisations commit to awareness and competency of their employees tasked to drive these objectives in order to retain their certification successfully, in addition they comply with legal requirements. There are challenges highlighted by some authors which can delay implementation of the standard (Massoud, Fayad, & Kamleh, 2010; Mazzi *et al*., 2016), and these challenges include the cost involved, size of the organisation, difficulties in incorporating the standard into organisation management system, employee skills in implementing the standard, continual changes of ISO standards, and organisations being unable to measure economic value of adopting the standard (Massoud, Fayad, & Kamleh, 2010; Mazzi *et al*., 2016).

2.5 LEGISLATION

South Africa has numerous acts, guidelines and policies administered by different spheres of government relating to environmental protection and to the management of hazardous waste. section 24 of the constitution of the republic of South Africa (1996) states that everyone has a right to live in an environment that is safe for his or her health and wellbeing, and to have such environment protected from pollution and degradation for the benefit of future generations through measures that:

I. prohibit environmental pollution
II. promote conservation of natural resources
III. Sustainable use of natural resources that can promote economic and social welfare.

National Environmental management (Biodiversity Act No 10 of 2004) deals with the conservation of biodiversity including plants, animals, soil, and water. Natural Environmental Management: protected areas (57 of 2004) was enacted with the purpose of conserving protected areas that at risk of extinction. National Environmental Management: Waste Act (59 of 2008) prohibits pollution of natural resources by mismanagement of hazardous waste in order to protect environment and the health of those living on it. The aim of the National Water Act (36 of 1998) is to promote conservation of water resources and their protection from any kind of pollution including waste. Water from this Act is regarded as a scarce resource which requires conservation and sustainable use in order to equally benefit all the citizens of the Republic of South Africa. Management and control of hazardous substances, including hazardous waste is regulated by Hazardous Substances Act (15 of 1973). The Act stipulates that any substances regarded as hazardous must be controlled to avoid injury, ill-health or death.

National Environmental Management Act 107 of 1998 (NEMA)

According this Act, any generated waste that may cause harm to the environment must be avoided, reduced, reused, recycled for generation of secondary products, and that way waste quantities aimed for disposal can be reduced to alleviate space reserved for landfilling. The Act further states that where quantities of waste cannot be reduced by recycling, must be disposed in a manner which has little or no harm to the environment and persons living on it. This Act links to section 24 of the Republic of South Africa which states that everyone has a constitutional right to live in an environment which has no harm to his/her health and wellbeing. According to the Act the spheres of government has duty to protect and fulfil social, economic and environmental rights of everyone in order to meet the basic needs of previously disadvantaged groups.

National Environmental Management: Air Quality Act 39 of 2004

Pollution through emissions and other means of atmospheric contamination is highly regulated by Air Quality Act in order to protect natural resources which survive through clean air processes. The Act states that organisation must have strict measures which reduce the impact to air quality which may results to ecological degradation. According to this Act organisations are required to monitor processes that may contribute to air pollution. Spheres of government have a duty to regulate air quality monitoring and management. In cases where provisions of this Act are not adhered, penalties and imprisonment may apply. Literature (Van der Linde & Feris, 2010) note that quality of ambient air in many areas of the world, including South Africa is not healthy due to industrial processes that negatively contribute to air quality. Van der Linde (2010) note that pollution through air quality usually affects the poor communities who are seldom polluters and with little knowledge about such pollutions. The Act is in agreement with NEMA 107 of 1998 and section 24 of the Republic of South Africa which states that everyone has a constitutional right to live in an environment which has no harm to his health and the wellbeing.

National Environmental Management: Waste Act 59 of 2008

Pollution of environment by mismanagement of waste including illegal dumping or disposal has been witnessed in many parts of South Africa. Proper management of waste is regulated by Waste Management Act (59 of 2008). The Act was enacted after many parts of the country (South Africa) were affected by waste pollution in order to secure natural resources from waste pollution which results from unsound waste management practices. According this Act, all waste producers are required to hold waste licences, and are responsible for any environmental pollution which may results from their products, services or activities, in addition where waste spillages are experienced, waste producers must be able to remediate to minimise the impact. This Act also states that everyone has a right to live in an environment which has no harm to his health and wellbeing, including future generations. According to this Act, in order to protect natural resources from waste pollution, where waste productions are anticipated, minimisation strategies such as reuse, recycle, and environmental friendly disposal must be planned ahead and be integrated to organisation management systems (Godfrey, 2007). When waste management strategies are implemented correctly, generated waste can positively contribute to the economy of the organisation where secondary products are recovered from waste ready for disposal (Godfrey, 2007). This Act applies to all hazardous waste, except radioactive waste (regulated by Hazardous Substances Act 15 of 1973, National Nuclear Regulations Act 47 of 1999, and Energy Act 46 of 1999) and disposal of animal carcasses which is regulated by Animal Health Act 7 of 2002. According to the Act, it is the duty of local municipalities to ensure that generated waste is safely stored, collected and transported for disposal in an environmental friendly through compliance of waste producers to municipal by-laws.

Hazardous Substances Act (HSA) 15 of 1973

The Act has a bearing on material or substances regarded as hazardous, and which may be included on wastes aimed for disposal. Such substances may pose threat to the environment and human health (Kotze, 2006). It gives guidelines for the control of hazardous substances which may impact negatively to the environment and cause ill-health or death to humans by their degree of toxicity, irritant or flammable nature (McLean, Watson & Muswena, 2007). The Act aims to categorise hazardous substances according to their level of risk when illegally disposed or exposed to the environment and health. The Act provides guidance on how to control hazardous substances which may cause:

i. ill-health to humans by their level of their toxicity, corrosiveness , irritant or flammable nature;
ii. death to humans by their level of toxicity, corrosiveness , irritant or flammable nature;

iii. damage to property including buildings by the level of their toxicity, corrosiveness , irritant or flammable nature;

iv. generation of poisonous gases which may result to death due to by their level of their toxicity, corrosiveness , irritant or flammable nature;

Another objective of this Act is to control illegal transportation, manufacture, use, sale and disposal of hazardous substances which may negatively impact the environment and human health (Kotze, 2006). The Act applies to all persons who manufacture, distribute, or sell hazardous substances such as hazardous chemicals with the aim of avoiding damage to receiving environment and human being. There are four groups or classes of hazardous substances mentioned under this Act: Group I and II include substances of a toxic, corrosive, irritant, and flammable nature. Group III includes hazardous electronic products and Group IV covers radioactive substances. Hazardous chemical waste may include more than one class of hazardous substances, therefore the Act applies to everyone who manufactures, distribute, use, sell, or dispose group III and IV hazardous substances such as waste. The Act also stipulates that if any substance after analysis, is regarded as hazardous substance, it must at all times be kept away from food facilities, and stored in lockable facilities to control access (Wiese, 1979). According to this Act, waste containing hazardous substances must be stored in leak-free and sealed containers at all times, and be inspected on regular basis in order to prevent escape of such waste to the environment (Wiese, 1979). The Act also stipulates that any person who uses or buys hazardous chemical substance is subject to have the copy of their Material Safety Data Sheet (MSDS). MSDS document describes how to safely handle hazardous substances such as chemicals including their storage and disposal, and also highlights consequences of mishandling of such substances to the environment and human health (Singh, Oats, Plant & Voulvoulis, 2015). According to the Act, any person who contravenes any provision of this Act is guilty of offence and is liable for a fine or imprisonment for up to a period of 10 years or to both fine and imprisonment. The Act prescribes preventive measures to be implemented by manufactures, users and distributers of hazardous substances to ensure the protection of environment and ill-health to humans:

i. list all hazardous substances used, categorise them and ensure applicable valid licences or registrations are in place;

ii. conduct adequate risk assessments to identify level of risks and consequences that are associated with hazardous substances in use in order to develop preventive measures;
iii. ensure MSDS's are in place and understood by users.

National Water Act of 1998

Water in South Africa is regarded as a scarce resource that needs to be used equally across all the citizens of South Africa. The Act was enacted to ensure prohibition of water pollution by industrial processes. Section 2 of this Act states that national water resources must be protected and conserved in order to meet basic water needs of ordinary South Africans, including future generations. The Act also provides for pollution prevention of water resources which can affect aquatic life, their ecological diversity, safety of dams and other ecosystem services. The Act states that everyone who occupies land has a duty to ensure that water pollution is prevented at all times. It further states that, where water pollution incidents are experienced, remedial actions must be implemented to reduce the impact. Section 19 of this Act encourages all land users to take reasonable steps to:

I. stop or modify processes which may result in water pollution;
II. implement remedial actions where water pollution incidents are encountered;
III. have plans to prevent movement of pollutants from their services that may endanger water resources;

Section 20 (3) of this Act states that it is everyone's right who sees or in knowledge of any water pollution activity:

I. to report it to the Department of Water Affairs and Forestry;
II. to report it to the South African Police Service;
III. to report it to the relevant catchment management agency;
IV. to try and remedy to minimise the impact.

Section 24 of the Republic of South Africa states that everyone has a constitutional right to live in an environment that has no harm to his health and wellbeing, the objective of this Act also provides for the health of water consumers by reasonable legislation. The Act also provides insight to organisations to be aware of the consequences of pollution of water resources, and to enforce compliance to protect water resources and the environment for the benefit of both present and future generations.

2.6 Waste Management Principles

The Polluter Pays Principle enforces compliance and compensational costs to environmental pollution (Zhu & Zhao, 2015). According to this principle all waste generators are legally and financial responsible for sound waste management of their waste including treatment, and disposal (Zhu & Zhao, 2015). The approach of the principle is based on the fact that any person who is responsible for contamination of any land must be held liable for the remediation of such land (Zhu & Zhao, 2015; Luppi, Paris & Rajagopalan, 2012).

The Precautionary Principle aims at anticipating and minimising potential irreversible environmental risks under conditions of uncertainty (Wager, Eugster, Hilty & Som, 2005; Sheng, Ricci & Fang, 2015). According to this principle, organisations must be cautious and assume that waste is hazardous until proven safe, and where the hazardous rating is unknown, it is important to take all precautionary measures (Wager, Eugster, Hilty & Som, 2005; Sheng, Ricci & Fang, 2015). Understanding types of uncertainties helps decision makers to apply the precautionary principle to decide when to invest resources to reduce the uncertainty, and how to take that uncertainty into account in decision making (Sheng, Ricci & Fang, 2015).

The proximity principle looks at the benefits of treating and disposing of waste in the geographical area where it was originally produced or closest location to reduce pollution risks associated with transportation, and addressing problems of non –point source pollution problems (Hamilton *et al*., 2013). Centralised collection and disposal is an integral component of waste management strategies for controlling environmental damage and disposal costs associated with transportation of waste over longer distances (Hamilton *et al*., 2013). In order to ensure economic and technical feasibility, and safety of the environment and its humans, locations including distance and transportation routes considered of disposal facilities need to be carefully selected (Yilmaz, Kara & Yetis, 2016).

