

**INVESTIGATING THE EFFECT OF LEACHATE FROM SOLID
WASTES MANAGEMENT PLANT ON SURFACE WATER
QUALITY IN MBAI**

BY

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18/U/GMEW/22178/PD

**A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH
AND GRADUATE TRAINING IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE IN
WATER AND SANITATION ENGINEERING DEGREE OF
KYAMBOGO UNIVERSITY**

SEPTEMBER, 2024

DECLARATION

I, Alunyu Denis, hereby declare that this submission is my own work and that to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree of any university or other institute of higher learning except where due acknowledgement has been made in the text and reference list.

Signed: Date:

APPROVAL

The undersigned approve that they have read and hereby recommend for submission to Directorate of Research and Graduate Training of Kyambogo University, a dissertation entitled “Investigating the effect of leachate from solid waste management plant on surface water quality in Mbale City” in partial fulfillment of the requirements for the award of Master of Science in Water and Sanitation Engineering Degree of Kyambogo University.

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ABSTRACT

This study investigated the effect of leachate from solid wastes composite plant on River Namatala water quality in Mbale City. Data was collected on the amount of solid wastes generated per day within Mbale city. Concentrations of water pollutants in the leachate produced from the decomposed solid wastes were tested in the laboratory. Possibility of treating lead as a pollutant using low cost adsorbent was explored. The results indicated that 273.5 tons of solid wastes are collected per day and deposited at the wastes management plant. Of this total, biodegradable and non-biodegradable wastes constituted 84.4% and 15.6%, respectively. The concentrations or values of water pollutants especially total phosphorus, chemical oxygen demand, total nitrogen, lead and electrical conductivity from the leachate were higher than the limits recommended by the World Health Organisation (WHO). The heavy metals such as copper, iron, nickel, silver, chromium had lower values compared to maximum acceptable limit set by WHO. However, heavy metals should not be ignored as they are potential sources of pollution to nearby environments. The differences in the means of upstream and downstream pH, iron, chromium, lead, copper, total nitrogen, total phosphorus concentration and electrical conductivity were statistically significant ($p < 0.05$) while nickel, silver chemical oxygen demand, biochemical oxygen demand were statistically not significant ($p > 0.05$). Raw avocado seeds had a higher lead removal efficiency (93.97%) compared to activated avocado seeds (89.7%). The households in Mbale city should be sensitized on the need for separation of wastes into biodegradable and non-biodegradable. Water from River Namatala should be first treated before its domestic use.

ACKNOWLEDGEMENT

My gratitude goes to Mbale City that allowed my research to be conducted at their solid waste management plant. I thank the Principal of College of Natural Sciences at Makerere University for granting permission to undertake laboratory tests at the Biochemistry Department. Equally, I thank the staff at the Biochemistry laboratory especially Mr. Mukisa Ambrose for helping me in identifying sampling points, sampling and water quality testing in laboratory. Appreciation also goes to chemistry department at Kyambogo University for the assistance rendered during the laboratory tests at the laboratory. I am also grateful to my supervisors Dr. Charles Onyutha and Dr. Anne Nakagiri for their guidance from the start to successful completion of this research. I thank Mr. Waluya Nathan of Mbale City for his support in organizing some of the key staff at the waste plant and participating in pre-field planning meetings.

DEDICATION

To my family, late parents and my brothers who have made tremendous contributions towards my education and up bring up to now.

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LIST OF ABBREVIATIONS AND ACRONYMS

BMP	Biochemical methane potential
BOD	Biochemical Oxygen demand
COD	Chemical oxygen demand
DI	Degradation index
DO	Dissolved Oxygen
DOC	Dissolved Organic Compounds
EC	Electrical conductivity
GPS	Global Positioning System
HRT	Hydraulic Retention Time
NDP II	Second National Development plan
NEMA	National Environment Management Authority
PCB	Polychlorinated biphenyl
SDG	Sustainable Development Goal
TDS	Total Dissolved Solids
TOC	Total organic compounds
TS	Total Solids
TSS	Total Suspended Solids
VFA	Volatile fatty acids
XOC	Xenobiotic organic compounds

CHAPTER ONE: INTRODUCTION

1.1 Background

Every year, about two billion tonnes of solid wastes are generated within municipalities and cities across the world (Kaza et al., 2018). More than 33% of municipal wastes tends to be undertaken in environmentally hazardous manner (Kaza et al., 2018). Low-income nations are anticipated to produce three times as much solid garbage by 2050 (Kaza et al., 2018). However, waste production is expected to decrease drastically due to prevention, reduction, recycling and reuse by the year 2030 (United Nations, 2014). World cities and municipalities are expected to improve on their air quality and also other waste management through prioritizing them in their programmes by the year 2030 (United Nations, 2014). This situation calls for immediate and serious work in urban authorities in managing solid wastes much better than the current practice.

Over two million informal waste pickers are involved in recycling business with markets available internationally (Hoorweg, 2012). Urbanization is occurring considerably more slowly than the volume of solid garbage generated globally (Hoorweg, 2012). Cities that are unable to manage their solid wastes effectively are not able to offer basic social services such as health, education, transportation to their residents (World Bank, 2012). This means that provision of social services is impacted negatively by poor solid waste management. Solid waste management institutions and authorities have been formed in most countries with a view of developing policies and legislation for waste management (World Bank, 2018).

However, over 70 % of local public entities are directly involved in solid waste management services provision with central government providing supervisory role (Kaza et al., 2018). The disposal of solid waste occurs in a variety of methods around the world, including 37% in landfills, 8% in sanitary landfills with gas collecting systems, 33% in open dumping, 19% recycling, and 11% incineration (Kaza et al., 2018). These statistics show that there is a significant direct and immediate pollution of surface water resources from storm run-off from especially open dumping and incinerated solid wastes.

Contaminated leachate generation is still an unavoidable consequence of using landfills for waste disposal, even if landfill technology has advanced from uncontrolled, open dumps to highly engineered facilities meant to reduce any negative effects the garbage may have on the environment (El-Fadel et al.,1997). Therefore, if left unchecked, landfill leachates can result in a major environmental hazard by continuously discharging heavy metals (Al-Wabel et al.,2011). Leachate is created when the moisture content of the solid wastes surpasses its field capacity, which is the highest amount of moisture that can be held in a porous media without causing downward percolation (El-Fadel et al.,1997).

African cities are working hard to manage their solid waste, and there is a push to limit garbage output through public awareness campaigns (Kaza et al., 2018). The limited financial resources being faced by governments of Africa, rapid population growth have made waste services not being prioritized by many governments among other services (Wilson, 2007; Kaza et al., 2018). Enforcement of legislation on unregulated disposal and open dumping is not done due to the limited resources

(Wilson, 2007). This has made the urban poor involved in the informal sector recycled valuable wastes in the developing countries of Africa to earn a living in urban centers (UN-Habitat, 2010). Micro-franchising was experimented by International Labour Organization (ILO) in Dar es salaam, Moshi and Nairobi which resulted into increased collection of wastes in East Africa by 2006 (UN-Habitat, 2010).

In Uganda, solid waste management responsibility has been decentralized to the respective urban entities according to the Local Government Act (1997) and the Constitution of Uganda (1995). In the Second National Development plan (NDP II), Government of Uganda constructed twelve composite waste management infrastructures facilities for twelve municipal councils/cities through projects under National Environment Management Authority. The twelve municipalities/cities were producing between 80 metric tons to 250 metric tons per day of solid wastes and the management of solid waste was being done for a maximum of 70 metric tons per day in each of these municipalities/cities before construction of the said solid wastes management infrastructure facilities (NEMA, 2017).

Mbale city was among the cities that benefited from the municipalities/cities waste composite project. Currently, 150 tons of solid waste is being produced per day in Mbale (NEMA, 2016). The solid waste characteristics include household wastes, commercial wastes, market wastes, plastics, papers, batteries and many others which are difficult to classify. Mbale city used to dump solid waste in landfill before construction of solid waste plant. The solid wastes are currently being deposited at the waste composite plant located in Doko cell. The leachates produced from solid

wastes have become health hazards in and around households of the study area, polluting surface water sources of River Namatala and the leachate have also affected vegetation cover. Therefore, this research was intended to investigate the effect of leachates from the decomposing waste to surface water quality and propose possible solutions on natural treatment system using avocado seeds in order to avoid the effects on the environment. Natural or activated avocado seed has been proven to be an effective cheap material for making adsorbents for the lessening of water pollution (Boeykens et al., 2019). Avocado seed fibers are a cheap, sustainable material with less temperature dependence that is perfect for wastewater treatment (Muthuraman et al., 2021).

1.2 Problem statement

In order to lessen their adverse effects on the environment, towns and municipalities are urged by the United Nations in line with the Sustainable Development Goal (SDG) target 11.6 to enhance solid waste management by 2030 (United Nations, 2014). Following this SDG target, Government of Uganda in her Vision 2040 constructed 12 solid waste management facilities in 12 cities/municipalities with modern equipment (NDP II, 2015).

Mbale City Council is collecting solid wastes and disposing at the wastes composite plant site located 247 m from River Namatala in Doko cell.

Despite these efforts of collecting solid wastes by Mbale City Council, there are complaints of scattered solid wastes around the site, bad odours and contamination of water sources by leachates from solid waste by the members of households around the site. This has led to outbreaks of water related diseases like cholera with

153 cases reported and seven deaths for a period of five months (Ministry of Health, 2018). Other studies done on solid waste landfills identified institutional capacity gaps to manage solid waste sustainably (Mwiganga, 2005). Lohri et al., (2014) also identified the need to understand working relationship between cities and private sector in managing solid wastes.

Therefore, the study determined the quantity and characteristics of solids wastes being generated and made appropriate recommendation on waste management system to be adopted by Mbale city and also treated the heavy metal pollutants in leachate using avocado seeds as a low-cost material adsorbent.

1.3 Objectives

1.3.1 Main objective

The main objective of the study was to investigate the effect of leachate from solid wastes composite plant on surface water quality of River Namatala in Mbale City

1.3.2 The specific objectives

The specific objectives of the study entailed:

- i) characterizing solid wastes generated in Mbale City.
- ii) quantifying the concentrations of water pollutants from the leachates.
- iii) determining the effect of leachates on River Namatala water quality.
- iv) exploring the treatment of a key water pollutant from the leachates using avocado seeds.

1.4 Research questions

The following research questions were used in conducting this study:

- i) What are the characteristics of solid wastes generated in Mbale City?
- ii) What are the concentrations of water pollutants from leachates?
- iii) What are the effects of leachates on River Namatala water quality?
- iv) How effectively can avocado seeds treat a detected water pollutant from leachates?

1.5 Research rationale and justification

Target 6.3 of the SDG urges governments to reduce pollution, stop dumping, limit the release of hazardous chemicals and wastewater, significantly increase global recycling and safe reuse of materials, and reduce the amount of untreated wastewater by half by 2030 (United Nations, 2014). These actions will improve water quality by 2030 for the world community. The African Union Agenda (AUA) 2063, also urges African governments to recycle 100% of urban wastes by 2063 (AUA, 2015). Following this SDG and the African Union 2063 agenda, Government of Uganda in her Vision 2040 constructed Mbale city solid waste management plant among the 12 solid waste management plants in 12 municipal councils and cities and handed over their operations and maintenance to city councils and municipal councils (Uganda Vision 2040, 2015).

Despite these attempts, the functionality of Mbale city solid waste management facility is still a big challenge with wastes being littered everywhere around sites, none sorting of waste and little budget affecting the proper functionality of this waste plant. This has led to outbreaks of water related diseases like cholera with 153 cases reported and seven deaths for a period of five months in Mbale city

(Ministry of Health, 2018). Other studies done on solid waste landfills identified institutional capacity gaps to manage solid waste sustainably (Mwiganga, 2005).

This therefore called for investigation to ascertain if there was any effect of leachates from the waste composite plant on quality of water sources in Mbale City. The study was intended to generate knowledge on effects of leachates from solid wastes on quality of surface water sources.

1.6 Significance of the study

The urban authorities are anticipated to benefit from the study's findings in the following areas:

- i) For proper planning and budgeting during construction and management of solid waste sites so that leachates do not contaminate water sources.
- ii) This will in turn reduce the cost of water supplies.
- iii) The findings can also encourage the city council to have an effective leachate management plan on reducing on their impact on the environment.
- iv) Furthermore, the study will function as a resource for other scholars who may be interested in conducting additional research on effects of leachates from solid wastes on water sources quality.

1.7 Scope of the study

This section provides an overview of the areas of study, time range, and subject matter, as well as the span of time, geography, and substance.

1.7.1 Time scope

The study was done during the rainy period of the year which was May to October, 2022. This was deliberately done to obtain the maximum production of leachates from solid wastes during this period. Therefore, data from dry season was out of scope of this research.

1.8.2 Geographical scope

The study was done on the existing waste management plant located in Mbale city in eastern Uganda as shown in Figure 1.1. This waste management plant is owned and managed by the city authority. Data was collected from all the two divisions of Mbale city.

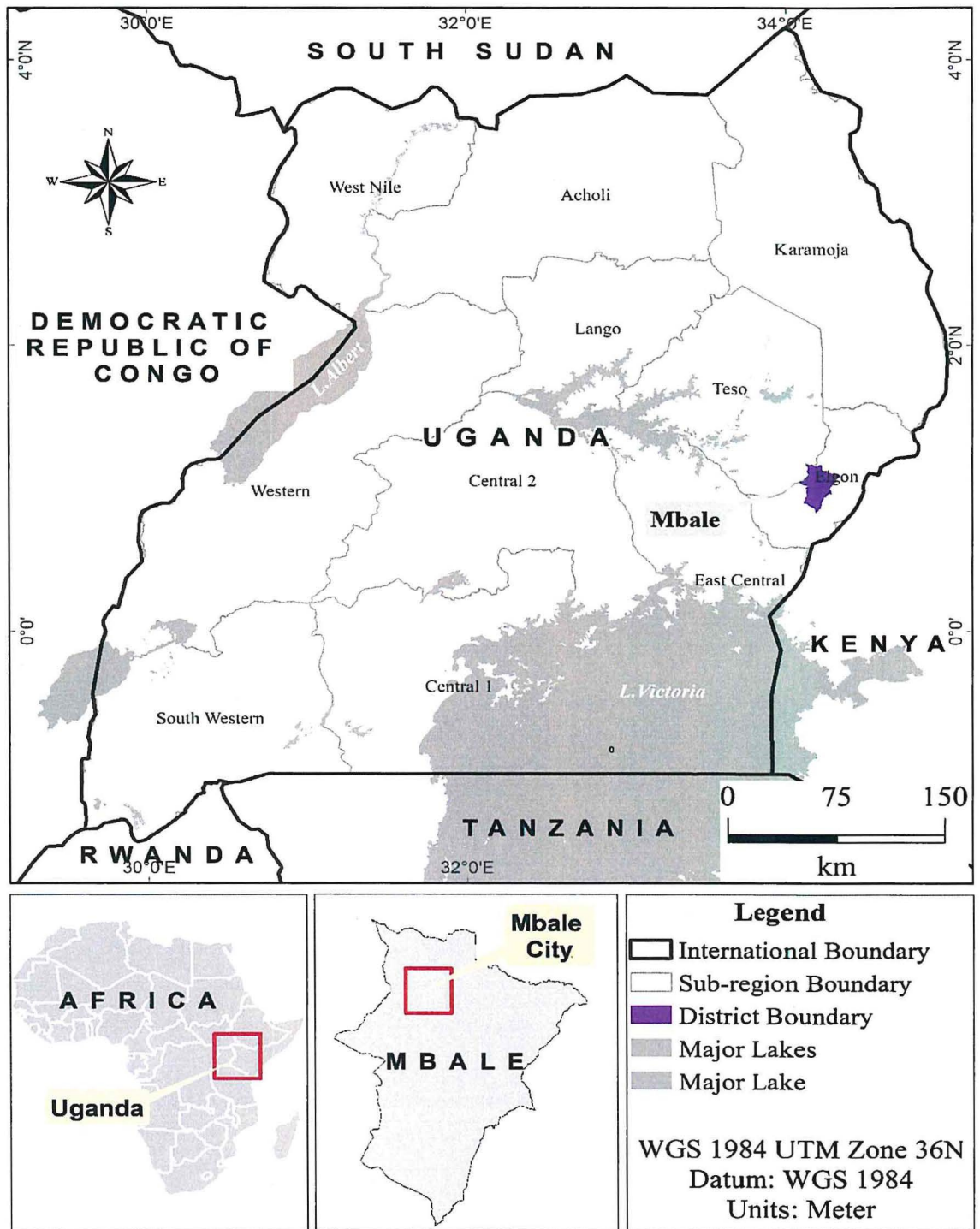


Figure 1. 1: Research study area location map

1.8.3 Content Scope

The study was done mainly on the composition and quantity of solid wastes, quantity of leachates, quality of the leachates and the surface water quality of River Namatala.