The waste prevention principle provides tools used for the prevention of waste generation. Three main types of actions can be employed - raising awareness about the need to prevent waste, increasing material efficiency and developing sustainable consumption (Carvellec, 2016). The principle is also based on actions to be taken that reduce both the quantity and the hazardous character of the waste (Carvellec, 2016), and incorporates strict avoidance and reduction at generation sources (Carvellec, 2016). There are advantages of adopting waste prevention methods (Schmidt, 2016), such as contribution towards sustainable waste management, and a means for waste producers to pay attention to a broader range of waste prevention technologies (Schmidt, 2016).

Traditionally waste management approach and disposal would produce secondary pollution (Liu & Huang, 2016). The cradle-to-cradle principle provides an understanding on creating production techniques that are waste free, and which can produce a secondary useful product (Liu & Huang, 2016). The principle includes waste reuse, recovery and/or recycling (Silvestre, Brito & Pinheiro, 2014). Analysing environmental impacts of the end of life of a waste material should exploit opportunities of waste reuse, recovery, and recycling potential in order to set up cradle to cradle life cycle of products used for production (Silvestre, Brito & Pinheiro, 2014; Ankra, Manu & Booth, 2015). Sustainable approaches which are based on eco-efficiency targets such as zero waste, zero emissions, or zero carbon are greatly supported by the cradle to cradle principle (Silvestre, Brito & Pinheiro, 2014; Ankra, Manu & Booth, 2015).

2.7 other studies conducted in the similar context

According to Mena, Adenso-Diaz and Yurt (2011), government efforts to improve how waste is managed has focused more on diverting waste away from landfills by means of regulations, more tax, and public awareness, however efforts to understand why waste is produced is still limited, and this is an element forsaken for a long time and might contribute to the failure of many waste systems (Mena, Adenso-Diaz & Yurt, 2011). Mena, Adenso-Diaz and Yurt (2011) emphasise a need to identify main rot-causes of waste production before regulations, awareness and training come into play. Waste management, especially solid waste has become the issue of global concern as populations and industries continue to grow, with generation patterns changing, and Marshall and Farahbakhsh (2013) note that resource scarcity, awareness, and participation act as drivers of integrated waste management, however urbanisation, inequality and economic growth added part of failure to sound management practices, and the study (Marshall & Farahbakhs, 2011) suggest the importance of new approaches which can be adaptive to waste changing patterns due to changing world.

Ikau, Joseph and Tawie (2016) point lack of knowledge and experience in many industries, including construction as the causal of poor waste management. Also poor planning is a key element contributing to poorly management waste, example, in situations where organisations fail to anticipate their waste productions and their predicted impacts, and also failing to inculcate waste in the management system makes it a less priority with no accountabilities (Ikau, Joseph & Tawie, 2016). The studies (Ikau, Joseph & Tawie, 2016; Mena, Adenso-Diaz & Yurt, 2011) conclude that inappropriate storage facilities, lack of knowledge and understanding, experience in waste lead to failures of the waste management systems, especially hazardous waste (Ikau, Joseph & Tawie, 2011).

Other similar studies (Al-Khatib, Kontogiann, Abu Nabaa, Alshami & al-Sari, 2015) reveal similar findings that lack of knowledge, skilled manpower, irregular collections, poor storages, transportation, inadequate treatment and disposal, poor equipment used to manage this waste, inadequate legal provision, and resource constrains are common challenges in most waste management scenarios. Al-Khatib et al. (2015) also make a mention that, some of these activities are not performed due to the lack financial prioritisation on the onset on the waste realisation, and conclude by saying, legislation improvement, environmental education, and waste management facilities should be the primary concern of every organisation anticipating or producing hazardous waste.

A study (Sharma & Gupta, 2017) on biomedical waste indicates that improvement in the area of waste management, especially infectious waste can be made by increasing knowledge, awareness and practices amongst the waste stakeholders, by provision of mandatory trainings. The findings (Sharma & Gupta, 2017) continue and emphasise proper understanding of colour coding of waste bins in order to achieve best waste separations for best disposal, a parameter which can minimise the impact of waste going to wrong landfills.

A number of other studies have identified factors influencing management of hazardous wastes (e.g. Guerrera, Maas & Hogland, 2013; Sharholy, Ahmad, Mahmmod & Trivedi, 2008), generation of waste and its management is influenced by many factors, such as the size of the organisation, education level of the employees, people's attitude towards waste reduction and separation and its impact to natural resources, lack of knowledge in treatment strategies and waste products. Other contributing factors affecting best practices, by Sharholy et al. (2008), are aspects such as lack of financial prioritisation to facilitate performance of the system, lack of proper equipment for treatment and sorting, and the absence of decision makers interest in environmental issues (Sharholy *et al*., 2008).

CHAPTER 3: METHODOLOGY

3.1 Study area

Crime Scene Laboratories (CSL) also known as Forensic Science Laboratories (FSL) are the only laboratories using the application of scientific methods in the investigation of crime, and specifically the exhibit material (any material collected from the crime scene for finger print identification). The word "forensic" is derived from the Latin word, meaning "in open court" or "public. These laboratories service crime scene field investigators by receiving collected exhibits from the crime scenes, and analyse them for fingerprints to build evidence. A variety of organic and inorganic matter is analysed. Typical examples of organic matter include plastics, synthetic fibres, clothes, fuels, vegetable medicines or poisons. Inorganic matter includes soils, gold, metals, prime residues etc. Scientific methods of analysis include use of hazardous chemicals, DNA analysis, chemistry and ballistics. These laboratories generate about 2.74 tons of hazardous waste a month which is disposed by a contracted service provider.

A site visit was conducted in six forensic laboratories (Figure 2) in Mpumalanga Province, South Africa for the purpose of facility walk-throughs . All the laboratories selected analyse and process crime scene material using hazardous chemicals and produce similar waste. Selected laboratories included one in Witbank, Nelspruit, Secunda, Ermelo, Acornhoek, and Lydenburg. The walk-through audit gave perspective on the waste management system, and amongst other things, the procedure of handling, collection, storage and disposal.

To enhance data collection, questionaire developed by Manyele and Lyasenga (2010) was modified and distributed to crime scene laboratory workers and crime scene investigation field workers. The focus was to evaluate the management system, assesing the level of sustainability, determing the time taken before disposal, availability of management records, such as disposal certicates, and the level of understanding and knowlede for the waste management stakeholders. Questionairs were divided into different components or parts, and each part was aimed to gather specific information from the waste stakeholders:

Majar parts of the questionaires/ assessment tool

General conditions of the management facilities

This part of the questionaire mainly focused on the general conditions of the facilities housing generated waste.

Waste generation

This part of the questionaire sought to inquire about the type and the nature of waste produced. The following types of waste were investigated: chlorinated waste (chloroform, dichloromethane, benzene, acetonitrite), Non-chlorinated waste (ethanol, methanol, acetone, hexane, Isopropanol, Ethyl acetate, parrafin), Non-anatomic biological waste(objects contaminated withi biological substances), Anatomic bilogical waste (human tissue, bone, any body fluid), Inorganic and organic acids and bases (sulphuric acid, Hydrochloric acid, formic acid, acetic acid), Heavey metals (Mercury waste, Lead, Cadnium), Not otherwise specified (empty plastic acid containers, empty solvent containers, fluorescent tubes, Miscellaneous waste (any hazardous waste contaminated with hazardous substances).

Temporary storages

This part of the questionare investigated on the presence of the waste temporary storages and their suitability (bund walls, proper ventilation, impemeable base, access control to avoid vandalism) as recommended on the waste management Act 59 of 2008 and the time taken before collection for disposal as guided by Waste managemtn Act 59 of 2008. Another part of the questionare was to investigate the management records, such as waste registers, when the waste is booked in, and out from the storage facilities as a tool of monitoring produced and disposed quanties correlation.

Waste separation

This part of the questionaire sought to investigate whether the sites practice proper waste segragations by means of waste compatibilities ,and proper labelling of waste containers thereof.

Emergency prepadness

This part of the questionaire ,investigated the capability of the sites to handle emergencies or chemical spillage incidents , such as the availabilty of chemical spillage kits for spill containments, and sought to evalute the competiecy of workers to utilise suck equipment.

Waste collection and disposal

In this part , the questionaire sought to evaluate the disposal methods, sucha as the availability of qualified service providers assigned or contarcted for collection and disposal, and the type and the distance of the landfill sites utilised.

Waste management knowlegde

This part of the questionaire sought to investigate whether there is training provided to workers handling waste, to whom the training was provided, competency certificates, records of attendence to waste management courses, reqular awareness. Knowledge assessed mainly focused on the exsting policies, laws, regulations, waste management principles, sustainable approaches, technology and tools that guide sustainable management.

Life cycle of produced waste

This part of the questionaire investigated cyles or stages to predict impacts which may come out from each stage

During an audit for, temporary waste storage sites were inspected to determine their effectiveness for the management of the waste produced (Abulfaraj, Samman & Kamai, 1994; Wagner & Bilitewski, 2009). Storage facilities were inspected to assess if they have the ability to:

I. provide physical containment of the waste in conjuction with the waste containers (e.g waterproof base, sump walls, concrete floor and bund walls)

II. protect the waste from accedental intrusion, vandalism and other adverse acts through effective access control;
III. labelling with composition of waste
IV. sufficient separation distance between waste that should not mix (incompatible waste);
V. drainage system that permits sump up of any liquid material that escapes or fall on it;
VI. facilty that has easy access for the movemnt of waste transportation to and from storages.

Use of waste registers was examined to determine if they were pasted or attached on each container to indicate:

I. type of waste;
II. quantity;
III. initial date of accumulation; and
IV. final date of accumulation.

Inspection of waste bins was undertaken to see if waste bins keeping waste are in good condition to prevent harm the environment or employees. Aspects covered included:

I. overfilling, a practice which lead escaped waste if not adhered;
II. proper closing;
III. safely stored (e.g chance of fall);
IV. free from rust;
V. dents;
VI. cracks; and
VII. other forms of corrosion.

Waste managemnt strategies were assessed against waste hierarch which supports avoid,reuse, recovery , recycle and disposal of waste. an opportunity to oversee collection for disposal of waste by the contracted service provider was granted to examine legality of the service to handle dangerous goods. Aspects examined included:

I. vehicle conditions (e.g signs of fluid leaks);

II. abilitiy to hold waste containers against bumping each other;
III. hazchem placards (cards posted on the vehicle indicating that it is dangerous goods vehicle);
IV. spillage containment kit;
V. training records to handle hazardous chemical/dangerous substances;
VI. emergency response numbers posted on the vihicle to reach emergency departments in case of spillages.
VII. Registration with department of transport
VIII. PDP (Public Driver's Permit) to drive heavy vehicle/s

Photographs were taken from each waste management facility including temporary storages per site (laboratories) by digital cameras as qualitative data. Quantities of waste per type were recorded to determine if there are differences in waste productions per waste class.

Storage facility can have considerable environmental risks as a result of inadequate or poor construction and design (Wagner & Bilitewski, 2009). Well designed storages is of relevant to reduce the portion of waste going to disposal sites (landfills), and fulfils the provisions made by legislation (Wagner & Bilitewski, 2009). In addition well constructed temporary storages support best waste management practices (e.g waste hierarchy, LCA etc) which minimise environmental risks associated with untreated waste going to landfills (Wagner & Bilitewski, 2009).

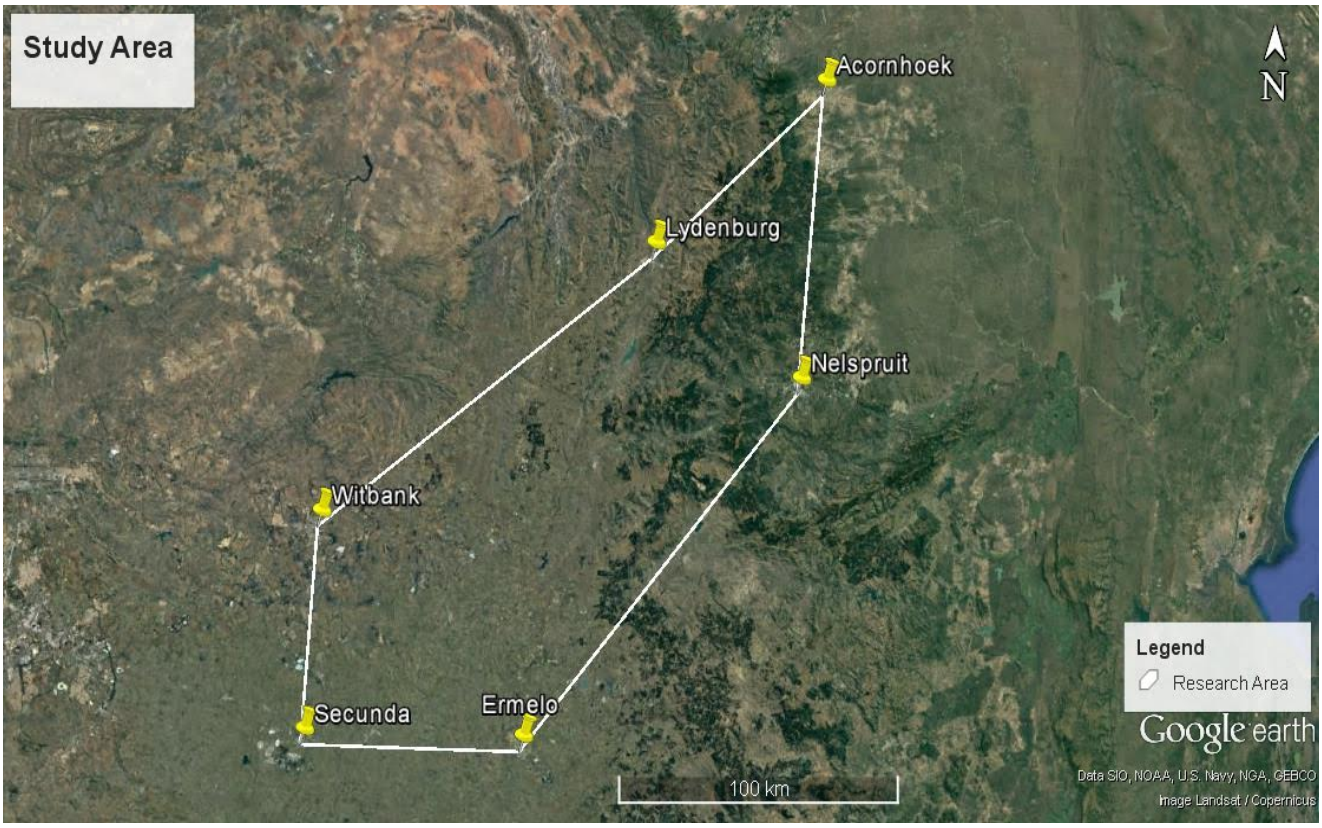

Figure 2: Study site indicating areas where data was collected

3.2. Data collection

Waste quantities

Filed records of monthly waste generation per each laboratory were collected to determine how much waste is produced, nature and types of waste being produced. The records included waste generated from biological sources as well as hazardous chemical substance sources.

Records of waste disposal certificates were requested from laboratory supervisors to determine whether the waste produced reaches landfill sites. Disposal certificates serve as proof that waste generated reached appropriated landfill instead of being illegally dumped.

Training records

Training records for waste handling personnel were requested to see if people managing waste have a proper knowledge and skills to manage such waste in order to protect the environment from degradation by waste mismanagement. Aspect examined included records (certificates) of attendance to hazardous waste management short courses and workshops at least once a year, regular awareness on policies, law and regulations. Competency enables people to handle waste in an environmentally sound manner, in addition such knowledge can empower people handling waste to know what to look for in monitoring of compliance to the company contracted for collection and disposal, and positively change their behaviour how perceive waste in relation to environment impact.

Emergency preparedness

Equipment to handle accidental release of hazardous waste per laboratory was requested to see if the laboratories have the equipment in place in order to manage accidental spillages should they occur before they can escape and endanger natural resources such as under groundwater through seepage. The equipment to manage or control spills requested included spillage containments kits. In addition competency records (certificates on spillage containment workshops or training and short courses attendance) of the users were also requested to determine if they can use such equipment. Assessment of waste categories recorded on waste manifestos was also conducted to reach a final conclusion of what type of emergency equipment to be present should sites experience accidental spillages.

Statistical analysis

The statistical analysis (Statsoft) was performed to predict the statistical differences on waste types, nature of waste, locations and months at the significant level of 0.05 and confidence level of 95%. Statistical analysis (statsoft) has been adopted in many studies for the manipulation of data. Statica data analysis can provide a systematic method of building advanced analytical models to relate one or more dependent variables to a number of independent predictor variables. Variables with statsoft can be analysed as continuous or categorical. Continuous variables are usually associated with regression. Statistical analysis is capable of building predictive models for regression and classification analyses. Many studies choose statistical analysis due to its capability of eliminating redundancy which might exist in the data set. According to Thomas and Kreb (1997), it is one of the best methods in creating various predictive models. The statistical analysis can also be used to make predictions on new data or unseen data, such as scoring (). With the statistical tool, one can save projections, and reload them in the future for further analysis. Various statistics can be reviewed in a data set, such as mean, standard deviation, skewness, kurtosis, and observations of minimum and maximums.

Table 1: Crime Scene Laboratories waste description

WASTE CATEGORY	WASTE COMPOSITION
Chlorinated waste and carcinogeneric material	Chloroform, dichloromethane, benzidene acetonitrile
Non Chlorinated waste	Ethanol, Methanol, Acetone, Hexane, Isopropanol,Ethyl Acetate, Paraffin
Non Anatomic Biological Waste	Any object contaminated with biological substance
Non Anatomic Biological Waste	Sharps and blades in a sharp container
Anatomic Biological Waste	Human tissue, bone, bone, food, blood, contaminated glass, anybody fluid
Strong Oxiders	Ammonia, Sodium Hydrochloride
Inorganic and Organic acids and bases	Sulphuric acid, Hydrochloric acid, Formic acid, acetic acid
Heavy metals	Mercury waste, Lead, cadnium
Not otherwise specified	Empty plastic acid containers, empty solvent containers, fluorescent tubes
Miscellaneous	Any hazardous objects, liquid or material that is contaminated with hazardous substances

CHAPTER 4: DATA ANALYSIS AND RESULTS

4.1 Waste separation and storage

In Acornhoek lab, biological waste was temporarily stored in the main passage of the lab due to limited space inside the lab where generated waste is usually stored, and due to delayed collection for disposal by the contracted service provider. On the same site it was noted that waste was placed on the floor due to the shortage of proper waste bins. Chemical waste was mixed together in one chemical drum where one wash basin is designed to decant all the chemical waste (Figure 3).

Figure 3: Temporary waste storage at the Acornhoek Laboratory

Chemical waste pours into one drum with separation despite their compatibility (segregation of chemical waste by type) recommended by their MSDS utilised the lab (Figure 4). The site had no temporary storage and generated waste, both biologicals and chemicals are stored inside the lab. New stock of chemicals in boxes was also placed where waste was temporary stored.

Figure 4: Temporary waste storage at the Secunda laboratory

In Witbank a similar practice where produced chemical waste was decanted into one chemical drum despite compatibility was observed (Figure 5). The chemical waste drum was labelled as biological waste, an indication of incorrect labelling. Records for waste collection for disposal indicated that waste was not collected consistently with one or two months being skipped, resulting in hazardous waste being placed in the lab for a longer period. No disposal certificate copies were on site for the waste collected by the contracted service provider.

Figure 5: Temporary waste storage at the Witbank laboratory

In Lydenburg, waste was also stored in the laboratory; no storage facilities were found for temporary storage of generated waste. When there is no more space to keep waste in the laboratory due to delayed waste collection for disposal, another office (Figure 6) is used as temporary storage, and it was found during the site visit that the office used had no access control, no demarcation, no proper ventilation, and was also used to store other material such as equipment.

Figure 6: Temporary waste storage at the Lydenburg laboratory

All chemical waste in Nelspruit is poured into one drum like the previous discussed labs. An incorrect labelling of waste containers was noticed whereby waste stored in red bags (biological waste) was labelled as chemical waste, and the biological waste containers were left open. Records of collection for waste disposal showed that in 2016 waste was collected consistently. It was also noted from the same site visit that waste in this facility is kept in passages due to the challenge of space where generated waste is usually stored (Figure 7).

Figure 7: Temporary waste storage at the Nelspruit laboratory

4.2 Comparison of waste quantities

From the waste generated between January and august (Figure 8), chlorinated waste was produced more in Witbank by January with 75 litres. There was no production of chlorinated waste from other months (February, March, April, May, June, and August).