1.9 Conceptual framework

The conceptual framework shows the relationship between the different parameters found in leachates from solid wastes as the independent variable and surface water quality as the dependent variable.

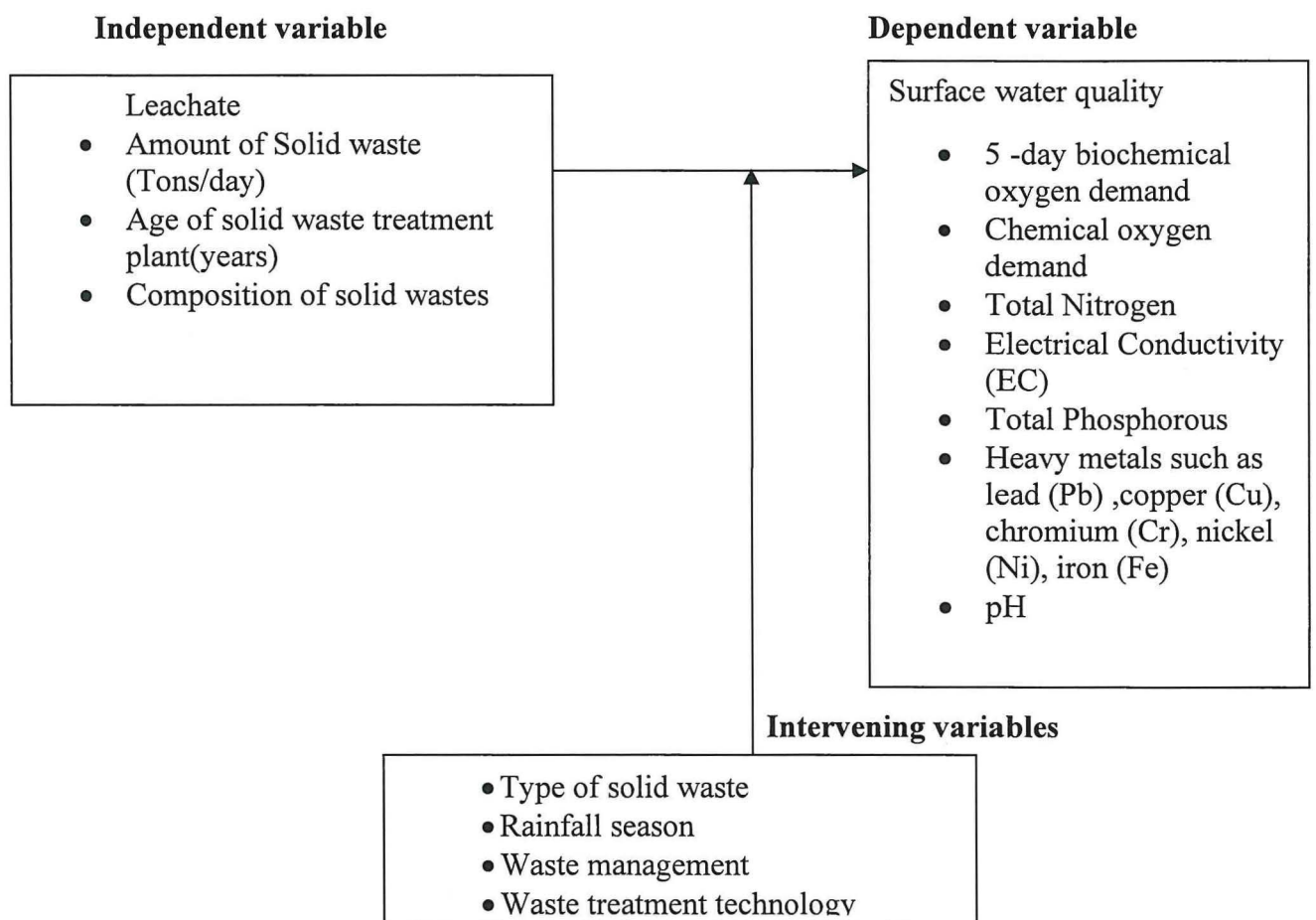


Figure 1. 2: Conceptual framework

From the conceptual framework above, it can be hypothesized that leachates from solid wastes (through domestic, industrial wastes, agricultural waste, construction wastes) may lead to contamination of surface water along the river while the reverse can be true if the leachates are not toxic.

1.10 Summary of introduction

The leachates produced depend on the quantity and kind of solid wastes, the age of the waste plant, and the technology for treating solid wastes. However, leachate production is accelerated by the amount of rainfall, moisture content and waste management practices. Consequently, physical, biological and chemical characteristics of solid wastes were reviewed in the chapter two that follows.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Review of literature on characteristics of solid wastes, characteristics of leachate and pollutant treatment options have been structured based on the various specific objectives. The chapter concluded with identified gaps and conceptual framework for this research.

2.2 Characterization of solid waste

Characterizing solid waste is crucial for a number of reasons, including: (1) data collection for planning and economic analysis; (2) design, management, and operation of solid waste disposal systems or facilities for recovering materials and energy; (3) renovation of solid waste facilities; and (4) solid waste plant optimization and emission monitoring (Nyoti et al., 2016). Solid waste characteristics are influenced by societal structure and income levels (Ozcan et al., 2016). This means that solid waste generation rates and character depends on population at a particular place and time and accordingly varies with time.

Solid waste composition is assessed in either fieldwork or laboratory (Bareither et al., 2010). The fieldwork assessment option introduces flexibility of solid waste analysis in situations where laboratory analysis is either unavailable or available but prohibitively expensive. Source-based and type-based are the two broad classification categories of solid waste (Nyoti et al., 2016). Conventionally, solid wastes types are characterized into three main groups of physical, chemical and biological (Bareither et al., 2010; Nyoti et al., 2016; Palanivel and Sulaiman,

2014). Data and information on source, generation rates, kind of wastes produced, and composition are necessary for effective solid waste monitoring and management (Ozcan et al., 2016; Palanivel and Sulaiman, 2014; Phuong, Yabar and Mizunoya, 2021).

With data on composition of solid wastes, the predictive behaviour of individual sanitary landfills in generating leachates and gases can be understood (Bareither et al., 2010). Parameters for solid waste characterization are moisture content, ash content, volatility, fixed carbon, density and calorific value (Nyoti et al., 2016). The sections that follow characterizes composition of solid wastes.

2.2.1 Physical characteristics of solid wastes

Physical characterization parameters include moisture content and calorific content (Nyoti et al., 2016; Ozcan et al., 2016) and ash content and density (Nyoti et al., 2016). Calorific content, which is closely related to the quantity of chemical energy that can be transformed into different forms of energy is measured by moisture content (Ozcan et al., 2016). Since moisture content expectantly inhibits combustion of solid waste, caloric value and moisture content are expected to correlate inversely. Equation 2.1 by Ozcan et al. (2016) explains how to measure a solid waste's moisture content.

$$m = \{w - d|w\}X 100..... [2.1]$$

where

w: initial weight of sample, (kg)

d: weight after being dried under 105, (kg)

m: moisture content (%).

Plastics, paper, metals and glass are common types of solid wastes (Shatnawi, 2018). Mixed plastics, which include all types of plastic garbage, are the third-highest category of waste in Oman, ranging from 16.40% by weight and 34.01% by volume in winter to 16.60% by weight and 38.91% by volume in summer (Palanivel and Sulaiman, 2014). In Vietnam, plastics together with paper also ranked second in solid waste composition analysis (Phuong, Yabar and Mizunoy, 2021). Plastics have high calorific values and can therefore be recycled as alternative source for energy generation. The fourth-largest solid waste in Oman is made up of glass wastes, which vary in weight from 8% in the winter to 8.60% in the summer (Palanivel and Sulaiman, 2014). Glass that is recyclable can be valuable material as aggregate in construction. Other physical solid wastes include wood, rubber, ceramics and textiles (Phuong, Yabar and Mizunoya, 2021).

2.2.2 Biological characteristics of solid waste

In Uganda, biodegradable municipal solid wastes constitute over 90% of total solid wastes (Tibihika et al., 2021). Biodegradable wastes comprising mainly mixed food wastes constitute the major portion of biological wastes ranging from 65.80% (in summer) and 71.20 % (in winter) of the total municipal solid wastes collected in Oman (Palanivel and Sulaiman, 2014). The same pattern was reported by Phuong, Yabar and Mizunoya (2021) in Vietnam with food and garden wastes scoring 78.9 %.

In South Korea, biodegradable wastes comprised 81.8 % compared to 18.2 % of non-biodegradable wastes (Choi, Choi and Rhee, 2020). This composition was

without food wastes that was reportedly banned in 2005 to appear in solid waste streams in South Korea (Choi, Choi and Rhee, 2020).

In Turkey, Ozcan et al. (2016) also found that organic solid wastes that constitute the largest share at 57.69 % relates inversely with income level. Accordingly, the amount of leachate, bio-oxygen demand and sanitary land fill gas depends largely on the amount of food wastes (Palanivel and Sulaiman, 2014). This presents a major potential for resource recovery for valuable products like organic fertilizer. The second-largest biodegradable waste in Oman is paper accounting for 32.40% by weight and 39.76% by volume (Palanivel and Sulaiman, 2014). However, paper was found to be the leading waste with 40 % composition at a university campus (Shatnawi, 2018). The emergence of paper as the most leading waste was probably due to the nature of the source as being an academic institution where paper work abounds. Apart from being biodegradable, waste paper can be recovered for energy generation on account of its high calorific value.

Biodegradable solid wastes encourage the effective operation of bioreactor landfills, which should have the following desirable characteristics: increased methane production, quicker waste stabilization, in-situ leachate treatment, and increased waste settling (Bareither et al., 2010). This suggests that non-biodegradable solid wastes should be avoided as much as possible in solid waste streams. Volatile solids (VS), biochemical methane potential (BMP), cellulose (C), hemicelluloses (H), and lignin (L) levels are the parameters that affect the decomposition of solid waste (Bareither et al., 2010). Accordingly, degradation index (DI) was suggested as a

measure for solid waste biodegradation potential by (Bareither et al., 2010). This formula is as given in equation 2.2 by (Bareither et al., 2010).

$$DI = \left(\frac{BMP/VS_i - BMP/VS_f}{BMP/VS_i} \right) \times 100 \dots\dots\dots [2.2]$$

where:

DI=Degradability Index,

BMP/VS_i=the initial/fresh state and

BMP/VS_f= the final/degraded state.

The DI increases with increasing degradation (Bareither et al., 2010).

2.2.3 Chemical characteristics of solid waste

Chemical solid wastes include hazardous wastes (Phuong, Yabar and Mizunoya, 2021). Hazardous wastes are medical wastes, chemical wastes and some house hold wastes like used old batteries (Phuong, Yabar and Mizunoya, 2021). This implies used batteries that contain heavy metals like lead used in batteries are classified as chemical wastes. Ammonium nitrogen under high alkalinity ionizes into toxic ammonia (Slomczynska and Slomczynski, 2004). Further, ammonia concentrations increase and is major long-term constituent in leachates (Kjeldsen et al., 2002). This suggests that older landfills whose pH ranges 8.0 – 8.5 are toxic to life. Eluates is another source of toxicity in solid wastes (Slomczynska and Slomczynski, 2004). Heavy metals, pesticides, polychlorinated biphenyl (PCBs) and crude oil derivatives (Slomczynska and Slomczynski, 2004). Other parameters like pH, conductivity,

copper, zinc and chlorides are also feared to contribute to aquatic toxicity (Kjeldsen et al., 2002).

2.2.4 Conclusion on characterization of solid wastes

The broad two categories of solid wastes are organic and inorganic wastes. Organic wastes are mainly food and garden wastes that are biodegradable. Inorganic wastes that are non-biodegradable are mainly plastics. Both organic and inorganic wastes are recoverable and recyclable. Biodegradable wastes can be recovered for composting to yield organic manure. Plastics and paper are recoverable for use in incineration to generate energy. Organic wastes are the main generators of leachates and greenhouse gases in sanitary landfills. Chemical solid wastes are largely viewed in terms of their toxicity to human and animal lives. In this regard, chemical solid wastes include ammonium nitrogen, heavy metals, some medical wastes, pesticides, polychlorinated biphenyl (PCB) and crude oil derivatives.

Biodegradation of organics in landfills occurs largely under anaerobic conditions because of initial mechanical compaction and eventual self-weight compaction that reduces bulk density and porosity. This mechanism renders solid wastes in different landfills to be similar hence comparable. The heterogeneity of solid waste from one landfill to another, from one season to another, even within the same landfill, necessitates the characterization of solid waste in terms of physico-chemical and biological properties like density, moisture content, etc. and (physical characteristics/properties) calorific content, BOD, COD, etc. (bio-chemical characteristics/properties). These quantities were used to address the first specific

objective of this study which was to determine the characteristics of solid waste at the solid waste treatment plant within Mbale city.

2.3 Quantification of concentrations of water pollutants from the leachates

This section defines leachates and reviews its mechanism of formation and its various components.

2.3.1 Definition of leachates

Leachate is orange-brown to dark-brown liquid created when rainwater filters through buried solid waste in landfills that extracts chemicals or waste components (Greene and Reichert, 2016). Another alternative way of conceptualizing leachate is the product that results when precipitation infiltrates through solid waste layers (Slomczynska and Slomczynski, 2004). Leachate originates when water percolates through wastes laden with pollutants (Makan et al., 2015). A liquid that seeps into a landfill and either leaks out or is retained there is also known as leachate (Wdowwczyk and Szymanska-Pulikowska, 2020). All these definitions of leachate emphasize interaction of water (as solute) and solid waste pollutants (as solvents and particulates) to form leachates.