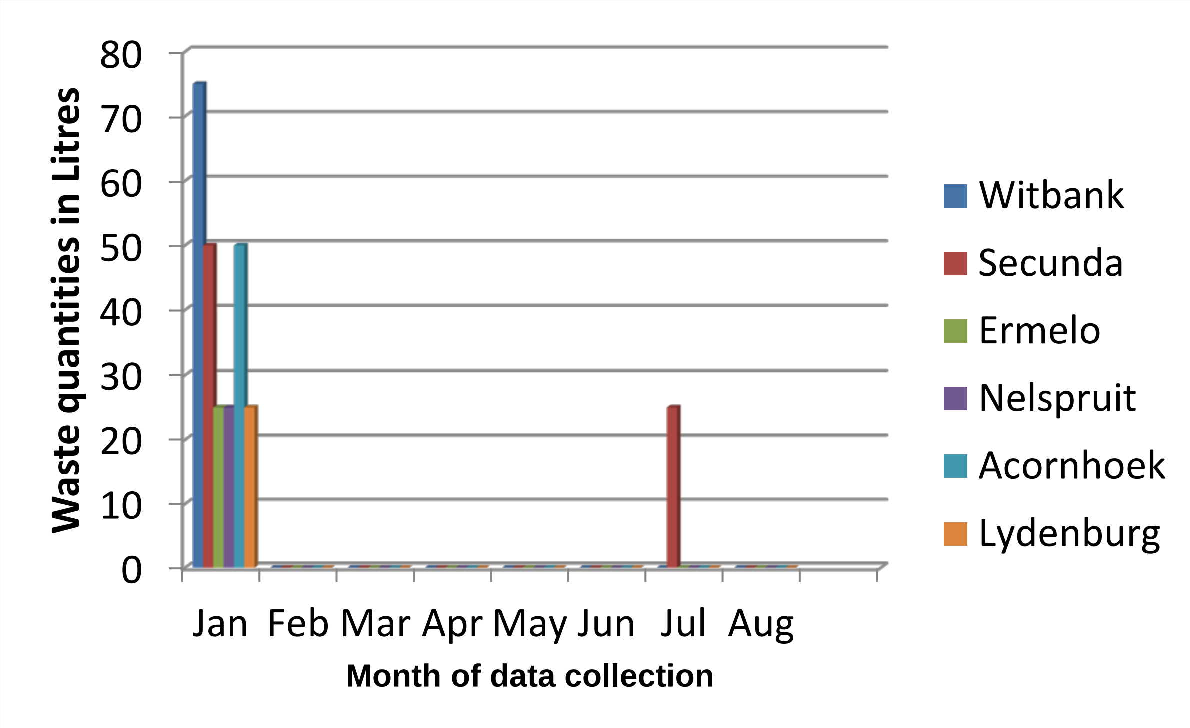

Figure 8: Collected data on the amount of chlorinated waste produced between January and August 2016

From the waste generated between January and august (Figure 9), non- chlorinated waste was produced more in Ermelo with 660 litres by January. A regular generation of this type of waste throughout the year was noticed unlike chlorinated waste where it was only produced more beginning of the year (figure 8).

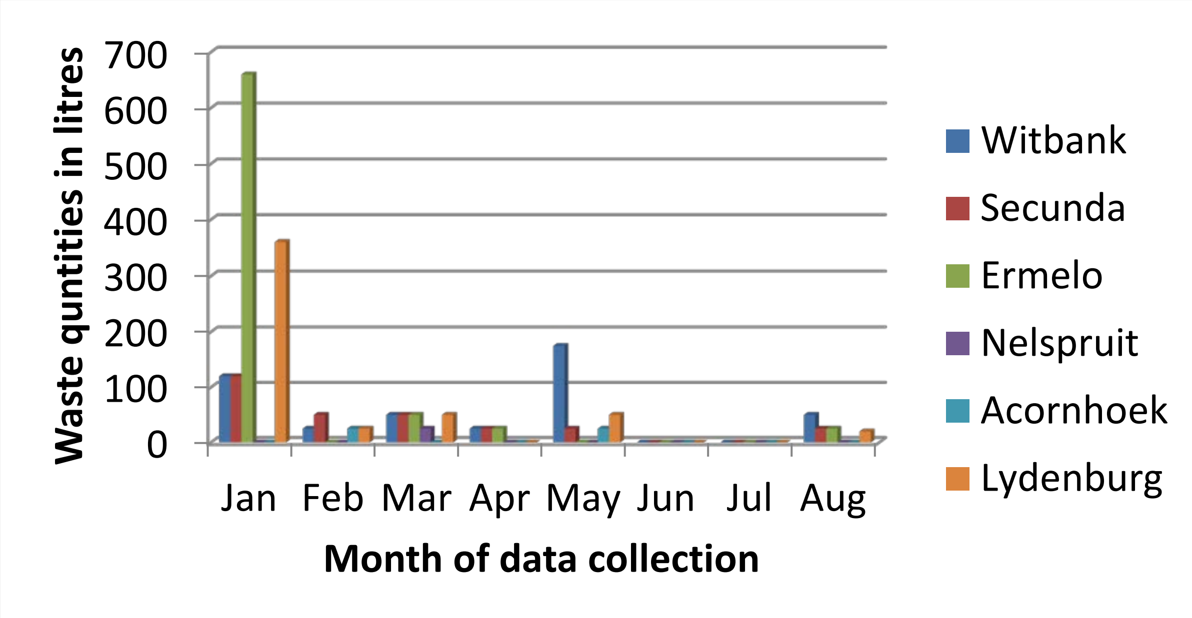

Figure 9: Collected data on the amount of non- chlorinated waste produced between January and August 2016

From the waste generated between January and august (Figure 10), non- anatomic biological waste was produced more in Ermelo by March with 2240 kg. This type of waste was not generated consistently throughout the year, however other generation was recorded more towards the end of the year, July and August.

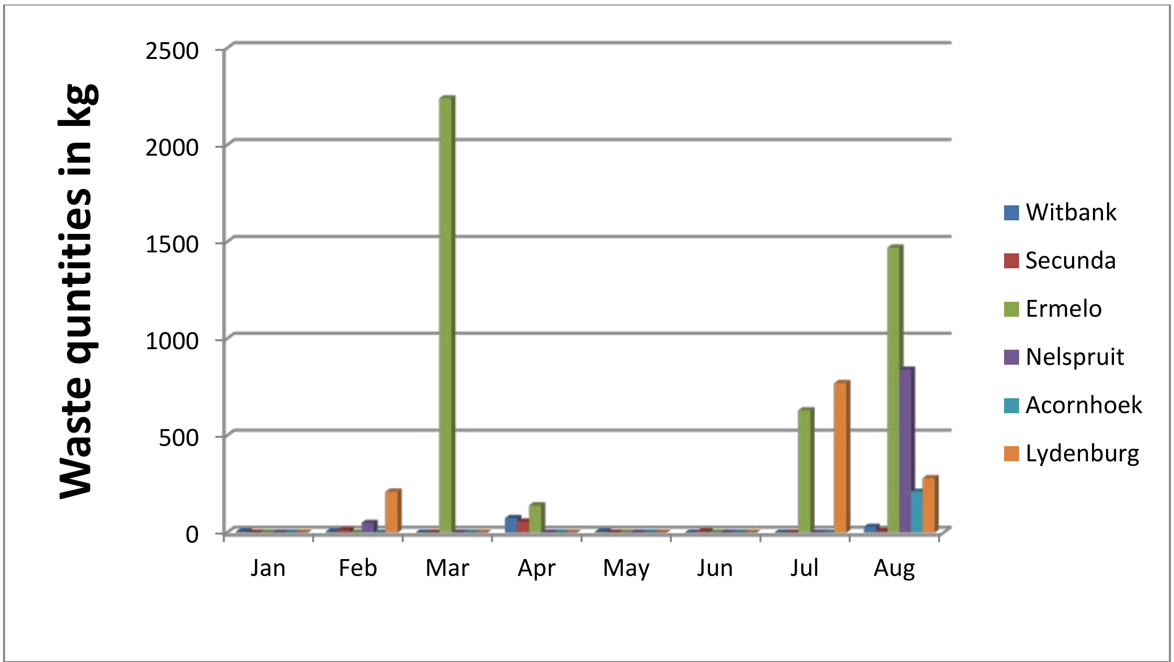

Figure 10: Collected data on the amount of non-anatomic biological waste produced between January and August 2016

From the waste generated between January and august (Figure 11), anatomic biological waste was produced more in Nelspruit in August with 240 kg. This type of waste was produced in few months (only in January, February and August) throughout the year. Anatomic biological waste was noticed to be generated by only two sites (Witbank, Nelspruit) throughout the year.

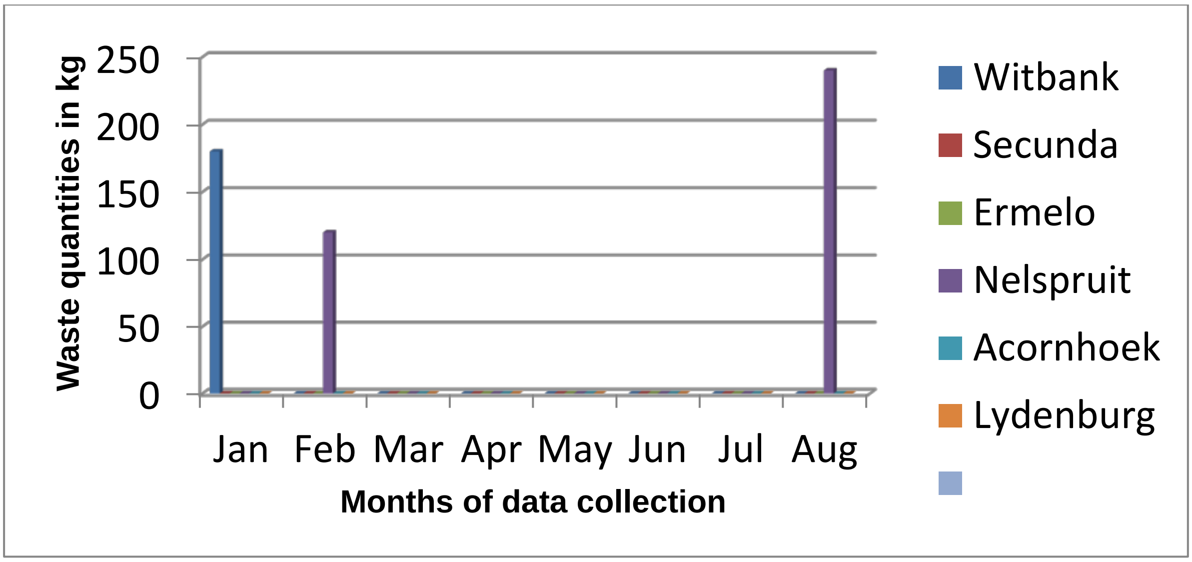

Figure 11: Collected data on the amount of anatomic biological waste produced between January and August 2016.

From the waste generated between January and august (Figure 12), waste containing organic and inorganic acids and bases was only produced in Lydenburg in April and July with 50 and 25 litres throughout the year, and it was not produced consistently throughout the year even in Lydenburg but in only two months (April and July).