2.3.2 Mechanism of formation of leachates

Leachate is a byproduct of the mass transfer that takes place in a bioreactor between the solid phase (solid waste), the liquid phase (leachate), and the gas phase (mostly methane and carbon dioxide) (Al Sabahi et al., 2009). Inorganic ions and organic materials from the solid phase are solubilized or suspended in the liquid phase (Al Sabahi et al., 2009). The removal of soluble materials, the removal of soluble

products of chemical reactions, the dissolving of soluble materials, and the washing of particles and colloids are the mechanisms of leachate generation (Jahan et al., 2016).

Leachates are soluble organic and inorganic compounds and suspended solids whose flow varies with climate (Naveen, Sivapullaiah and Sitharam, 2014). This suggests that the concentration of leachates varies with time depending on the rain season of a particular place. However, biodegradation of organics and compaction solid wastes in landfills makes it anaerobic (Kjeldsen et al., 2002). Therefore, what solid wastes are made of in different landfills is essentially similar (Kjeldsen et al., 2002).

The parameters of leachate whose values depend on the age of solid waste landfill can be determined in terms of pH (increases with age), BOD (decreases with age), COD (decreases with age) and ammonium nitrogen (decreases with age) (Greene and Reichert, 2016; Jahan et al.; 2016). Temperature, moisture, pH, air (oxygen), soil properties, land fill engineering, and operating characteristics are other elements that impact the composition of leachates (Al Sabahi et al., 2009; Choi, Choi and Rhee, 2020; Naveen, Sivapullaiah and Sitharam, 2014; Yusmartini et al., 2014). The inherent water in solid wastes (i.e. other than precipitation) also contributes to the formation of leachates (Slomczynska and Slomczynski, 2004). This is true because biodegradable solid wastes that constitute the largest element in solid wastes are largely water-laden.

Self-loading weight (weight of solid waste) and soil hydraulic conductivity are some additional factors that influence migration of leachate (Choi, Choi and Rhee, 2020).

Self-loading weight that induces effective soil pore pressure together with hydraulic conductivity combine to satisfy Darcy's law in facilitating leachate migration. Choi, Choi and Rhee (2020) consider moisture as the most influential factor in leachate development. Humid climates with 50-100 cm annual precipitation accelerates leachate generation (Kjeldsen et al., 2002). This is probably due to the unique property of water as a universal solute dissolving most of the compounds in solid waste to create leachate.

The variation of leachate parameters is due to chemical degradation and biological decay overtime (Naveen, Sivapullaiah and Sitharam, 2014). Waste stabilization of solid wastes occurs in four phases of aerobic phase, anaerobic acidogenesis, anaerobic initial methanogenesis and stable methanogenesis (Kjeldsen et al., 2002).

2.3.3 Categories of components in leachates

Dissolved organics, inorganic macro-components, heavy metals, and xenobiotic organic chemicals are the four primary types of leachate contaminants (Kjeldsen et al., 2002; Naveen, Sivapullaiah and Sitharam, 2014). These four groups in total contain 23 indicators (Wdowwczyk and Szymanska-Pulikowska, 2020). The main parameters of leachates include salts, metals and organics (Greene and Reichert, 2016). These parameters are reviewed separately in the following sub-sections. Transition phase (0–5 years), acid formation (5–10 years), methane fermentation (10–20 years), and final maturation (>20 years) are the four stages of solid waste stabilization (Yusmartini et al., 2014). The 0-5 years is regarded as young landfill where the pH ranges 3.7- 6.5 (Slomczynska and Slomczynski, 2004). The

intermediate phase is weakly neutral with pH range 7.0 -7.6 while older phases is strongly alkaline with pH range 8.0 - 8.5 (Slomczynska and Slomczynski, 2004).

The composition in terms of solid waste characterization parameters of BOD, COD, ammonia, TOC, TDS and TSS varies (Jahan et al.; 2016; Kjeldsen et al., 2002; Yusmartini et al., 2014). The age of landfill is considered young (< 5 years) characterized by BOD/COD ratio of > 0.63 and old and stable (> 5 years) when BOD/COD ratio is < 0.1 (Naveen, Sivapullaiah and Sitharam, 2014; Al Sabahi et al., 2009). However, Wdowwczyk and Szymanska-Pulikowska (2020) extend early limit young age of landfill up to 10 years characterized by acidic pH that does not exceed 6.6. Conversely, mature landfills are those above 10 years with pH above 7.5 and also characterized by lower fluctuations in composition (Wdowwczyk and Szymanska-Pulikowska, 2020). Most methanogenic leachates have BOD/COD ratios of < 0.1 (Kjeldsen et al., 2002). The BOD/COD ratio represents the biodegradability of organic compounds in solid waste or leachates (Kjeldsen et al., 2002). Landfills of < 5 years yields BOD/COD ratios in the range 0.22 - 0.70 averaging 0.54 while longer landfill exploitations of > 5 years yields BOD/COD ratios in the range 0.08-0.70 averaging 0.31 (Slomczynska and Slomczynski, 2004).

2.3.3.1 Dissolved organic matter in leachates

Food and green wastes constitute most biodegradable wastes that appear in leachates after disposal within the first few months (Naveen, Sivapullaiah and Sitharam, 2014) and are quantified as COD and TOC (Kjeldsen et al., 2002). Dissolved organic compounds occur during acidogenesis phase of waste stabilization where volatile fatty acids (VFAs) dominate about 95% of total organic compounds (TOCs)

(Naveen, Sivapullaiah and Sitharam, 2014; Slomczynska and Slomczynski, 2004). Similarly, more than 95% of DOC consist of VFAs (Kjeldsen et al., 2002). This is consistent with earlier study of Slomczynska and Slomczynski (2004) in which high strength leachates comprised 90 % of total organic compounds as organic acids (mainly acetic, propionic and butyric acids).

2.3.3.2 Inorganic macro components in leachates

Soluble inorganic compounds in solid wastes appear as pollutants in old stabilized leachates when the pH is about 8 (Naveen, Sivapullaiah and Sitharam, 2014). Inorganic compounds are mainly calcium (Ca^{2+}), iron (Fe^{2+}), manganese (Mn^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), ammonium (NH_4^+), hydrogen carbon, chlorides (Cl^-), bicarbonates (HCO_3^+), sulphates (SO_4^{2+}) (Kjeldsen et al., 2002; Naveen, Sivapullaiah and Sitharam, 2014; Wdowwczyk and Szymanska-Pulikowska, 2020). Inorganic macro components are low at high pH typical in the methanogenic phase of waste stabilization (Kjeldsen et al., 2002). This is due to their precipitation and lower concentrations of DOCs with which they form complexes (Kjeldsen et al., 2002). Moderate to strong correlations expressed by Pearson's correlation coefficient in the range of 0.4 to 0.69 for parameter in leachate were observed. (Wdowwczyk and Szymanska-Pulikowska, 2020).

2.3.3.3 Heavy metal pollutants in leachates

Heavy metals like copper (Cu^{2+}), nickel (Ni^{2+}), lead (Pb^{2+}), chromium (Cr^{3+}) and cadmium (Cd^{2+}) in leachates take several years to appear in leachates (Jahan et al., 2016; Kjeldsen et al., 2002; Naveen, Sivapullaiah and Sitharam, 2014; Yusmartini et al., 2014). This contradicts the fact that heavy metals occur early in waste

stabilization due to acidogenesis that is due to biodegradation of organic acids that dissolve metals. It implies that occurrence of heavy metals in leachates is early but its detection is much longer perhaps due to limitations of existing technologies. However, metal mobilization attenuating processes like sorption by solid waste, complexation with functional organic acids and precipitation may explain the apparent non-detection of heavy metals even in the early conducive acidogenesis phase of waste stabilization (Kjeldsen et al., 2002).

Volatile fatty acids (VFAs) that constitute about 95% of total organic carbons (TOCs) occur at lower pH values promoting dissolution of heavy metals (Makan et al., 2015; Naveen, Sivapullaiah and Sitharam, 2014; Yusmartini et al., 2014). Heavy metals are usually in low concentrations which at times is below permissible minimum standards (Kjeldsen et al., 2002).

2.3.4 Conclusion on characterization of leachate

Water is the most consistent and influential factor in stabilizing solid wastes. This is due to the water dependence of numerous physical, chemical, and biological processes that produce leachates. The broad two categories of solid wastes are organic and inorganic wastes. Organic solid wastes are largely biodegradable compared to inorganic compounds that are largely non-biodegradable. This BOD/COD ratio is the most common quantity used to describe the balance between biodegradable and non-biodegradable solid wastes during solid waste stabilization. Higher BOD/COD ratios indicate more biodegradable solid wastes that occur within 0 - 5 years while lower BOD/COD ratios indicate less biodegradable solid wastes that occur after 5 years respectively. This quantity was used to address the second

specific objective of this study which was to determine the characteristics of leachate produced from solid waste management plant in Mbale city.

2.4 Effects of leachate on water quality

The main consequences of leachate on the environment are surface and subsurface water contamination (Al Sabahi et al., 2009; Kjeldsen et al., 2002; Wdowwczyk and Szymanska-Pulikowska, 2020). When leachate with a high organic content is dumped into a body of water, it increases the oxygen required for biochemical reactions, which lowers the amount of oxygen accessible for living things (Mwiganga and Kansiime, 2005). Eutrophication may also occur due to nitrogen and phosphorus common in organic matter from plants (Mwiganga and Kansiime, 2005). High content of organic matters and inorganic ions found in landfill leachate normally cause negative impacts on the environment (Fan et al., 2006 and Mor et al., 2006).

The variations in leachate qualities are due to a number of factors such as soil cover, waste compaction level, waste thickness, dumping method, waste composition, age, daily cover, water entering the landfill, leachate storage and chemical reactions that take place (Xaypanya et al., 2018).

2.4.1 Environmental effects of leachate on underground water and surface water

Major environmental effects of leachate are pollution of underground and surface waters (Al Sabahi et al., 2009; Kjeldsen et al., 2002; Wdowwczyk and Szymanska-Pulikowska, 2020). Much of the expected pollution is in underground water and less in surface waters (Kjeldsen et al., 2002). The expected underground water pollution is much because of formation of leachate plumes when leachate migrates

underground. Surface water pollution is expected to be mainly oxygen depletion and ammonia toxicity (Hossain et al., 2014; Kjeldsen et al., 2002). Oxygen depletion is most probably due to biodegradation of biodegradable organics. This means oxygen depletion is most common in young landfills within the first 0-5 years when biodegradation is intense. Leachates that percolate in subsoils eventually migrate to surface waters (Parvin and Tareq, 2021). This means that underground water and surface water resources should be protected and managed in an integrated manner in as far as solid waste is concerned.

2.4.2 Influence of depth of subsoil and distance on leachate in underground water

The four major components of the environment in terms of leachate management are surface waters, ground waters, soils and plants (Hredoy et al., 2022). Electrical conductivity (EC), total dissolved salts (TDS), pH, turbidity, salinity, temperature, total hardness, and heavy metals are the physicochemical parameters to measure the influence of leachates on environmental quality (Hredoy et al., 2022, Hossain et al., 2014). Landfill leachate contain high levels of organics, inorganics, heavy metals and xenobiotics that percolate in subsoil to contaminate ground water (Negi et al., 2018). Percolation of leachate in subsoil is facilitated by the liquid nature and high concentration of leachate that ensures that leachate seep through soil to pollute groundwater thus rendering it unsuitable for domestic use (Onyedikachi, 2020). Underground water pollution is especially worse at shallow depths of less than 10 meters and distances of less than one kilometer from source of leachate (Hredoy et al., 2022; Negi et al., 2018). This means siting of underground water sources and facilities like boreholes and wells should be preferably upstream of source of

leachate. In case such water sources are downstream of source of leachate, they should be conveniently far away. This concern is supported by 35% of boreholes and wells around dumpsites that were found unsuitable for drinking in Lagos-Nigeria (Aboyeji and Eigbokhan, 2016).

2.4.3 Conclusion on effects of leachate on water quality

The age of landfills and season of the year influence the amounts and composition of the physicochemical parameters in underground water and surface water differently. Age of landfills determine what type of physicochemical parameters exist in leachate because of acidogenesis and methanogenesis. Rain season hydrolyses solid wastes and leaches out dissolved and undissolved chemicals from solid waste as much as possible in contrast to dry season when less of this happens. Therefore, time of year influences the quantity of leachate generated. These aspects of age of landfill and time of year are important in addressing the third specific objective of this study which was to determine the effect of leachate on water quality of River Namatala.

2.5 Treatment options for pollutants from leachate

2.5.1 Carbonization of biomass

Carbonization (char-making) is a slow process of thermal decomposition of biomass in a largely inert (oxygen-deficient) environment that outputs primarily carbon-rich solid char and secondary gases and liquids (Lohri, Sweeney and Rajabu, 2015). Agricultural wastes that are low-cost are precursors for activated carbon for physical and chemical (ad)sorption of pollutants in leachates (Kamaruddin et al., (2019). This gives importance to biomass wastes as a valuable source of renewable energy in the

context of increasing energy challenges for human livelihood. Therefore, carbonization is considered as a valorization strategy for stakeholders (producers, collectors, service providers, etc.) in waste management (Lohri, Sweeney and Rajabu, 2015).

Production of biochar (activated carbon from biomass) consumes up to 90 % less energy and resources compared to GAC (granular activated carbon) (Kwarciak et al., 2019). Hydrothermal carbonization that is wet thermal decomposition of biomass (Lohri, Sweeney and Rajabu, 2015) recovers plant nutrients and climate-neutral fuels from wet wastes (Gerner et al., 2021). This is possible under anaerobic digestion at 190⁰C-210⁰C for 1-3 hours (Volpe et al., 2020). Activated carbon (AC) adsorption has simple design, is easy to operate and removes a number of pollutants (Chávez et al., 2019).

2.5.2 Removal of nitrogen and phosphorus pollutants from leachate

N and P are nutrients for biomass growth that is found in leachate as well (Petry et al., 2020). However, biological treatment of leachate is insufficient because many of the pollutants in leachate are non-biodegradable (Chávez et al., 2019). Therefore, combination of physical, biological and chemical processes is better in leachate treatment especially for stabilized leachate (Chávez et al., 2019). Biological treatment is the most simple and cheap treatment options (Padhi et al., 2018). The low biodegradability of leachate because of mixture of biodegradable and non-biodegradable substances requires use of integrated technologies like advanced oxidation processes and physicochemical treatments like adsorption (Kamaruddin et

al., 2019). Biological treatment suits young landfills while physicochemical treatments suit stabilized landfills (Kamaruddin et al., 2019).

This means that determination of biodegradability of landfills is necessary in deciding which leachate treatment technology or technologies to use. Biodegradability can be evaluated in terms of age of leachate being young (0-5 years), medium (5-10 years) and old (over 10 years) (Kwarciak et al., 2019; Petry et al., 2020). Adsorption is the most suitable leachate treatment technology for stabilized leachates (Kwarciak et al., 2019). New approach of landfill leachate management is about the simultaneous removal of contaminants and recovery of resources (Golwala et al., 2022).

Nitrogen and phosphorus are major constituent of plant and animal proteins and cells (Cadmus Group, 2009; Magri et al., 2020). Therefore, they are vital for the normal function of bio cells (Louisiana Department of Environmental Quality, 2015). However, too much nitrogen and phosphorus cause eutrophication, oxygen depletion and toxicity in water bodies leading to poor water quality (Bhambri and Karn, 2020; Cadmus Group, 2009). Nitrogen also decreases other minerals hence causing imbalance in soil chemical profile (Bhambri and Karn, 2020; Magri et al., 2020). Phosphorus is an essential element of all living cells and tissues and chlorophyll (Sengupta et al., 2015) and it is vital as ingredient in biomass cellular energy generation (Cadmus Group, 2009).

2.5.3 Biological nutrient removal of nitrogen (bio N) and phosphorus (bio P)

Nutrient pollution in form of N & P has been identified as one of the widespread, most costly and environmental challenges in the 21st century (De Borba et al., 2016).

Therefore, it is imperative that nitrogen and phosphorus are removed from wastewaters like leachate before wastewater effluents are discharged into receiving water bodies.

2.5.3.1 Biological nitrogen removal (bio N)

The key target in biological nitrogen removal is ammonia-nitrogen (Magri et al., 2020). Nitrogen is one of the toxic pollutants found in urban landfill leachates (Petry et al., 2020). Wastewater ammonia is nitrified to nitrates which infiltrate to groundwater (Curtin et al., 2011). Twenty percent of BOD in household wastewater is contributed by nitrogen per capita, which varies from 20 to 70 mg/l for wastewater with low to high strength (Cadmus Group, 2009). This is a significant per capita contribution of nitrogen in wastewaters. This situation can be even worse especially in urban environments with high population densities.

Nitrification (*nitritation*) and denitrification (*nitratation*) are the two natural and biological processes in which ammonia-nitrate is removed stage wise (Magri et al., 2020). Nitrification under aerobic conditions oxidizes ammonia to nitrates while denitrification under anoxic conditions reduces nitrates to nitrogen gas (Magri et al., 2020). Optimal operating conditions for nitrification include influent nutrient ratios of C:N:P of 100:5:1, temperature of above 7⁰C (Curtin et al., 2011) and as high as 20⁰C-25⁰ C (Cadmus Group, 2009), pH of 6.8-8(Cadmus Group, 2009; Curtin et al., 2011), alkalinity of 50-200 mg/l and DO of at least 2 mg/l (Curtin et al., 2011) and preferably 3-4 mg/l(Cadmus Group, 2009).

Optimal operating conditions for denitrification include low DO less than 0.1 mg/l with C-source, long SRTs (Solid Retention Times) and HRTs (Hydraulic Retention

Times) (Curtin et al., 2011).carbon source (e.g. external sources like methanol, ethanol, glucose, acetic acid, glycerol, molasses, industrial wastes, etc.) or internal sources like influent BOD (Cadmus Group, 2009). Conventional post-treatment denitrification uses methanol for removal of nitrate (*nitratation*) (Yamashita and Yamamoto-Ikemoto, 2014). Since methanol is flammable and expensive, use of municipal waste/refuse, agro and industrial residues and wood waste is safer and cheaper. Treated wastewater effluents are less in organic matter (BOD) but have reasonable quantities of N and P in them. Therefore, post-treatment/tertiary treatment with addition of C is necessary for the removal of N and P (Yamashita and Yamamoto-Ikemoto, 2014).

2.5.3.2 Biological phosphorus removal (bio P)

Phosphorus recovery is important because it is an exhaustive non-renewable resource (Gerner et al., 2021) that are fast depleting (Khanzada, 2020; Sengupta et al., 2015). Consequently, the EU 2017 report listed phosphorus as one of the critical materials because of its importance in supporting agriculture and other vital human life functions (Volpe et al., 2020). Phosphorus is non-manufacturable and non-destroyable (Magri et al., 2020). Classification of phosphorus by EU as a critical raw material is because of its finite nature and irregular global distribution whose supply may therefore depend on geopolitical considerations (Magri et al., 2020). Global depletion of non-renewable finite phosphorus reserves justifies its recovery from wastewaters like leachate.

Favourable operational conditions for P removal include COD:P ratio of at least 40 or BOD:P of at least 18 (Cadmus Group, 2009) which was specified as 20:1 by

(Curtin et al., 2011), Others are initial anaerobic condition (Cadmus Group, 2009; Curtin et al., 2011) followed by aerobic condition, minimum SRT (Sludge Retention Time) of at least 1 hr – 2 days to ensure adequate contact/reaction time for EBPR (Enhanced Biological Phosphorus Removal) (Curtin et al., 2011) or as much as 3-4 days (Cadmus Group, 2009), anaerobic HRT to aerobic HRT ratio of between 3-4 (Cadmus Group, 2009), temperature of 5 °C-25 °C (Cadmus Group, 2009), adequate DO in aerobic zone for uptake/removal of P in activated sludge (Cadmus Group, 2009). Volatile fatty acids as food source for phosphorus accumulating organisms is required (Curtin et al., 2011).

2.5.4 Physico-chemical removal of nitrogen and phosphorus

Physicochemical treatments suit stabilized landfills (Kamaruddin et al., 2019). This means that physico-chemical treatment technologies should be applied to leachates from landfills that are over 10 years old. Adsorption is a surface phenomenon where gas or liquids are attracted to adsorbent solid surfaces through attachments of physical and chemical bonds. This is influenced by surface properties of surface area, pore micro-structure and pore size distribution (Kamaruddin et al., 2019). Instead of full-scale physico-chemical treatment that is high energy-intensive, it is used to pretreat leachate before biological treatment (Padhi et al., 2018).

2.5.4.1 Physico-chemical removal of nitrogen

Air stripping of ammoniacal solution in temperatures of over 75°C and pH of over 9 removes nitrogen as ammonia gas. The pH is provided by lime (Ca (OH)₂) or caustic soda (NaOH) (Sengupta et al., 2015). Membrane-based recovery by MF

(microfiltration), UF (ultrafiltration), NF (nanofiltration) and RO (reverse osmosis) technologies are also used for recovery of ammonia gas (Sengupta et al., 2015).

2.5.4.2 Physico-chemical removal of phosphorus

Phosphorus recovery (P-recovery) is by chemical precipitation /crystallization/ mineralization of dissolved low salts of orthophosphates by supplying metal ions of Mg^{2+} , Ca^{2+} or Fe^{2+} to form MgP, CaP and FeP minerals respectively (Magri et al., 2020). Chemical precipitation recovers 80 – 99 % of dissolved P in wastewaters as struvite fertilizer (Sengupta et al., 2015).

2.5.5 Lead removal

Lead is one of the heavy metals that is detrimental to aquatic and human life, even at low concentrations in water, soil, and the environment (Chowdhury et al., 2022; Wani et al., 2015). All human body's systems and organs can be affected by lead, including the hearing and learning abilities of young children (Wani et al., 2015). Similarly, adults typically experience cardiovascular symptoms, hypertension caused by high blood pressure, decreased kidney function, and reproductive issues. (Charkiewicz and Backstrand 2020; Wani et al., 2015).

Lead is considered a human carcinogen because of its toxicity. (International Agency for Research on Cancer, IARC, US Environmental Protection Agency, USEPA 2004 and World Health Organization, WHO 2006).

Lead ions removal for drinking water and wastewater protects the water sources and also provides safe water supplies to human and aquatic life.

Precipitation, coagulation- flocculation, ion exchange, adsorption, and membrane separation are methods used to remove lead ions from industrial water and effluent (Chowdhury et al., 2022).

2.5.5.1 Chemical precipitation

Chemical precipitation using sodium sulfide and sodium carbonate is one of the most efficient and affordable method of lead removal in wastewater (Sadeghi et al., 2017). The effectiveness of sodium sulfide and sodium carbonate in removing lead (II) increased with increase in pH (Sadeghi et al., 2017). The maximum lead removal using sodium sulfide and sodium carbonate at pH 11 were 99.3% and 95.7% respectively (Sadeghi et al., 2017).

2.5.5.2 Lead removal by adsorption

Low cost absorbents can either directly be used for lead (II) removal or be used for preparing absorbents during lead (II) removal (Chowdhury et al., 2022). The absorbents have been categorized into different classes such as natural materials, industrial byproducts, agricultural wastes, forest waste and biotechnology base materials (Chowdhury et al., 2022). The lead (II) removal efficiency ranged between 13.6% to 100% at temperature range of 15⁰C to 60⁰C with optimum pH and different concentrations (Chowdhury et al., 2022). These adsorbents removed lead under different conditions such as adsorption capacity, optimum pH, temperature, initial concentration, sorbent dose and contact time (Chowdhury et al., 2022).

2.5.5.3 Lead removal using avocado seeds

Low amounts of heavy metals in wastewater can be effectively treated using adsorption and the biomass of avocado seeds was utilized as an adsorbent in

activated carbon, chemically activated, and natural form (Boeykens et al., 2019). The avocado seeds usually adsorb lead metals when measured using the isothermal adsorption technique (Montañez et al.,2023). 85.43 percentage removal efficiency of Lead II ions was observed with increase in dosage of avocado seeds to 0.18g (Montañez et al.,2023). The batch approach revealed that the adsorption capacity of avocado seed fibers was more influenced by lead II ion concentration, pH and contact time than by temperature (Muthuraman et al.,2021). The different effects of metal ion concentration (0.5-3.0 mg/L), contact period (15-180 mins), and adsorbent dosage (0.5-3.0 g) of avocado seeds powder were examined in the batch adsorption tests revealing that the maximum percentage of lead (Pb 2+) removal was greater than 97% (Ukpong et al.,2024). When comparing the outcomes achieved utilizing the activated biomass, there was a noticeable increase in the removal of Pb (II) ions. The clearance per gram of original biomass does not change considerably, though, given the loss of biomass caused by the pre-treatment (Boeykens et al., 2019). The voids on the surface of the seed powder significantly diminishes as a result of bond arrangement with the groups on the adsorbent of metal ions (Muthuraman et al.,2021)

2.6 Summary and conclusion of literature review

Solid waste stabilization is the breakdown of solid wastes under aerobic (anoxic), anaerobic and mixed (aerobic and anaerobic conditions). Solid waste stabilization occurs in phases starting from initial aerobic transition phase, anaerobic acidogenesis (acid formation phase), anaerobic gasification mainly methanogenesis (methane fermentation phase) and final maturation or stable methanogenesis. The

factors that contribute in leachate formation can be divided in three broad categories. These are (1) factors external to solid wastes and (2) factors internal to solid wastes and (3) operation of leachate treatment plant. The factors external to solid wastes are: climate (i.e. precipitation), hydrogeological conditions of the landfill and mode and operation of solid waste landfill. The internal factors to solid waste are: biodegradation, chemical degradation, moisture content, temperature, pH, overburden pressure and age of landfill.

Physico-chemical and biological properties such as density, moisture content, calorific value, BOD and COD are the standard and conventional methods used to characterize heterogeneous solid wastes in landfills. These quantities were used to address the first specific objective of this study which was to determine the characteristics of solid waste at the solid waste treatment plant within Mbale city. A useful quantity for characterizing leachate is BOD/COD ratio in which smaller BOD/COD ratios (< 0.5) and higher BOD/COD ratios (> 0.5) indicate old (> 5 years) landfills and young (0-5 years) landfills respectively. This was used to address the second specific objective of this study which was to quantify the concentration of water pollutants from the leachate being produced from solid waste management plant in Mbale city.

The age of landfill influences quality of groundwater and surface water resources in terms of suitability for domestic consumption. Similarly, the season of a year in terms of rain and dry spells influences the amount of leachate generated from solid waste. These aspects are important in addressing the third specific objective of this study which was to evaluating the effect of leachate on water quality of River

Namatala. Biological nutrient treatment for removal of nitrogen and phosphorus is a low-cost treatment technology. However, biological nutrient treatment suits treatment of leachate from young landfills that are less than five years old. Leachate from older landfills requires physico-chemical treatment technologies. One of these is hydrothermal carbonization of biomass like agricultural wastes under aerobic conditions. Hydrothermal carbonization performs dual function of nutrient removal and climate-neutral resource recovery from agricultural wastes that would have generated leachate.

Standard laboratory test procedure for the physicochemical parameters mentioned above are detailed in the next chapter (chapter three: methodology) for treatment of pollutants from leachate for specific objective number four

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter presents the procedure used in order to obtain the results during the research. It gives a description of the study area, research design and approach, data collection and analysis.

3.2 Study area

The research was conducted in Mbale city with an approximate projected population of 108,703 people (UBOS, 2014) with growth rate of 3.2 % per year (UBOS, 2014). Mbale is located in eastern part of Uganda at the boarder of Mount Elgon National Park which lies across the border with Kenya. Mbale receives an average annual rainfall of 1,183 mm with two rainfall seasons of March to June and August to November with average temperature of 23⁰ C (NMAU, 2021). The waste composting facility is located at Doko Cell, Namatala Ward (Parish) Mbale city at a latitude of 1.0805 and longitude of 34.1493.

3.3 Research Design and Approach

The study used descriptive survey and analytical research design. The descriptive research design was used to obtain information concerning the status of solid waste treatment plant and also describe what was existing with respect to the situations on the ground. The descriptive survey was used to investigate solid waste characteristics such as type of waste, dumping method, amount of waste produced daily, leachate storage and composition of solid wastes being introduced into the treatment plant.

The analytical research was used to measure leachate characteristic such as the concentration of heavy metals such as lead, iron, chromium, copper, mercury, nickel, 5-day biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), pH, total nitrogen and total phosphorus.

The study used both qualitative and quantitative research approaches. The qualitative research approach focussed mainly on the kind of wastes being introduced into the waste management plant and the quality of leachate from the plant. The quantitative research approach was used to describe numerical variables from the amount of solid wastes received by the solid waste management plant and also variables from the leachate quality.

3.4 Data collection strategy

3.4.1 Sampling of Leachate

Brilliant Blue FCF was used as a dye tracer to determine and visualize the flow path of leachate from the waste composite plant to River Namatala. Brilliant Blue FCF is nontoxic dye which is used in the field. The pH values of the brilliant blue FCF determines whether the dye is either neutral or dissociates to a mono- or bivalent anion. An amount of 120g of brilliant blue FCF was mixed in bucket containing 20 litres of clean tap water and dispensed at the origin of leachate. The flow pattern of the brilliant blue FCF tracer was followed and samples taken at every 25 meters from the composite waste plant. The sampling distance was based on the advice of the laboratory staff at the College of Natural Sciences at Makerere University. Samples were collected from the solid waste management plant to a distance of 582 m downstream where the brilliant blue FCF colour disappeared and 98 m upstream

of the location where leachate join the river at the upper side. A total of 30 samples at different points were collected and their GPS coordinates were recorded in table 3.1 below. Figure 3.2 shows leachate flow channel and sampling points from the solid waste management plant to River Namatala.