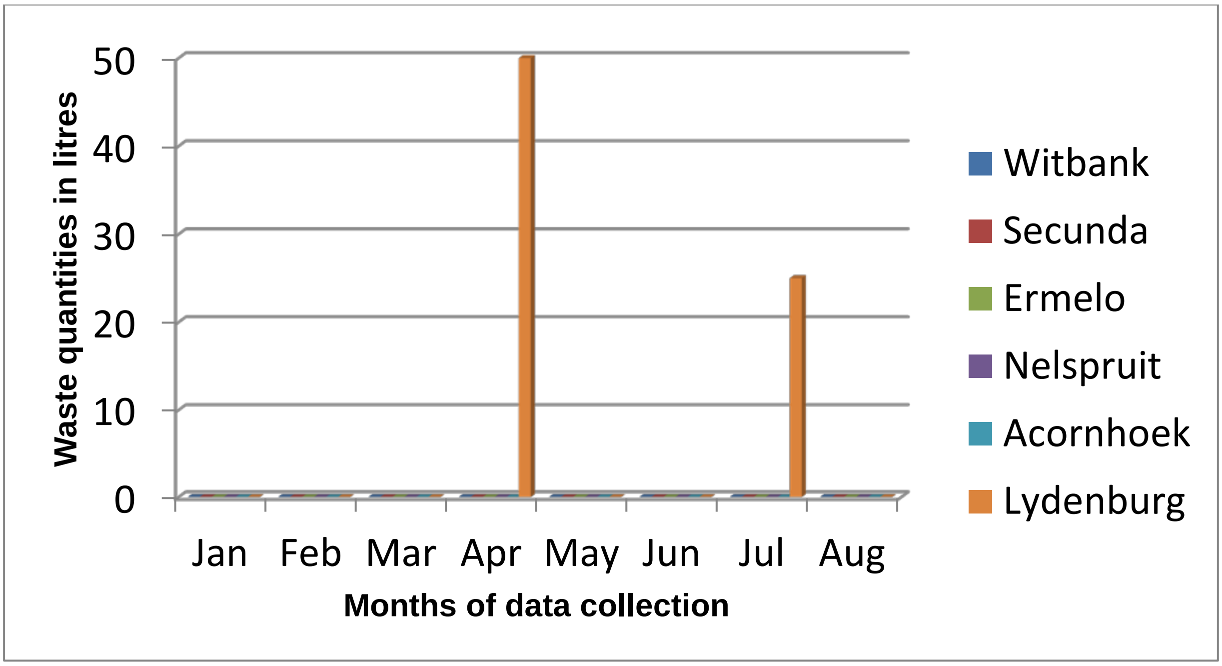

Figure 12: Collected data on the amount of waste containing organic and inorganic acids and bases produced between January and August 2016.

From the waste generated between January and august (Figure 13), waste with heavy metals was only generated by Witbank laboratory in January and May with 5 litres throughout the year. This type of waste was only produced at the beginning and the middle of the year (January and May).

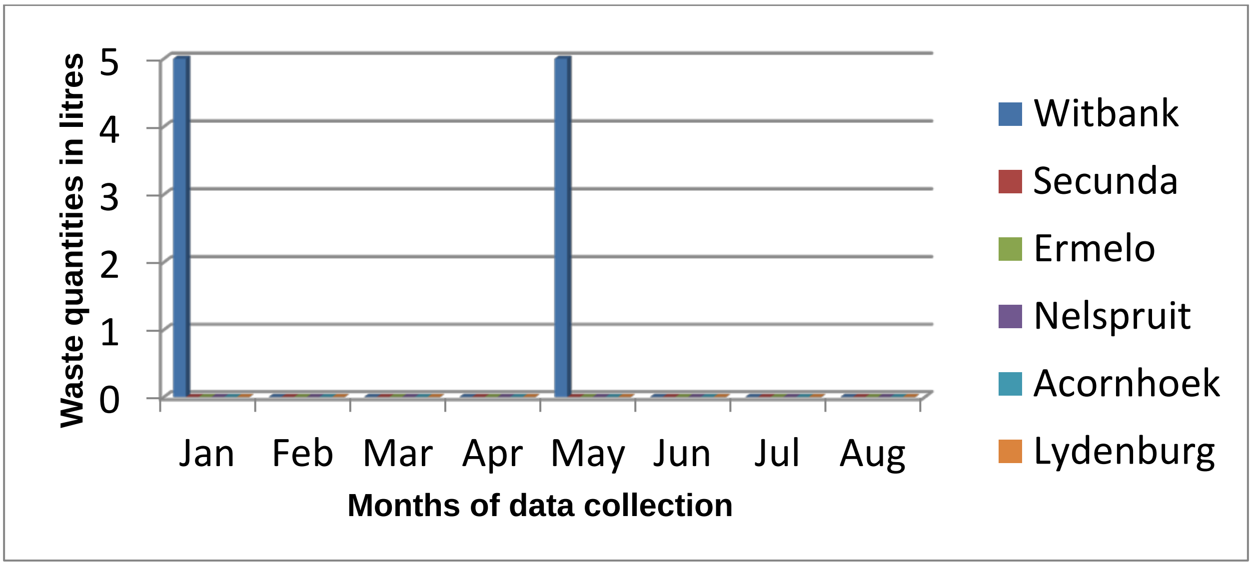

Figure 13: Collected data on the amount of waste with heavy metals produced between January and August 2016

From the waste generated between January and august (Figure 14), miscellaneous waste was produced more in Acornhoek in March with 2040 kg. This type of waste was produced throughout the year and with quantities higher than other types by all the sites.

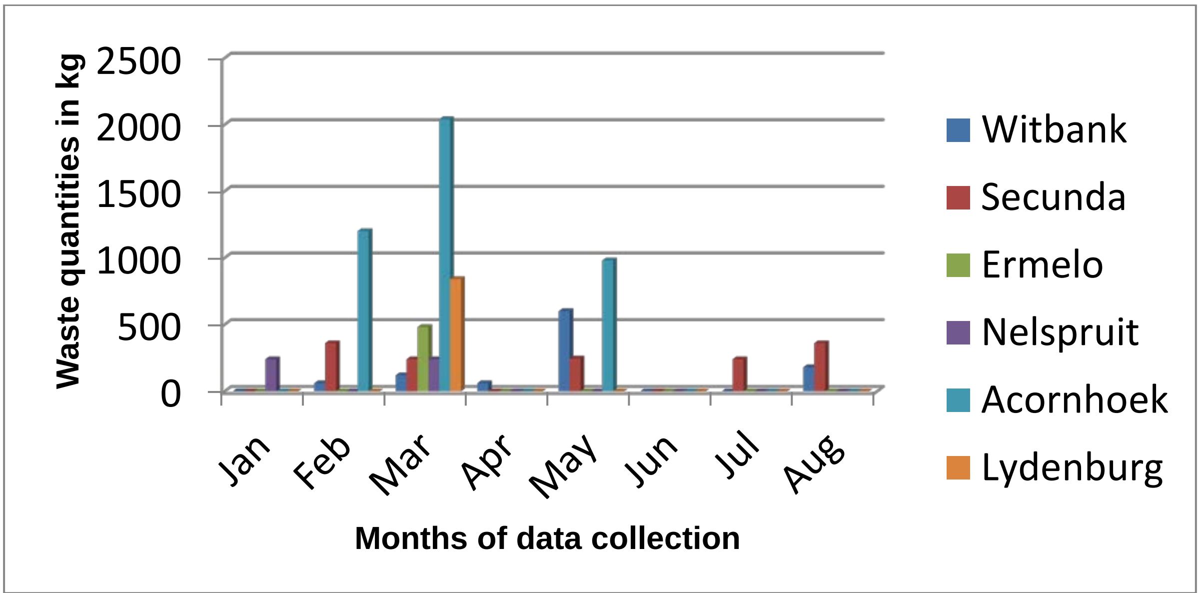

Figure 14: Collected data on the amount of miscellaneous waste produced between January and August 2016

4.3 Statistics analysis

Statistics results based on the locations (sites), Ermelo produced significantly more non-anatomic biological waste (P-value = 0.035883<0.05) than other locations, while Witbank produced significantly more heavy metals waste (P-value=0.012127<0.05) than other locations. Inorganic and organic acids and bases were significantly generated more in Lydenburg (P-value=0.018568 <0.05). Statistics results based on months showed that non-anatomic biological waste was significantly produced more in January (P-value= 0.001257 <0.05), May (P-value= 0.033245 <0.05), June (P-value=0.033305<0.05) and August (P-value=0.03305<0.05) than other months. Miscellaneous waste was significantly produced more in March (P-value= 0.003695<0.05) than other months. Statistics results based on the nature of waste, chemical, biological and miscellaneous waste were significantly produced more in February (P-values = 0.04015, 0.016404, 0.016404 <0.05), March (P-values= 0.003232, 0.041875, 0.041875 <0.05), May (P-values= 0.000242, 0.000439, 0.000439 <0.05). Non –chlorinated waste was significantly produced more in January (P-value= 0.012924 <0.05) than the other months. Results on the waste types, all were significantly produced in February than the other months with p-values less than 0.05, also in March all waste types were significantly produced, except non-anatomic biological waste (P-value= $0.273742>0.05$), however it was significantly produced more in April (P-value= $0.019033 <0.05$), July (P-value= $0.027121<0.05$) and August (P-value= $0.007542<0.05$) than the other months.

4.4 Training records

No records of training on hazardous waste management for laboratory personnel handling generated waste were presented at any of the laboratories. It indicated that the knowledge power to oversee compliance of the waste collection by the contracted service provider (Mampuru waste management) was limited.

4.5 Emergency preparedness

Equipment to handle accidental release of hazardous waste such as spillage containment kits were assessed and each laboratory was found to have one in place except Acornhoek, however there were no records of training of people on this type of equipment.

4.6 Disposal certificates

During the visit for data collection, copies of disposal certificates for waste collected for disposal were requested. None of the labs could produce waste disposal certificates.

4.7 Times frames for waste disposal at the CSL

Situation for the crime scene laboratories as it stood did not show any consistent collection of waste by the service provider for disposal purposes. Waste was taken inconsecutively from almost all the sites for disposal. In Witbank one month to three months was skipped without waste being disposed (Table 10). Secunda (Table 10) there was one month in between where waste was not disposed. Similarly in Ermelo and Nelspruit (Table 10), a month would pass without waste being collected for disposal. In Acornhoek waste was not disposed for a period of five months from January to May, and the first collection began in June, after which two months were skipped, and waste was taken again at the end of September (Table 10). In Lydenburg a similar practice as noticed in Acornhoek reflected in which waste was not collected from January to May, and the first collection was started in June, and while July and August has no removal again until September (Table 2).