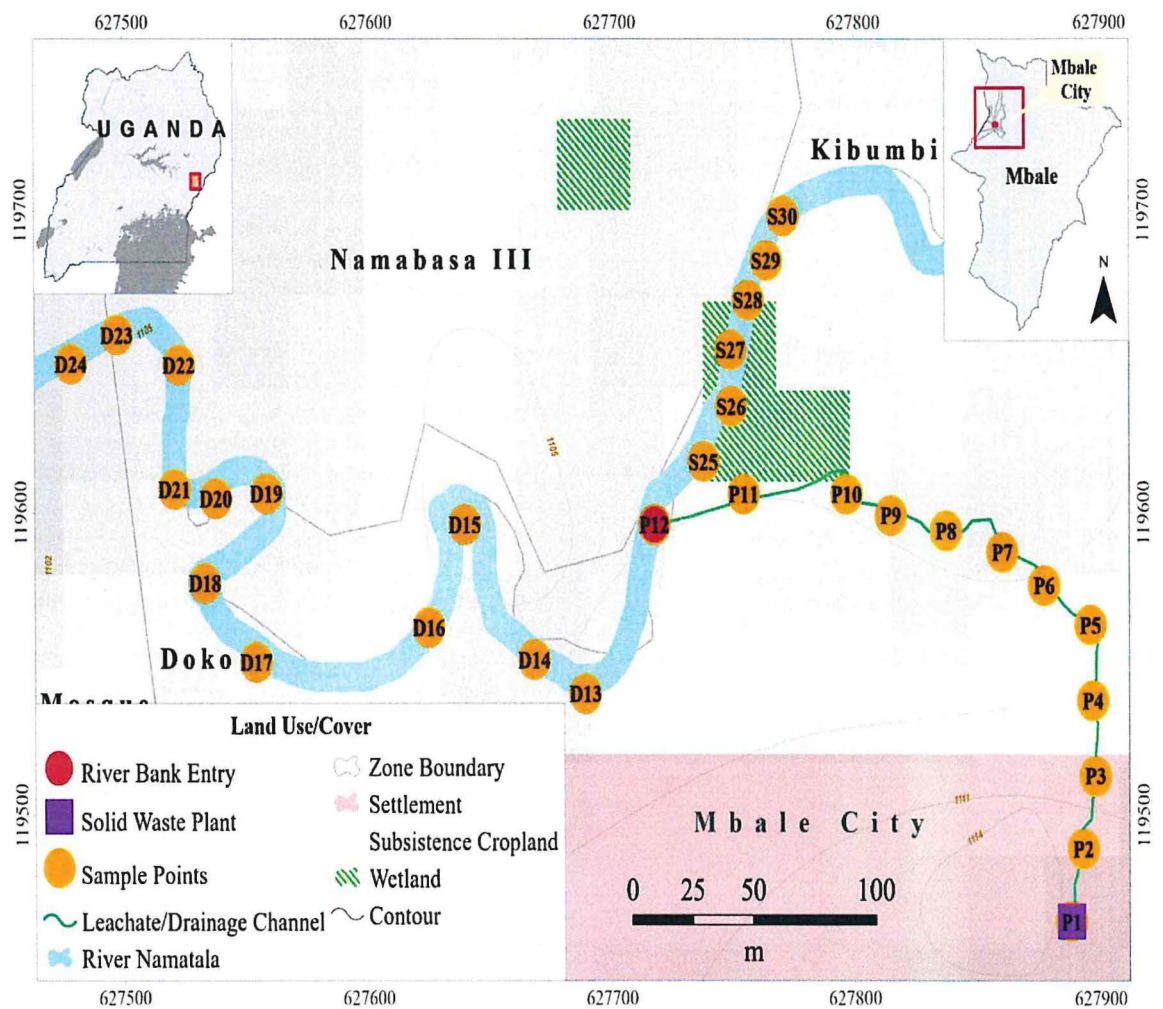


Figure 3. 1: Leachate flow channel and sampling points from solid waste management plant to the River Namatala

Table 3. 1: GPS Coordinates of the sampling points

SN	Sample Point	Longitude	Latitude	Elevation
1	P1	627888	119465	1114
2	P2	627893	119489	1114
3	P3	627898	119513	1110
4	P4	627897	119538	1108
5	P5	627896	119563	1106
5	P6	627877	119576	1105
7	P7	627860	119587	1104
8	P8	627837	119594	1105
9	P9	627815	119599	1105
10	P10	627797	119606	1104
11	P11	627755	119606	1105
12	P12	627718	119596	1105
13	D13	627690	119534	1107
14	D14	627667	119542	1106
15	D15	627640	119596	1107
16	D16	627628	119558	1108
17	D17	627543	119548	1108
18	D18	627519	119577	1107
19	D19	627549	119603	1107
20	D20	627541	119602	1108
21	D21	627523	119601	1105
22	D22	627514	119648	1107
23	D23	627496	119650	1107
24	D24	627497	119651	1107
25	S25	627741	119615	1110
26	S26	627750	119635	1110
27	S27	627759	119663	1110
28	S28	627758	119673	1110
29	S29	627761	119678	1110
30	S30	627766	119681	1110

Source: Primary Data

3.4.2 Solid wastes

The existing six solid waste collection service providers were used to collect data on the amount of wastes generated daily within the city. The households in the city

were sensitized by the waste collectors to separate their wastes into biodegradable and non-biodegradable wastes. Each household was given additional waste container to separate the wastes. The solid wastes were then collected by the service providers and weighed before dumping at the solid waste treatment site for a period of two weeks.

3.5 Data collection personnel

The data collection team comprised four people as follows: research student, laboratory technician from Makerere University and two staff from Mbale City Council in charge of solid waste plant. The research student coordinated field data collection and ensured that correct and standard data collection procedures were followed in order to obtain quality data. The researcher also picked GPS coordinates along the flow path of leachate and also along the river banks at locations where samples were collected. The laboratory technician sampled and analyzed some of the parameters like pH at each sample point and also carefully packed samples in standard one litre bottles for delivery to the main laboratory. The two staff in charge of solid waste plant were moved along leachate path following the brilliant blue FCF tracer and marked the distance and sampling points. The samples were placed in a standard ice box and delivered to the College of Natural Sciences laboratory on the same day for further analysis of other parameters.

3.6 Data collection instruments

The data was collected using the following portable instruments as summarized in Table 3.2. The related photographs of data collection are shown in Plate 3.1.

Table 3. 2: Instruments used for data collection

S/N	Instrument	Purpose
1	Weight bridge/weighing scale	Measure weight of the vehicle both empty and loaded
2	Orion 4-star PH. Do portable	Tests pH
3	Calibrated 20-liter bucket	Mixing of brilliant blue FCF with water
4	Garmin GPSMAP 64s	Picking GPS coordinates of water sampling points along leachate path and along the river
5	Standard 1-liter plastic jerrycan	Sampling jerrycans/ bottles
6	Standard ice box	Preservation of samples collected
7	Calibrated 5-liter plastic jerrycan	Leachate flow rate measurement
8	Stop-watch	Timing filling of calibrated 5-liter plastic jerrycan
9	COD reactor	Incubating the samples
10	Marker and plastic tape	For marking the samples for easy identification
11	Atomic absorption machine GTA120 Graphite tube atomizer	Tests heavy metals
12	Spectrophotometer Aquamate 600.nm	Tests COD, BOD, Total Nitrogen,
13	Wastes containers	Separation of wastes

Table 3. 3: Details of sampling and testing photographs

S/N	Plate	Details
1	(a)	20 litre jerrycan and calibrated bucket used for mixing tracer brilliant blue FCF
2	(b)	Application of tracer brilliant blue FCF
3	(c)	Spectrophotometer Aquamate 600.nm
4	(d)	Testing of COD in laboratory
5	(e)	Tying of plastic wastes to be weighed
6	(f)	Some of the separated paper wastes.
7	(g)	One of the waste vehicle with solid wastes



(a)



(b)



(c)



(d)

Figure 3. 2 (a) – (b): Preparing for Sampling and (c)-(d) testing of leachate at Biochemistry Department Makerere University



(e)



(f)



(g)

Figure 3. 3 (e) – (g): Tying of separate wastes, separation of wastes and transportation of wastes

3.7 Data collection procedure

3.7.1 Data collection procedure for characterizing solid wastes

Documents about the type and quantity of solid wastes were got from the records kept by Mbale city council to determine the pattern of generation of solid wastes, types and practices of the households. The researcher collected more field data on the types and amount of wastes being generated by households with the assistance of solid wastes service providers in the city. The wastes collected were sorted into non-biodegradable and biodegradable wastes and placed in different containers which were weighed and the weights of each container with the waste was recorded from different households. The wastes in the containers were loaded into the trucks and finally the trucks were weighed as they entered the solid wastes plant.

3.7.2 Data collection procedure for quantifying the concentrations of water pollutants

The researcher measured the flow rate of leachate using calibrated 5 litre plastic jerrycan to determine its quantity on rainy days and dry days with only sunshine. The sampling bottles were used to collect samples at every 25 m distance from the waste treatment plant up to River Namatala to determine its quality. The samples collected were delivered to the laboratory at Makerere University College of Natural Sciences for analysis.

3.7.3 Data collection procedure for determining effect of leachate on water quality

Sampling bottles were used to collect samples at every 25 m distance from the solid waste plant which were delivered to laboratory at Makerere University College of

Natural Sciences. The sampling distances kept on increasing depending on the visibility of the tracer poured at the plant. The increasing distance at which the tracer was visible was probably because of increasing decay hence decreasing strength of the tracer. The samples were also collected from the downstream and upstream of the river to a distance of 582 m on the downstream side and 98 m on the upstream side of the river.

The samples were labeled with identification numbers from one (1) up to thirty (30). The samples from solid waste management plant to the river were labeled P1 to P12, samples downstream of the River Namatala were labeled D13 to D24 and samples upstream of River Namatala were labeled with numbers S25 to S30.

Laboratory analysis were done to determine the concentration of heavy metals: lead, copper, chromium, iron, silver, nickel, 5-day biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), pH, electrical conductivity, total nitrogen and total phosphorus.

3.7.4 Data collection and procedure for exploring treatment of a key water pollutant from leachate using avocado seeds

Avocado seeds were extracted from avocado fruits and thereafter washed. The seeds were ground using electric motor. The ground seeds were dried in an oven for six hours at $105 \text{ }^{\circ}\text{C} \pm 3 \text{ }^{\circ}\text{C}$. The avocado seeds were crushed and dried to enhance the adsorption capacity. The ground seeds were sieved through 1mm sieve to obtain the right sizes for the experiment. The ground seeds powder was then divided into two for the carbonised and raw(non) carbonised experiment.

The portion of the ground seeds was carbonised at 300 °C for two hours then activated using one molar (1M) sulphuric acid, then washed with distilled water to a pH above 8.

The raw ground seeds and carbonised seeds were weighed into 1 g, 2 g, 3 g, 4 g and 5 g using an electric digital scale and put into separate falcon tubes.

0.2 g of lead nitrate, $\text{Pb}(\text{NO}_3)_2$ was weighed and dissolved in 1,000 ml volumetric flask with distilled water to get a solution of lead nitrate (synthetic effluent of known concentration).

Each of the above falcon tube was mixed with 45 ml of synthetic effluent of known concentration (lead nitrate, $\text{Pb}(\text{NO}_3)_2$) at a contact time of 5 minutes at room temperature. The samples were then filtered using filter membrane into a beaker after 5 minutes and labelled appropriately to identify contact time, weight and category of avocado seeds. The above procedure was repeated for contact time of 10 minutes, 15 minutes and 20 minutes for both raw avocado seeds and activated avocado seeds at room temperatures. Atomic absorption spectrophotometer was used to determine the residual lead (II) ion concentration in the samples.

3.8 Data analysis

Data analysis involved organizing and interpreting the information generated into useful data. The researcher used both quantitative data analysis and qualitative data analysis techniques.

3.8.1 Data analysis for characterising solid wastes

Determination of the characteristics of solid wastes introduced into solid waste treatment plant answers specific objective number one. The statistical method used to determine the characteristics of solid wastes were frequency analysis, pie charts and bar charts.

The main sources of solid wastes were from domestic refuse, market refuse, construction sites, commercial/industrial refuse and abattoir wastes. The wastes were sorted into biodegradable and non-biodegradable, weighed, recorded and entered into an excel spread sheet which was used to generate the charts.

3.8.2 Data Analysis for quantifying the concentration of water pollutants

Quantification of the concentrations of water pollutants from leachate answers specific objective number two. The portable Orion 4 Star pH meter was used to measure the samples' pH.. Chemical analysis was used to determine the concentration of electrical conductivity (EC), total nitrogen, total phosphorus and 5-day BOD or BOD₅ .

The BOD₅ was then calculated using the equation 3.1 below as adopted from (Haslina et al., 2021) :

$$\text{BOD}_5 = \frac{W_i - W_f}{Q} \quad (3.1)$$

where W_i is the initial concentration of dissolved oxygen (mg/l),

W_f is the concentration of dissolved oxygen remaining after the 5-day incubation period and

Q is the fraction of environmental sample used in the standard 300 ml BOD bottle.

The BOD/COD ratio was used because it profiles the solid waste stabilization which is made out of biodegradation and chemical degradation. The heavy metals nickel, copper, silver, lead and chromium were determined using atomic absorption method. The descriptive statistics (range, mean, maximum, minimum, standard deviation) were used to determine the characteristics of leachate produced from solid wastes.

3.8.3 Data analysis for the effect of leachate on water quality

Determination of the effect of leachates on River Namatala water quality answers specific objective number three. The statistical method used to determine the effect of leachates on water quality of River Namatala was Student's t-test and z-test or analysis of variance (ANOVA). The t-test was used when the sample size was less or equal to 30 and z - test was used when the sample size was greater than thirty (30). In order to assess the difference between upstream river flow and downstream river flow with respect to a number of water quality parameters, a null hypothesis H_0 (the mean of a parameter like BOD₅, COD, pH, Cu, Ni, Fe, Ag, Total Nitrogen, Total Phosphorus and conductivity from upstream river flow \bar{y}_1 was the same as that from downstream river flow \bar{y}_2) were analyzed using the formula in equations 3.2 and 3.3 below as adopted and modified from (Onyutha et al., 2022).

$$q = \bar{y}_1 - \bar{y}_2 \times \left(M_r \sqrt{\frac{1}{z_1} + \frac{1}{z_2}} \right) - 1 \quad (3.2)$$

$$M_r = \sqrt{\frac{(z_1-1)s_1^2 + (z_2-1)s_2^2}{z_1 + z_2 - 2}} \quad (3.3)$$

where \bar{y}_1 and \bar{y}_2 are the mean values of parameters (such as BOD₅), s_1 and s_2 denote the standard deviations of the parameters (such as BOD₅) from upstream and

downstream of the river and z_1 and z_2 denotes the sample sizes from upstream river flow and downstream river flow respectively.

The degree of freedom in the t -test was determined by sample size. The tail of the Student's distribution starts getting thinner with increase in sample size and if the sample size is small, the tail of t-distribution becomes thick. The rate of rejection of the H_0 is determined by the thickness or thinness of the tail of the Student's t-distribution. The t-statistics value was computed and the inverse of t- statistic value also computed and comparison was done with the inverse of t student distribution of which $\alpha = 0.05$. The null hypothesis H_0 would not be rejected for t-statistics value less t-inverse or else the H_0 would be rejected for t-inverse value being greater than the computed t-statistic value.