Table 2: Time taken for waste disposal in 2016

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Witbank		**X**		**X**				**X**				
Secunda		**X**		**X**		**X**		**X**				
Ermelo		**X**		**X**		**X**		**X**				
Nelspruit	**X**	**X**		**X**		**X**			**X**			
Acornhoek						**X**			**X**			
Lydenburg						**X**			**X**			

CHAPTER 5: Discussion and recommendations

Across all the crime scene laboratories there was no application of assessment tools such as LCA as an aid to provide an overview of environmental aspects associated with strategies used to handle the waste (Cherubini, Bargigli & Ulgiati, 2009) . The environmental risk associated with waste produced by these sites is obvious because they generate hazardous waste (Cherubini, Bargigli & Ulgiati, 2009). Currently these sites are only addressing the cost associated with collection and transportation for disposal of their waste, which puts the environment at risk of impacts unevaluated per each waste treatment (Cherubini, Bargigli & Ulgiati, 2009). The key task for the CSLs is to improve their waste management strategies by reviewing the environmental impacts associated with each stage of their waste treatment (Cherubini, Bargigli & Ulgiati, 2009). Many organisations use LCA methodologies to measure environmental impacts which may be associated with their product, process or activity by identifying, for example, energy consumption, material use and waste released to the environment, and also to evaluate opportunities that contribute to environment protection or improvement (Arena, Mastelloone & Perugini, 2003). At this stage the CSLs are at risk of being unable to practice impact assessment and improvement assessment of their waste (Arena, Mastelloone & Perugini, 2003). They can learn from the LCA methodologies to address their waste impacts, LCA is a method that is able to look at resource efficiency and impact assessment of different stages of waste management (Arena, Mastelloone & Perugini, 2003). For instance within the CSLs, the impact associated with the waste transportation can be evaluated from the viewpoint of emissions to the air, water, risks of accidents, temporary storage, the opportunity to assess if the waste management can contribute to climate change (Arena, Mastelloone & Perugini, 2003). Compiling an inventory of material inputs and environmental impacts related to each activity may assist CSLs to make informed decisions on their waste management strategies (Arena, Mastelloone & Perugini, 2003). LCA method can be used to compare environmental impacts associated with each stage of waste treatment by, for example quantifying material inputs and outputs and evaluate how they contribute to environmental performance, and such information can be used to measure and improve waste management system (Finnveden *et al.*, 2009). Adoption of LCA helps to plan for the best waste management strategy that can provide most preferable environmental outcomes (Yay, 2015). The crime laboratories are also missing an opportunity to employ material recovery from the waste produced which renders all the waste produced to go to landfill sites (Finnveden *et al.*, 2009). According to LCA studies (Yay, 2015; Fiorentino, Ripa, Protano, Hornsby &Ulgiati, 2015; Arena, Mastellone & Perugini, 2003) landfilling has the highest environmental impacts without emission control to the atmosphere, and with methane gas as the main contributor to global warming.

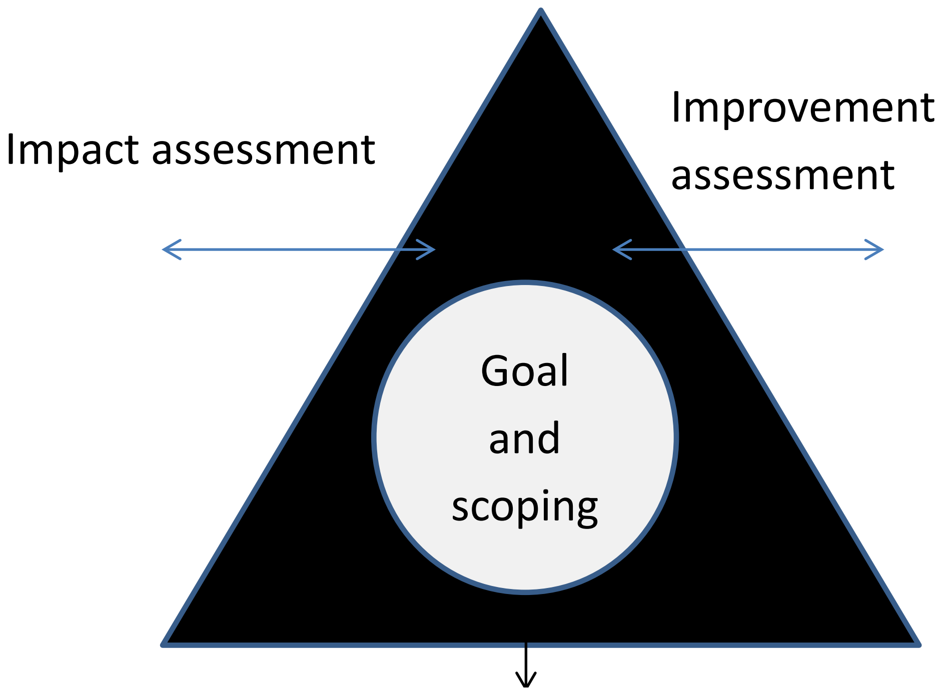

Figure 15: Life Cycle Assessment flow diagram for waste management (Yay, 2015)

A number of challenges were identified during data collection, such as lack of clear definitions and regulations about waste, limited accurate data on waste statistics (waste generated, collected or removed per month) on which decisions and strategies could be based, poor segregation of generated waste, limited training and treatment facilities that were fit for temporary storage. Waste material can escape easily when it is stored in unsound waste management facilities. It was noted from the facility audits that waste across all the laboratories is temporary stored inside the laboratory and in other sites (Acornhoek and Lydenburg) waste sits in main passages due to limited space inside the labs (Figures 3 and 6). Where the waste is stored on main passages there is no access control and waste is prone to vandalism and the risk of being accidentally released to the environment. Wagnes and Bilitewski (2009) list specifications for the waste storages which include, proper ventilation, proper size, concrete floors, proper roofing, sump and water base, access control, demarcation and zoning. These recommendations by Wagnes and Bilitewski (2009) are in line with the waste management standard specification of waste storages (SANS 10248) which specifies that the site must have a good drainage system, proper ventilation, water supply for cleaning or decontamination, environmental conditions (temperature and humidity) inspected and out of direct sunlight to avoid change in waste properties which may lead to disasters such as fire outbreaks or explosion of chemicals. Significant environmental pollution can arise from waste management facilities such as odours and escape of hazardous material when these facilities are not designed in a sound environmental manner (De-Feo, De-Gisi & Williams, 2013). Another impact from unsound waste storage can be the close communities and staff inhaling odours from these facilities (Bouvier & Wagner, 2011). To minimise unprotected exposure (Albulfaraj, Samman & Kamal, 1994), waste must be quantified, separated according to their compatibility, collected and stored on storage facilities that prevent vandalism and easy escape, and these waste treatment stages must be carried out under monitored safety waste storages. Waste storage facilities specification suggested by Albulfaraj, Samman & Kamal (1994) indicate that limited exposure to man and his environment, provision of physical strict containment of waste with leak-free containers, and protection of waste from accidental release, vandalism. These findings are in accordance with specifications for temporary waste storages suggested by Wagner and Bilitewski

(2009). All these challenges pose significant risks to staff and the environment in general (Caniato, Tudor, Vaccari, 2016).

Although regulation was lacking in several aspects in the CSL environment, it was also evident that existing waste management laws were not well-known by all the staff managing waste and they were confused about what to combine and what to separate in terms of waste classes , and the gap of knowledge was evident (Caniato, Tudor, Vaccari, 2016). Waste not separated at generation point is disposed on in landfill site causing more harm and overload (Nguyeni, Zhu & Le, 2015). Waste separation is important to reduce the weight of materials which are known to contribute more on environmental damage (Nguyeni, Zhu & Le, 2015). Another consequence of poor separation is that, it increases the risk of merging of incompatible waste which might result on chemical explosions (Nguyeni, Zhu & Le, 2015).When considering the environmentally friendly strategies, there are two approaches generally recommended, waste reduction and separation (Nguyeni, Zhu & Le, 2015). All the hazardous waste categories should be better analysed and tracked from production to final disposal to comply with national standards and local municipal by-laws (Caniato, Tudor &Vaccari, 2016, Botelho, 2012).

Despite the limited knowledge on generated waste and other waste management challenges, a range of waste categories of approximately 0.165-0.95 kg/L is generated by CSLs per month comprising of non-chlorinated waste produced from chemicals such as DFO, Ninhydrin, Basic yellow, Rhodomine 6G, Cyanobloom, and Polycyano, non-anatomic biological waste such as disposable PPE (Personal Protective Equipment) from the crime scene contaminated with blood, anatomic biological waste produced such human tissues and bones, heavy metals such as Mercury and Lead, and miscellaneous waste, including any hazardous objects, liquid or material that is contaminated with hazardous substances (Alves-Girelli, 2016; Virkler & Leanev, 2009) . Therefore there is a need for more accurate data on which to develop waste policies and practices for managing mentioned waste for lesser environment risks. There are various policies and regulations published by national departments which can be key guides for effective implementation of waste management programs. CSLs should take initial responsibility to implement those regulations.

In order for one to be able trace back waste compliance in terms of date booked, quantity, origin, waste type, and treatment, it is always important for waste producers to utilise waste registers for such traceability. Waste registers can also assist to monitor compliance with collection and disposal time frames. It was noticed during laboratory visits that none of the sites (laboratories) used waste registers and it was evident that the importance of waste registers was not understood. A great deal of environmental pollution may come from poor separation of waste from the source of origin and collection. One of the major indicators of eco-efficiency is the separation ratio at the stage when waste is collected and the proportion of waste treatment and optimisation (Yang, Zhou & Xu, 2015). As is the case in the Crime Scene Laboratories (CSL), during the visits it was noticed that waste is segregated into only chemical and biological waste, however many different types of waste were recorded (chlorinated waste, non- chlorinated waste, non-anatomic, biological waste, anatomic biological waste, strong oxidisers, inorganic and organic acids and bases, heavy metals, miscellaneous) but do not appear as waste ready to be collected for disposal. Proper separation of waste at the point of generation and collection is sound waste management practice aimed at reducing adverse effects of mixed waste in receiving environments (water, soil, air) (Nguyeni, Zhu & Le, 2015).

Botelho (2012) notes that many organisations put focus on proper waste separation at the source, however this goal can only be achieved if waste management is part of the management system of the organisation and training programs of the employees which can influence perceptions and behaviour towards maintaining good waste practices.

Waste optimisation including waste hierarchy (avoid, reuse, recover, and recycle) can improve when staff are provided with proper training both on handling and legislation level (Alves-Teixeira, Chiappetta Jabbour and Sousal- Jabbour, 2012), in that manner conservation of resources and cost of disposal is optimised. According to Alves-Teixeira, Chiappetta Jabbour and Sousal- Jabbour (2012) waste optimisation should be complemented with management of human and behaviour aspects that support green management technologies (Iglezakis & Moustakas, 2015).

Nguyeni, Zhu and Le (2015) also note that separation is a fundamental condition to avoid unforeseen pollution. This is in line with the recommendations made by Zhou, Yang and Xu (2015) who pointed out that specific environmental impact from waste pollution can be attributed to waste management errors such as poor separation. As is the case in Mpumalanga crime scene laboratories, proper waste separation is compromised during temporary storages. Again waste which has been sorted merges with other types of waste when the contracted service provider collects for disposal and during temporary storages as well when space to keep generated waste becomes a challenge. According to Fikri, Purwanto and Sunako (2015), this happens when staffs handling waste become discouraged to participate actively in waste separation practices. It is argued by Yang, Zhou and Xu (2015) that one of the important indicators of eco-efficiency is the separation ability during collection.