3.9.4 Data analysis for the treatment of lead (II) ions using avocado seeds.

Determination of treatment options for pollutants using avocado seeds answers specific objective number four. Adsorption method using ground avocado seeds was used to determine the percentage of Lead (II) ions removal. The percentage removal of lead (II) ion was calculated using the equation 3.4 below as adopted and modified from (Boeykens et al., 2019).

$$\text{Percentage Removal} = \left(\frac{M_i - M}{M_i} \right) \times 100 \quad (3.4)$$

where M_i is the initial ion concentration of synthetic effluent of known concentration (mg/l),

M is the ion concentration of synthetic effluent after passing through the ground avocado seeds and filtering.

3.10 Summary of methodology of waste disposal

Figure 3.4 summarizes the linkages between solid waste generation sources, private service providers collecting the wastes and waste management plant where processes of recycle, reuse, recover and biological process of leachate generation.

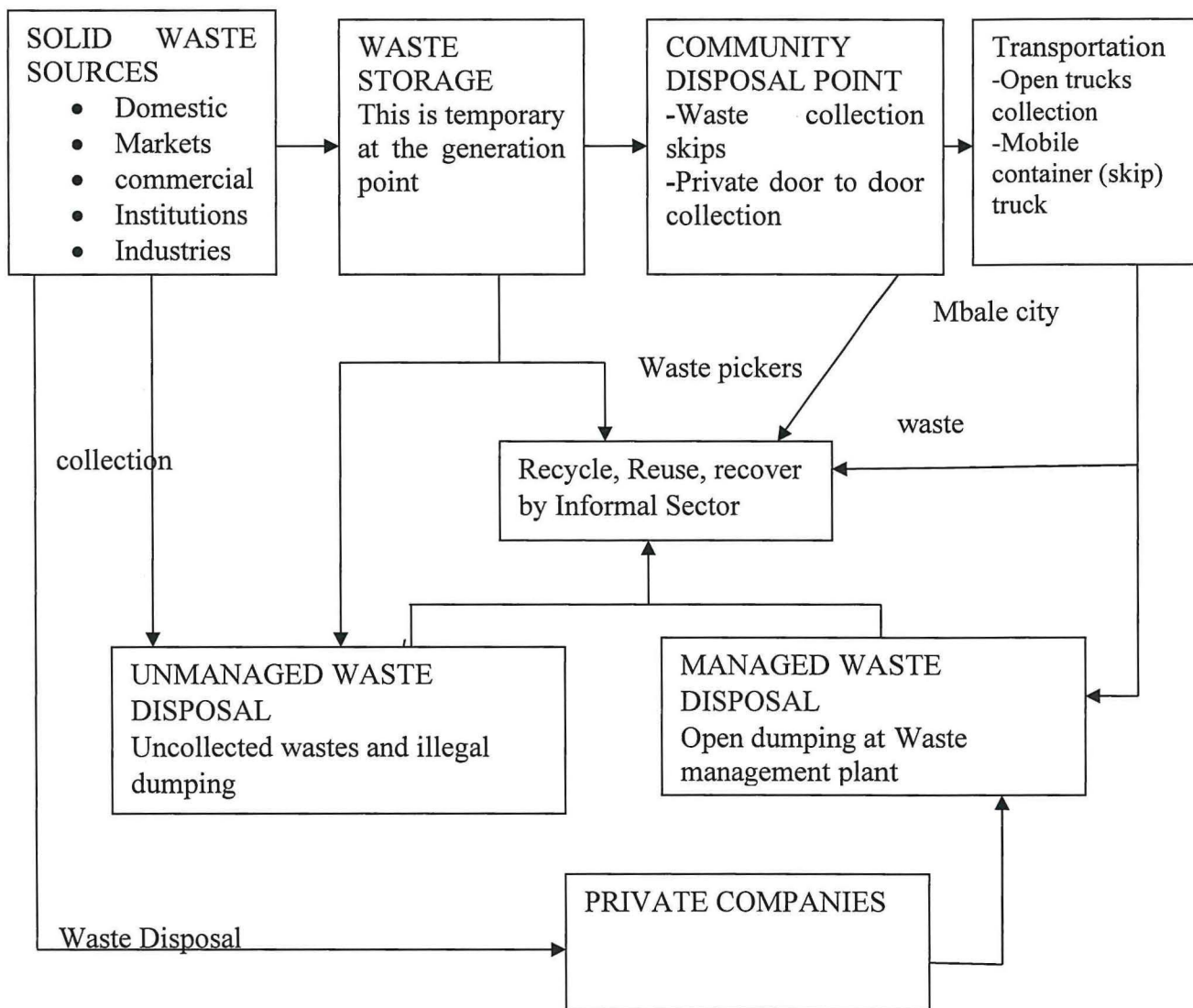


Figure 3. 4: Typical solid waste management in Mbale City (Adopted and modified from Okot -Okumu J. and Nyenge R., 2011)

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the findings on : (1) the characterization of solid wastes generated in Mbale city, (2) the quantification of the concentrations of water pollutants from leachates, (3) the determination of the effect of leachate on River Namatala water quality and (4) explore treatment of a key water pollutant from the leachate using avocado seeds. This is to guide on decision making for improvement of the waste management plant. The results of each of these sections are presented and discussed.

4.2 Characterization of solid wastes generated in Mbale city

4.2.1 Comparative analysis of characteristics of solid wastes

Table 4.1 below indicates the amount of biodegradable and non-biodegradable collected per day within Mbale city for a period of 14 days of data collection.

Table 4. 1: Amount of Solid waste types collected in Mbale City

Days	Total wastes	biodegradable	non-biodegradable	Percentage of biodegradable	Percentage of non-biodegradable
2/5/2022	267	229	38	86	14
3/5/2022	270	224	47	83	17
4/5/2022	274	226	48	82	18
5/5/2022	277	232	45	84	16
6/5/2022	278	236	42	85	15
7/5/2022	279	231	48	83	17
8/5/2022	276	237	39	86	14
28/5/2022	266	230	36	86	14
29/5/2022	276	230	46	83	17
30/5/2022	273	219	54	80	20
31/5/2022	281	245	37	87	13
1/6/2022	265	226	40	85	15
2/6/2022	272	238	34	87	13
3/6/2022	275	232	43	84	16
Total	3829	3231	595.5	1181.5	217.7
Average	273.5	230.8	42.5	84.4	15.6

Source: primary data

According to the statistics in Table 4.1 above, 3231.1 tons of biodegradable wastes was collected representing 84.4 % while non-biodegradable wastes was represented by 595.5 tons (15.6 %) of the wastes collected by the city. The biodegradable wastes composition is from organic wastes from households, perishable food items from the markets, industries and abattoirs. The non-biodegradable wastes was composed of polythene, plastics, construction materials, metals, glasses and papers. The average daily wastes collected by the city was 273.5 tons per day as shown in Table 4.1 above.

Table 4.2 shows the breakdown of wastes collected by the different service providers within Mbale city.

Table 4. 2: Breakdown of different categories of solid wastes collected

Days	Total wastes (tons)	Biodegradable (tons)	polythene, plastics (tons)	Papers (tons)	metals, glass and others (tons)	%age of biodegradable	%tage of polythene, plastics, construction material	%tage of papers	%tage of metals, glass and others
2/5/2022	267	229	34	0.56	2.98	86	12.91	0.21	1.12
3/5/2022	270	224	41	0.97	4.34	83	15.26	0.36	1.61
4/5/2022	274	226	44	0.75	3.71	82	15.96	0.28	1.35
5/5/2022	277	232	39	0.98	4.53	84	14.26	0.35	1.64
6/5/2022	278	236	38	1.14	2.79	85	13.69	0.41	1.00
7/5/2022	279	231	45	0.90	1.94	83	16.19	0.32	0.69
8/5/2022	276	237	35	0.14	4.01	86	12.63	0.05	1.45
28/5/2022	266	230	32	0.18	3.48	86	12.16	0.07	1.31
29/5/2022	276	230	44	0.05	1.94	83	15.95	0.02	0.70
30/5/2022	273	219	51	0.08	2.55	80	18.82	0.03	0.93
31/5/2022	281	245	35	0.15	1.36	87	12.45	0.05	0.48
1/6/2022	265	226	37	0.28	2.15	85	13.99	0.11	0.81
2/6/2022	272	238	33	0.05	1.27	87	12.01	0.02	0.47
3/6/2022	275	232	41	0.04	2.23	84	14.81	0.02	0.81
Total	3829	3231	550	6.3	39.28	1181.46	201.08	2.29	14.38
Average	273.5	230.8	39.3	0.4	2.8	84	14.4	0.2	1.03

Source: Primary Data

The 15.6 % non-biodegradable wastes generated within the city was composed of mainly 14.4 % plastics, polythene and construction materials, 1.03 % metal and glasses and 0.2 % papers which were sorted and sold to recycling agents buying for their respective factories and industries. According to the statistics in Table 4.2 above, solid wastes collected daily was evenly distributed implying that there were slight differences in the waste collected. Biodegradable waste collected in the 14 days of the study ranges between 80 % to 87 % of the total wastes. The days with the high percentage of 87 % had supply of agricultural products such as bananas (commonly known as *Matooke*), irish potatoes, cabbages, watermelon, carrots and pineapples into the main markets in the city.

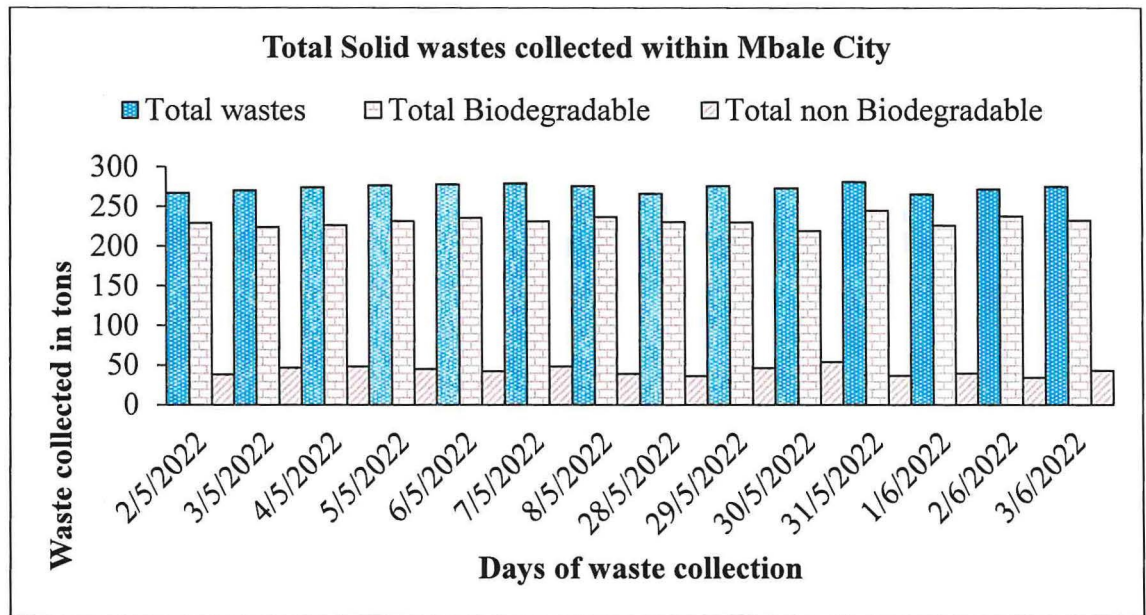
The non-biodegradable wastes which consists of construction materials, metals, papers, glasses, plastics and polythene are mostly generated from the households, mushrooming construction sites and shops utilizing and dealing in these items. Table 4.3 shows the total amounts of wastes collected by different service providers in the different days of waste collection.

Table 4. 3: Total solid wastes collected by the different service providers per day

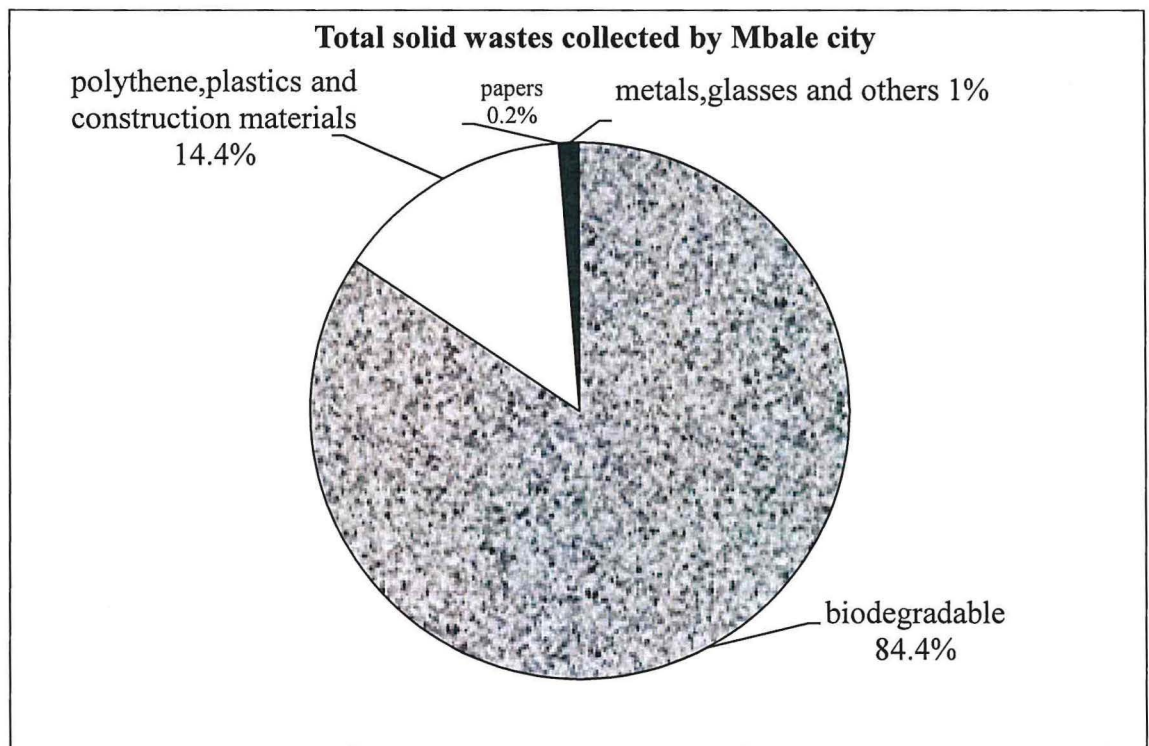
Days	Service providers						Total Tons
	Wagila Ltd (Tons)	Mbale City trucks (tons)	Orient Ltd (tons)	Pick it Ltd (tons)	Umar (tons)	Eco pick Ltd (tons)	
2/5/2022	35	101	45	36	15	35	267
3/5/2022	38	99	46	37	16	34	270
4/5/2022	34	104	48	38	14	36	274
5/5/2022	36	103	46	39	15.5	37	276.5
6/5/2022	38	104	48	35	17	35.5	277.5
7/5/2022	37	109	44	39	16	34	279
8/5/2022	36	102	49.6	38	15	35	275.6
28/5/2022	35	104	36	37	18	36	266
29/5/2022	39	109.5	46	34	14	33	275.5
30/5/2022	36	105	49	33	15	35	273
31/5/2022	38	106	47	36	17	37	281
1/6/2022	35	103	43	37	13	34	265
2/6/2022	39	103.5	44	34	18	33	271.5
3/6/2022	36	105	47	35	16	36	275
Grand Total							3829

Source: Primary Data

Figure 4.1 shows the comparative analysis of total solid wastes collected using bar charts and pie charts



(a) Bar chart statistics

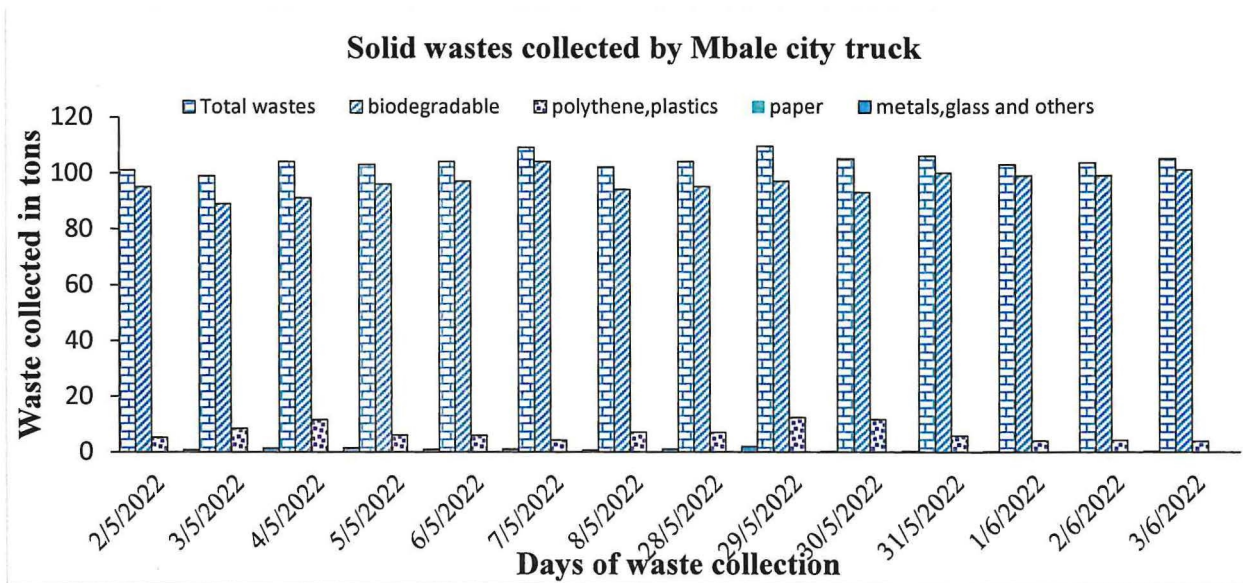


(b) pie-chart statistics

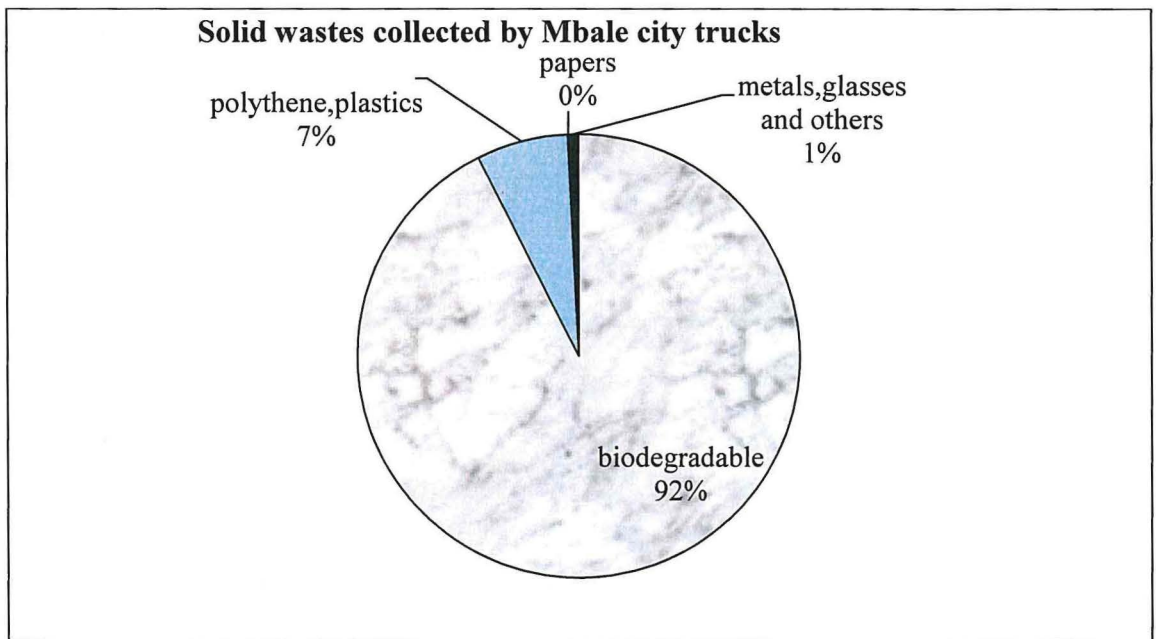
Figure 4. 1: Comparative analysis of daily total solid waste collected

Mbale city has been working with five solid wastes service providers under framework contract of collecting the solid wastes within the city. These service

providers have been allocated different cells and wards. The service providers collect solid wastes from households within the city at a cost met by the households. Mbale city trucks are responsible for collection of wastes in markets. The solid wastes collected on daily basis are illustrated in Figures 4.2 to 4.7 below.



(a) Bar chart statistics



(b) Pie chart statistics

Figure 4. 2: Solid waste collected by Mbale City truck from markets

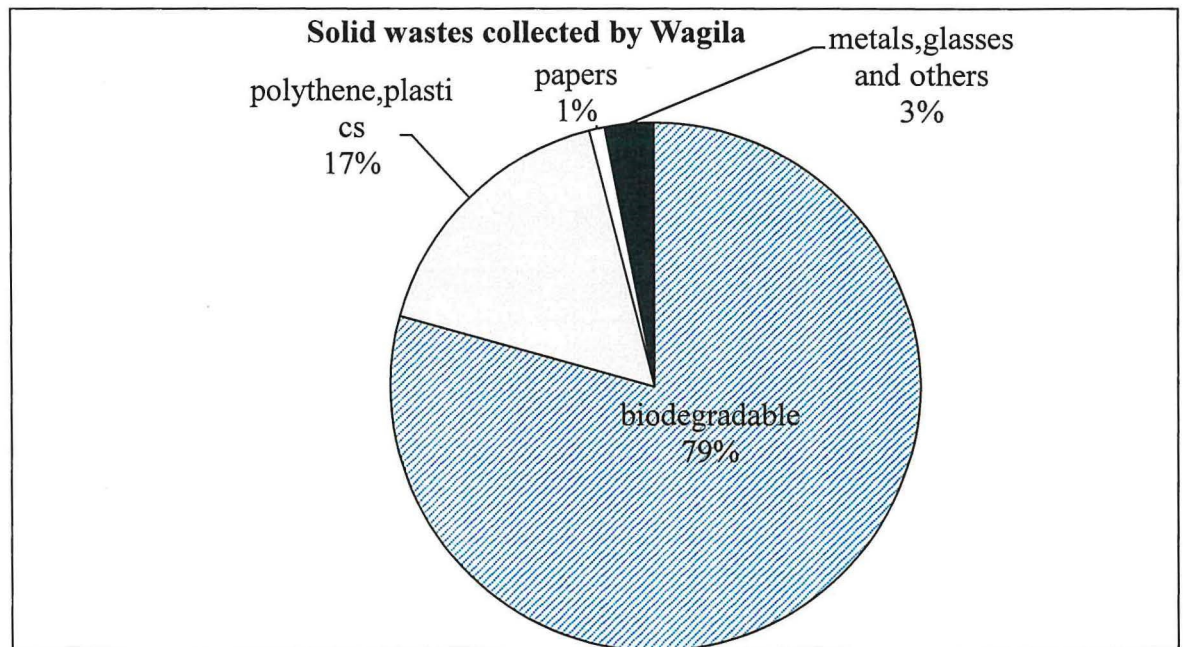
From Figure 4.2 above, Mbale City trucks collect different types of solid wastes such as biodegradable wastes, polythene plastics, papers and metals, glasses and others from markets around the city. The city trucks collected more than 104 tons of wastes on average daily and out this, 92.5 % were biodegradable wastes while 7.5 % were non-biodegradable wastes. This could be due to the fact that supplies to the markets were mainly from agricultural products such as bananas (commonly known as *Matooke*), irish potatoes, cabbages, watermelon, carrots and pineapples on a daily basis.

4.2.2 Solid waste collected by service providers under framework contracts

Figure 4.3 shows the statistics of solid wastes collected by M/S Wagila Limited that is one of the private service providers for solid waste collection in Mbale City.



(a) Bar statistics

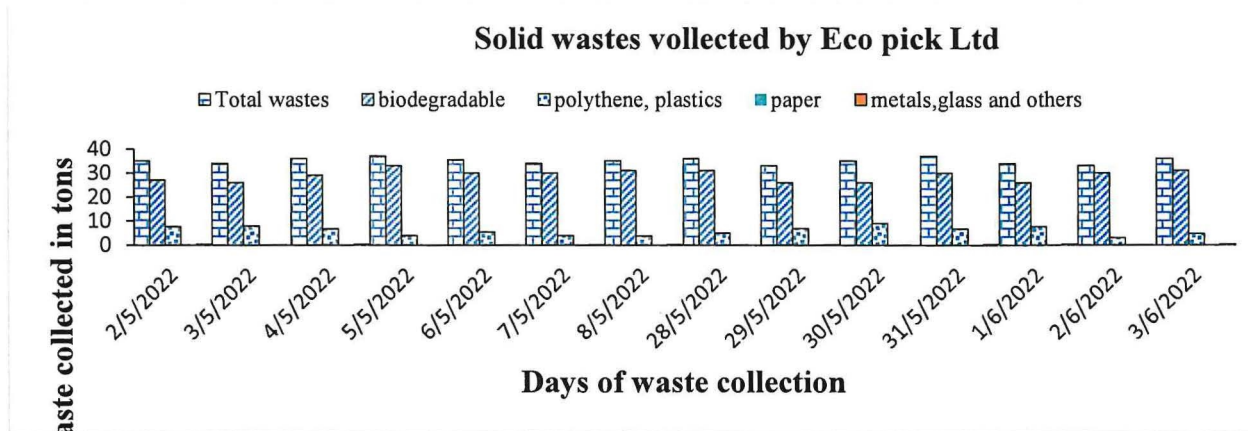


(b) Pie-chart statistics

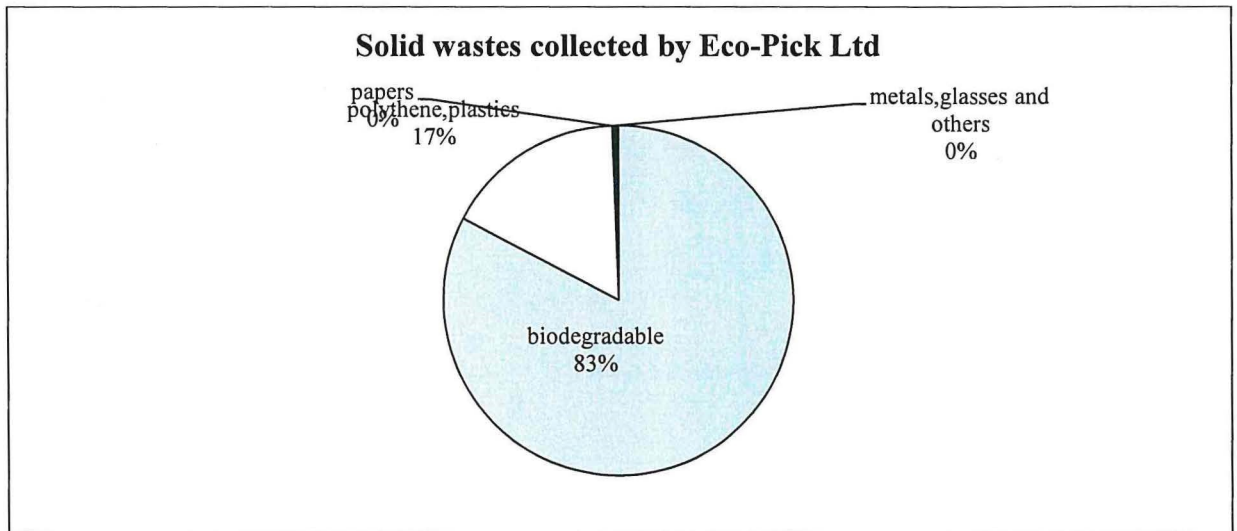
Figure 4. 3: Solid wastes collected by Wagila Ltd.

From Figure 4.3 above, Wagila collected 36 tons of wastes on daily average in the city. 79 % of the wastes were biodegradable, 17 % were plastics polythene and construction material wastes, 3 % were metals, glasses and others while 1 % was

papers and stationery. The 79 % biodegradable wastes were from residential areas with very many construction sites.