The situation noticed at the Crime Scene Laboratories indicated that there was no hazard rating practiced (Nguyeni, Zhu and Le (2015). During the visit waste manifestos reflected inconsistent waste removal in terms of time frames (Table 3). Within all these sites it would take one to a maximum of three months without waste being collected, and in that time it is left inside the labs and the main passages. The practice can contribute to environmental impacts and health problems for those exposed (Sing, Datta and Nema, 2009). Sing, Datta and Nema (2009) recommend that after waste has been sorted and classified, the waste stream must be further classified to indicate its hazard rating (Sing, Datta and Nema, 2009). Hazard rating determines the type of disposal site at which waste can be disposed (Sing, Datta and Nema, 2009). De and Debnath (2010) also have the same finding that hazard rating separates between extremely hazardous moderate hazardous waste, and the practice of hazard rating determines the choice of landfill to dispose based on the hazard rating (De & Debnath, 2010).

Current waste management practices at these laboratories were strongly influenced by the waste disposal which recommends collection of waste to a landfill site, which is the last preferred option according by waste hierarchy (De & Debnath, 2010). For example, it was observed during the visits that the waste management hierarchy at the time was not practiced in meeting the goals of sustainable development as it focused only on disposal rather than reduction, reuse, recycling, or recovery. However, there can be limitations to the use of waste management hierarchy as an enabler of sustainable development (De & Debnath, 2010). These limitations are common when people handling waste lack knowledge as indicated by literature (Fikri, Purwanto and Sunako, 2015; Alves-Teixeira, Chiappetta Jabbour and Sousal-Jabbour, 2012). Education and individual training on waste management contribute significantly towards environmental awareness and sustainability (Fikri, Purwanto and Sunako, 2015; Alves-Teixeira, Chiappetta Jabbour and Sousal- Jabbour, 2012), and how employees perceive the issue of environmental degradation by pollution, as well as well as how they decide to handle waste (Fikri, Purwanto and Sunako, 2015). Generally at the CSL's, there is a lack of understanding and knowledge, awareness, and perception towards waste pollution, which is why sometimes even if the organisation can introduce waste minimisation technologies, it would take time to materialise (Fikri, Purwanto and Sunako, 2015; Alves-Teixeira, Chiappetta Jabbour and Sousal- Jabbour, 2012). People handling waste need to have an appropriate knowledge and awareness to be able to understand the relationship between how they manage waste and the consequences to the environment (Fikri, Purwanto and Sunako, 2015; Alves-Teixeira, Chiappetta Jabbour and Sousal- Jabbour, 2012).

Hazardous waste management is the biggest environmental issue in many countries including South Africa, and organisations highly dependent on landfilling as the only main waste management method in managing their waste can continuously increase experienced environmental impacts as landfills are only physical facilities used to dispose of waste on land space and ideally (Moh & Manaf, 2017), should be considered as the final disposal option for unrecovered waste (Moh & Manaf, 2017). Mostly where these landfill sites exceed their operating capacity, it usual results in serious environmental and social threats (Moh & Manaf, 2017; Cleeve-Edwards *et al*., 2015).

As hazardous chemicals are produced, stored, and transported for disposal from these laboratories, the environment can be vulnerable when there is an accidental release of these chemicals that can contaminate natural resources such as the water, land, air and can eventually result in death for exposed communities (Stewart-Evans, Hall, Czerczak, Manley, Dobney, Hoffer, Pałaszewska-Tkacz & Jankowska, 2014). Emergency preparedness and response help to prepare a response by planning actions to mitigate or prevent adverse environmental impacts in emergency situations (Stewart-Evans *et al*., 2014). The identification and availability of key equipment to contain chemical spillages is essential (Kirby, Gioia, & Law, 2014; Stewart-Evans *et al*., 2014). On a positive note, all the laboratories were noticed to have spillage containment equipment kits in place to use when there is an accidental release of hazardous chemicals, however the shortfall was that no training records indicated competency of persons in using such equipment. The efficacy of the response to any chemical release depends to the level of training and competency to measure and contain spillages, and level of scientific knowledge is considered an essential part as it provides personnel the necessary skills and knowledge to effectively contain and monitor chemical incidents (Kirby, Gioia, & Law, 2014). Crime Scene laboratories should consider training on waste management a priority in order to be effective in dealing with disasters that need immediate containments which may contaminate environment and for personnel to understand the risk and consequences of such incidents to environment and human health (Kirby, Gioia, & Law, 2014).

The CSLs are not certified on ISO 1400 standard. Adoption of this can give these laboratories a direction how they can achieve or work towards cleaner productions which can aid in reducing environmental impacts, and practices that contribute to the economy of the organisation whereby chances of reducing the waste quantity intended for disposal can be achieved (Singh, Bruecker & Padhy, 2014). Organisations with this standard certification usually maintain environmentally friendly practices and commit to the allocation of resources to achieve better environmental performance (Singh, Bruecker & Padhy, 2014; Oleveira *et al*., 2016). Oleveira et al. (2016) point out that organisations which constantly follow the standard guidelines or clauses easily achieve clear productions and end up with matured environmental management systems, this shows that adoption of the standard can improve organisation's environmental performances (Singh, Bruecker & Padhy, 2014). It is also noted from the literature (Mazzi *et al*., 2016) that organisations with this standard certification always strive to comply with environmental legal requirements and make efforts to improve the competency of their employees in order to retain the certification (Singh, Bruecker & Padhy, 2014; Mazzi *et al*., 2016). Literature (Massoud, Fayad & Kamleh, 2010; Mazzi *et al*., 2016) highlights some of the challenges organisations face to successfully implement the standard, such as the size of the organisation, cost of implementation, difficulties in integrating the standard into organisation's management system, and difficulties in achieving employee's commitment where the adoption is new, cost involved in training and development of employees (Massoud, Fayad & Kamleh, 2010). It was evident that for crime scene laboratories to successfully adopt the standard, commitment from senior management should be strong, firstly to close the gap of incompetency and considering the size of the organisation.

CHAPTER 6: CONCLUSION

As crime investigation and use of materials which generate hazardous waste increases with the crime rate (Tattoli, Tsokos, Sauter, Anagnostopoulos, Maselli, Ingravallo, Dellia, & Solarino, 2014), there is an evident of increase on waste generation from CSL facilities. Since a large fraction of the waste produced from these laboratories is most hazardous, waste must be carefully managed in accordance to relevant waste regulations in order to avoid damage to the environment. As most management regulations and standards focus or emphasise on proper waste separation at the point of source (Singh, Bruecker & Padhy, 2014), this is a condition to be achieved by CSL, and the law to be implemented that guides and enforces sound waste management such as waste management Act 59 2008. This study finds that compliance with waste management practices is far from ideal, and that CSL staff is seldom provided with training and awareness. Lack of training and awareness opportunities can delay implementation of waste legal requirements even when compliance is fully pursued from the top management. The study findings also suggest that along with the development of better waste management practices and knowledge empowerment of staff, more attention must be given to the management facilities especially storage facilities to ensure waste management system is economically sustainable, and environment friendly, the finding concurs with finding of other studies(Ikau, Joseph & Tawie, 2016; Mena, Adenso-Diaz & Yurt, 2011) which emphasise that inadequate or poor management facilitys are most causal of waste management failures. The findings of the study suggest a big gap in waste management knowledge by management staff, an element that has a detrimental effect on how people perceive waste and their environmental impact. This finding concurs with many studies (e.g. Ikau, Joseph & Tawie, 2016; Al-Khatib, Kontogiann, Abu Nabaa, Alshami & al-Sari, 2015) point out that lack of knowledge leads to poor management of wastes by staff.

LCA is the a tool to compare waste management strategies , and process selection in order to identify opportunities for reducing the impacts that can be associated with each waste management stage, therefore analysis of environmental impacts can indicate the highest contributor to environmental damage. Adoption of assessment tools such as LCA can improve how waste in management by crime scene laboratories, and reduce the risk of unpredicted environmental damage, landfilling, and loosing of products that can be recovered from reprocessing of waste being produced.

References

Abulfaraj, W.H., Samman, T.A. & Kamal, S.M. (1994) Design of a temporary Radioactive waste storage facility. Radiat. Phys. Chem. Vol. 44, 1/2, 149-156.

Alagöz, A.Z. & Kocasoy, G. (2008). Determination of the best appropriate management methods for the health-care wastes in Istanbul. *Waste Management*, *28*(7), 1227-1235.

Al-Khatib, I.A., Kontogianni, S., Nabaa, H.A. and Al-Sari, M.I. (2015). Public perception of hazardousness caused by current trends of municipal solid waste management. *Waste Management*, *36*, 323-330.

Alves –Girelli, C. M. (2016). The use of fingerprints available on the web in false identity documents: Analysis from a forensic intelligence perspective. *Forensic Science International*, 262, 84-96.

Aprilia, A., Tezuka, T. & Spaargaren, G. (2012) Inorganic and hazardous solid waste management: Current status and challenges for Indonesia. *Procedia Environmental Sciences*. 17, 640-647.

Arena, U., Mastellone, M. L., & Perugini. (2003). The environmental performance of alternative solid waste management options: a life cycle assessment study. *Chemical Engineering Journal*, 96, 207-222.

Beaven, R. P., Knox, K., Gronow, J. R., Hjelmar, O., Greedy, D., Scharff, H. (2014) A new economic instrument for financing accelerated landfill aftercare. *Journal of Waste Management.*34, 1191- 1198.

Blenkharn, J. I., (2006) Standards of clinical waste management in UK hospitals. *Journal of hospital infection*. 62, 300-303.

Bobnaite, V., Tarvydas, D. (2014) Financing instruments and channels for the increasing production and consumption of renewable energy: Lithuanian case. *Journal of Renewable and Sustainable Energy Reviews. 38, 259-276.*

Brown, P. (2009) Toxic waste in our midst: Towards an interdisciplinary analysis. *Journal of of Environmental Management.* 90, 1559-1566.

Corvellec, H. (2016) A performative definition of waste prevention. *Waste Management*, 52, 3–13.

Couth, R. & Trois, C. 2012) Sustainable waste management in Africa through CDM projects. *Waste Management*. 32, 2115-2125.

Ewijk, S. V., & Stegemann, J. A. (2016) Limitations of the waste hierarchy for achieving absolute reductions in material throughput. *Journal of Cleaner Production*, 132, 122-128.

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinee, J.,Heijungs, R., Hellweg, S., Koehler, A.,Pennington, D., & Suh. (2009) Recent developments in Life Cycle Assessment. *Journal of Environmental Management*, 91, 1-21.

Fischhendler, I. (2007) Escaping the "polluter pays" trap: Financing wastewater treatment on the Tijuana–San Diego border. *Ecological economics*, 6 3, 4 8 5 – 4 98.

Gharfalkar, M., Court, R., Campbell, C., Ali, Z., & Hillier, G. (2015) Analysis of waste hierarchy in the European waste directive 2008/98/EC. *Waste Management*, 39, 305–313.

Godfrey, L. (2007) Facilitating the improved management of waste in South Africa through a national waste information system. *Waste Management*. 28, 1660-1671.

Godfrey L., Nahman A. (2010) Economic instruments for solid waste management in South Africa: Opportunities and constrains. *Resources, Conservation and Recycling*. 54, 521-531.

Gouin, T. (2010) The precautionary principle and environmental persistence: prioritizing the decision-making process. *Environmental science & Policy*, 13, 175 – 184.

Guerrero, L.A., Maas, G. & Hogland, W. (2013). Solid waste management challenges for cities in developing countries. *Waste management*, *33*(1), 220-232.

Gu, B., Zhu, W., Wang, H., Zhang, R., Liu, M., Chen, Y., Wu, Y., Yang, X., He, S., Cheng, R., Yang, J. & Bi, J. (2014) Household hazardous waste quantification, characterization and management in China's cities: A case study of Suzhou. *Waste Management*. 34, 2414-2423.

Hamilton, S. F., Sproul, T. W.,Sunding, D., & Zilberman, D. (2013) Environmental policy with collective waste disposal. *Journal of Environmental Economics and management*, 66, 337-346.

Hossain, M. S., Santhanam, A.,Norulaini, N. A. N., & Mohd Omar, A. K. (2011) Clinical solid waste management practices and its impact on human health and environment – A review. *Journal of Waste Management*. 31, 754-766.

Hu, K., Hipel, K.W. & Fang, L. (2009) A conflict model for the international hazardous waste disposal dispute. Journal of Hazardous Material, 172, 138-146.

Ikau, R., Joseph, C. and Tawie, R. 2016). Factors Influencing Waste Generation in the Construction Industry in Malaysia. *Procedia-Social and Behavioral Sciences*, *234*, 11-18.

Inglezakis, V.J. & Moustakas, K. (2014) Household hazardous waste management: A review. *Journal of Environmental Management*. 150, 310-321.

Kuchibanda, K. & Mayo, A.W. (2015). Public Health Risks from Mismanagement of Healthcare Wastes in Shinyanga Municipality Health Facilities, Tanzania. *The Scientific World Journal*, *2015*.

Kluczek, A. (2014) Application of best available techniques in an enterprise producing heating devices. *Journal of Cleaner Production*. 83, 444-453.

Kirby, M. F., Gioia, R., & Law, R. J. (2014). The principles of effective post-spill environmental monitoring in marine environments and their application to preparedness assessment. *Marine Pollution Bulletin*, 82, 11–18.

Kotze, L. J. (2006) Improving unsustainable governance in South Africa: The case for holistic governance. *Potchefstroom electronic law Journal, 9, 1-44.*

Kumar, R., Somrongthong, R. & Ahmed, J., 2016. Impact of waste management training intervention on knowledge, attitude and practices of teaching hospital workers in Pakistan. *Pakistan journal of medical sciences*, *32*(3), 705.

LIorach-Massana, P., Farreny, R., & Oliver-Sola, J. (2015) Are Cradle to Cradle certified products environmentally preferable? Analysis from an LCA approach. *Journal of Cleaner Production*. 93, 243-250.

Liu, W.,Liu, S., & Huang, G. (2016) Research on the sorting reclaim system of municipal solid waste based on the concept of "cradle to cradle. *Procedia Environmental Sciences*, 31, 482 – 490.

Luppia, B., Parisi, F., & Rajagopaland, S. (2015) The rise and fall of the polluter-pays principle in developing countries. *International Review of Law and Economics*, 32,135–144.

Manga, V.E., Forton, O.T., Mofor, L.A. & Woodard, R. (2011) Health care waste management in Cameroon: A case study from the Southwestern Region. *Resources, Conservation and Recycling*. 57, 108-116.

Manyele, S.V. & Lyasenga, T.J. (2010). Factors affecting medical waste management in low level health facilities in Tanzania SV. *African Journal of Environmental Science and Technology*, *4*(5).

Mapes, A. A., Kloosterman, A. D., de Poot, C. J., & van Marion, V. (2016) Objective data on DNA success rates can aid the selection process of crime samples for analysis by rapid mobile DNA technologies. *Forensic Science International*, 264, 28-33.

Marshall, R.E. & Farahbakhsh, K. (2013) Systems approaches to integrated solid waste management in developing countries. *Waste management*, 33, 988-1003.

Massoud, M. A., Fayad, R., Kamleh, R., & E-L FADEL, M. (2010) Environmental Management System (ISO 14001) Certification in Developing Countries: Challenges and Implementation Strategies. *Environ. Sci. Techno,* 44, 1884–1887.

McLean, M.,Watson, H. K., & Muswema, A. (2007) Veterinary waste disposal: Practice and policy in Durban. South Africa (2001–2003). *Journal of waste management*, 27, 902-911.

Mena, C., Adenso-Diaz, B. & Yurt, O. (2011). The causes of food waste in the supplier–retailer interface: Evidences from the UK and Spain. *Resources, Conservation and Recycling*, *55*(6), 648-658.

Moh, Y. C., & Manaf, L. A. (2017) Solid waste management transformation and future challenges of source separation and recycling practice in Malaysia. *Resources, Conservation and Recycling*, 116, 1–14.

Montpetit, S. A., Fitch, I. T., O'Donnell, P. T. (2005) A Simple Automated Instrument for DNA Extraction in Forensic Casework. *Journal of Forensic Science*,50, 1-9.

Nahman, A. & Godfrey, L. (2009) Economic instruments for solid waste management in South Africa: Opportunities and constrains. *Resources, Conservation and Recycling*. 54, 521-531.

Oliveira, J. G., Oliveira, O. J., Ometto, A. R. & Ferraudo, A. S. (2016) Environmental Management System ISO 14001 factors for promoting the adoption of Cleaner Production practices. *Journal of Cleaner Production*, 133, 1384-1394.

Ojeda-Benitez, S., de Vega, C. A., Ramı´rez-Barreto, M. E. (2003) Characterization and quantification of household solid wastes in a Mexican city. *Journal of Resources, Conservation and Recycling*, 39, 211-222.

Papu-Zamxaka, V., Harpham, T. & Mathee, A. (2010) Environmental legislation and contamination: The gap between theory and reality in South Africa. *Journal of Environmental Management*. 91, 2275-2280.

Papargyropoulou, E., Lozano, R., Steinberger, J. K., Wright, N., & bin Ujang, Z. (2014). The food waste hierarchy as a framework for the management of food surplus and food waste. *Journal of Cleaner Production*, 76, 106-115.

Phuong Nguyen, T.T., Zhu, D. & Phong Le, N. (2015) Factors influencing waste separation intention of residential households in a developing country: Evidence from Hanoi, Vietnam. *Habitat International*. 48, 169-176.

Pieraggostin, C., Musati, M. C., & Aguirre, P. (2011). On process optimisation considering LCA methodology. *Journal of Environmental Management*. 96, 43-54.

Raymond, J. J., van Oorschot, R. A. H., Walsh, S. J., Roux, C. (2008). Trace DNA analysis: Do you know what your neighbour is doing? A multi-jurisdictional survey. *Forensic Science International: Genetics*, 2, 19-28.

Rossi, V., Cleeve-Edwards, N., Lundquist, L., Schenker, U., Dubois, C., Humbert, S., & Jolliet, O. (2015) Life cycle assessment of end-of-life options for two biodegradable packaging materials: sound application of the European waste hierarchy. *Journal of Cleaner Production*, 86, 132-145.

Schmidt, K. (2016) Explaining and promoting household food waste-prevention by an environmental psychological based intervention study. *Resources, Conservation and Recycling*, 111, 53–66.

Scudder, K. and Blehm, K.D. (1991). Household hazardous waste. *J. Environ. Health*, *53*(6), 18-20.

Sharholy, M., Ahmad, K., Mahmood, G. and Trivedi, R.C. (2008). Municipal solid waste management in Indian cities–A review. *Waste management*, *28*(2), 459-467.

Sharma, S.K. & Gupta, S. (2017). Healthcare waste management scenario: A case of Himachal Pradesh (India). *Clinical Epidemiology and Global Health*.

Sheng, H. X., Ricci, P. F., & Fang, Q. (2015). Legally binding precautionary and prevention principles: Aspects of epistemic uncertain causation. *Environmental Science & Policy*, 54,185–198.

Silvestre, J.D., de Brito, J., & Pinheiro, M.D. (2014) Environmental impacts and benefits of the end-of-life of building materials e calculation rules, results and contribution to a “cradle to cradle” life cycle. *Journal of Cleaner Production*, 66, 37-45.

Singh, K., Oates, C., Plant, J., & Voulvoulis, N. (2015) undisclosed chemicals — implications for risk assessment: A case study from the mining industry. Journal of Environment International, 68, 1-15.

Stewart-Evans, J., Hall, L., Czerczak, S., Manley, K., Dobney, A., Hoffer, S., Pałaszewska-Tkacz, A., & Jankowska, A. (2014) Assessing and improving cross-border chemical incident preparedness and response across Europe. *Environment International*, 72, 30–36.

Tattoli, L., Tsokos, M., Sautter, J., Anagnostopoulos, J., Maselli, E.,ngravallo, G.,Delia, M & Solarino, B. (2014) Postmortem bone marrow analysis in forensic science: Study of 73 cases and review of the literature. *Forensic Science International*, 234, 72-78.

Tekayak, D. (2016) from ‘polluter pays’ to ‘polluter does not pollute. Geoforum, 71, 62–65.

Thomas, L. & Krebs, C.J. (1997). A review of statistical power analysis software. *Bulletin of the Ecological Society of America*, *78*(2),126-138.

Virkler, K., & Lednev, I. K. (2009) Analysis of body fluids for forensic purposes: From laboratory testing.to non-destructive rapid confirmatory identification at a crime scene. *Forensic Science International*, 188, 1-17.

Wagner, J. & Bilitewski, B. (2009). The temporary storage of municipal solid waste – Recommendations for a safe operation of interim storage facilities. *Waste Management*. 29, 1693-1701.

Wager, P.A., Eugster, M., Hilty, L.M., & Som, C. (2005) Smart labels in municipal solid waste — a case for the Precautionary Principle. *Environmental Impact Assessment Review*, 25, 567– 586.

Wiltshire, P. E. J., Hawksworth, D. L., Webbe, J. A., & Edwards, K. J. (2015) Two sources and two kinds of trace evidence: Enhancing the links between clothing, footwear and crime scene. *Forensic Science International*, 254, 231-242.

Wiese, I. H. (1976) Pesticides and the South African Population. *South African Medical Journal.*

Wittmaier, M., Langer, S. & Sawilla, B. (2009) Possibilities and limitations of life cycle assessment (LCA) in the development of waste utilization systems – Applied examples for a region in Northern Germany. *Water Management*. 29, 1732-1738.

Yilmaz, O., Anctil, A. & Karanfil, T. (2014) LCA as a decision support tool for evaluation of best available techniques (BATs) for cleaner production of iron casting. *Journal of Cleaner Production*. 105, 337-347.

Yilmaz, O.,Kara, B. Y., & Yetis, U. (2016) Hazardous waste management system design under population and environmental impact considerations. *Journal of Environmental Management*, 1-12.

Zhu, L., & Zhao, Y. C. (2015) A feasibility assessment of the application of the Polluter-Pays Principle to ship-source pollution in Hong Kong. *Marine Policy*, 57, 36–44.