(a) Bar statistics

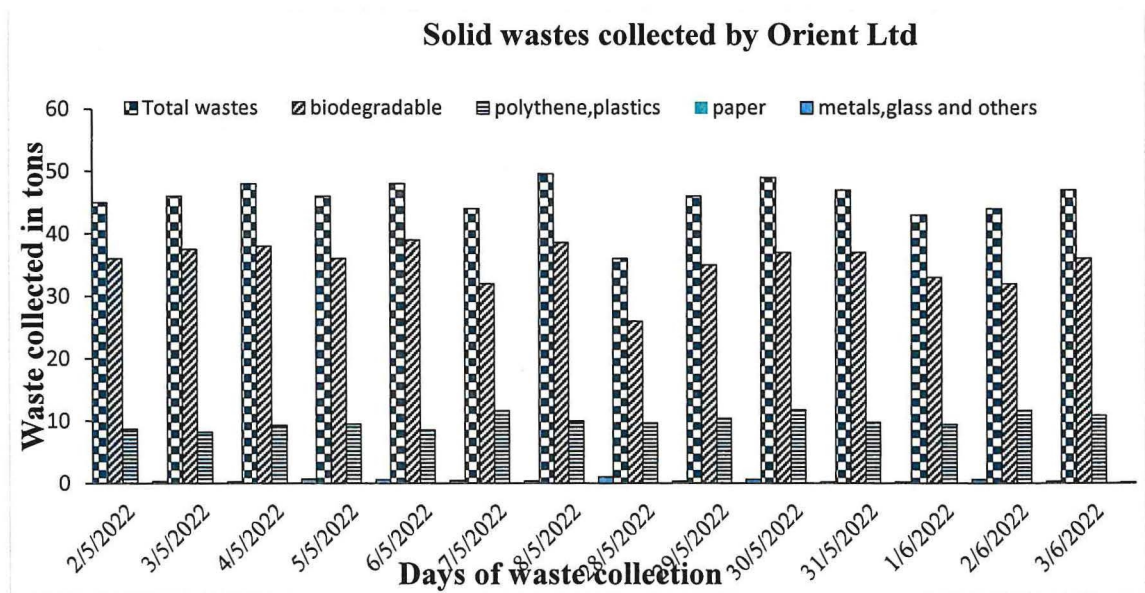


(b) Pie-chart statistics

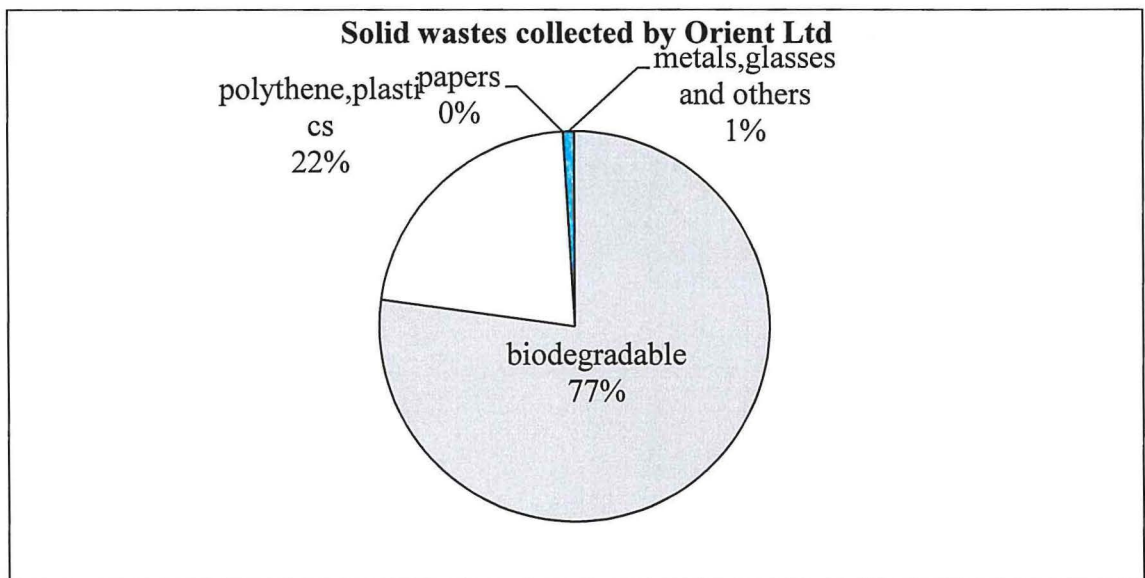
Source: primary data

Figure 4. 4: Solid wastes collected by Eco-pick Ltd

From Figure 4.4 above, Eco-pick collected an average of 35 tons of waste in the city on a daily basis. 82.8 % were biodegradable wastes, 16.7 % were plastics and construction materials and the rest were metals, glasses, papers and stationery collected from homesteads and a few businesses.



(a) Bar statistics

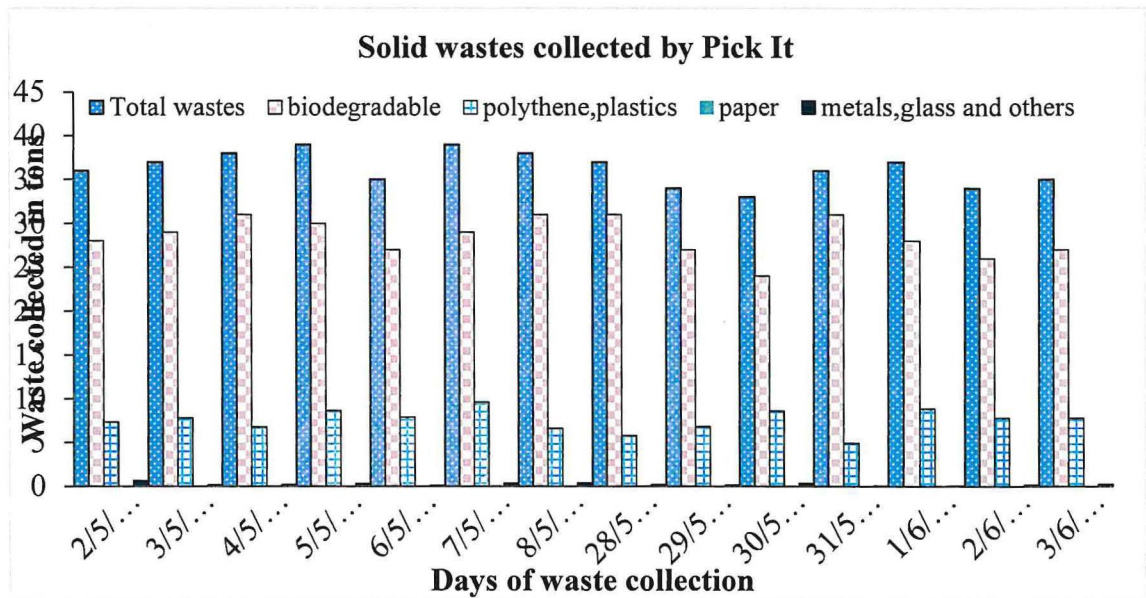


(b) Pie-chart statistics

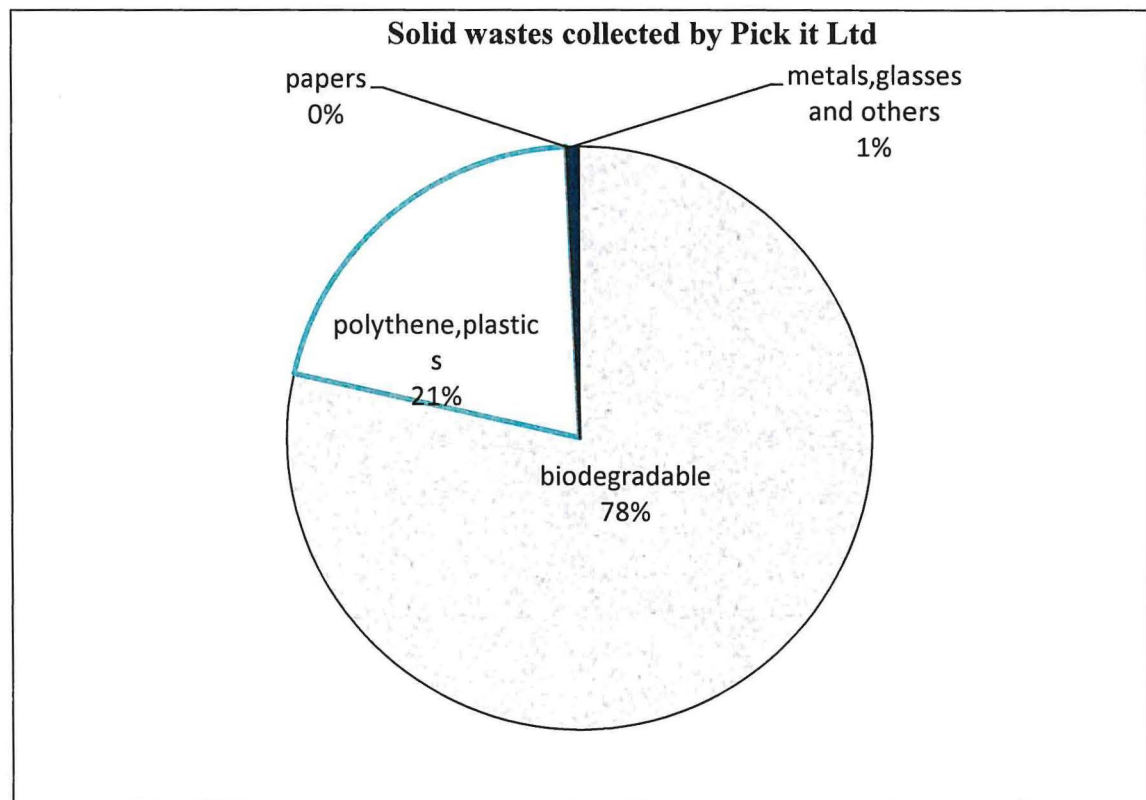
Source: primary data

Figure 4. 5: Solid wastes collected by Orient Limited

From the statistics in Figure 4.5 above, 77.2 % of solid wastes collected were biodegradable wastes, 21.8 % were from construction materials, plastics, polythene and the rest were from metals, glasses and others. These were wastes collected from households and construction sites and some shops in their areas of operation.



(a) Bar statistics



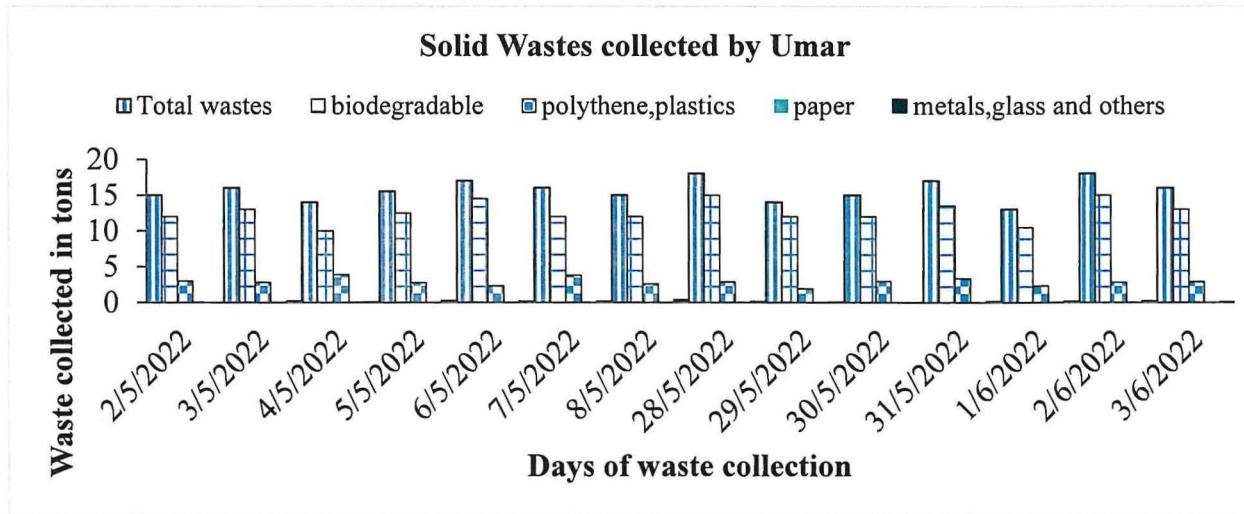
(b) Pie-chart statistics

Source: primary data

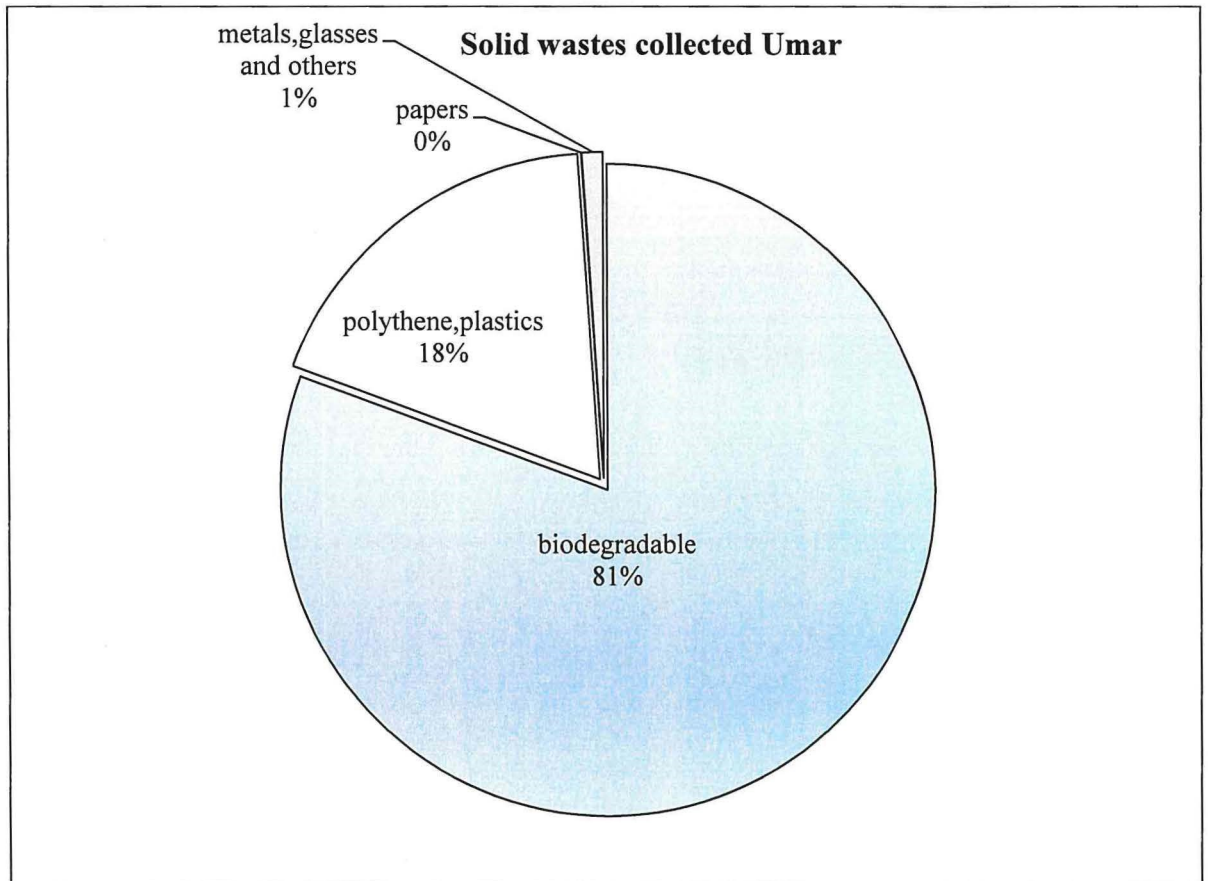
Figure 4. 6: Solid wastes collected by Pick it

From the statistics in Figure 4.6 above, *pick it* collected 78.5 % of biodegradable wastes of which 20.8 % were polythene, plastics and construction materials and the

rest were papers, metals, glasses and others. The 36 tons of wastes collected daily were from households and shops in the city.



(a) Bar statistics



(b) Pie-chart statistics

Source: primary data

Figure 4. 7: Solid wastes collected by Umar

From the statistics in Figure 4.8 above, Umar had an average daily collection of 15 tons of wastes from households in the northern division of the city. Out of these, 80.6 % were biodegradable, 18.3 % were plastics and construction materials and the rest were glasses, metal and papers. The low volume was due to the more of the peri-urban nature of the households with minimal activities in the area of collection of solid wastes.

4.3 Quantifying the concentrations of water pollutants from leachates.

Table 4.4 shows details of the various chemicals that were found in leachates from solid wastes at Mbale waste management plant.

Table 4. 4: Statistical summaries of chemicals in leachates from solid wastes

Parameter	Maximum	Minimum	Average	NEMA acceptable limit	WHO Acceptable Limit
PH	7.98	6.11	6.98	5.0 -8.5	5.5 -8.8
BOD ₅ (mg/l)	4.22	0.23	2.35267	50	1
COD (mg/l)	1047.2	23.03	364.3195	70	1
Total Nitrogen (mg/l)	666.24	0.01	137.51	10	0.1
Total Phosphorus (mg/l)	2367.49	176.29	768.55	5	0.005
Electrical Conductivity (EC) (μS/cm)	6010	282	1997.7	1000	1000
Copper (cu) (mg/l)	1.558	0	0.15697	0.5	2
Nickel (Ni) (mg/l)	0.129	0.011	0.05327	0.5	0.07
Chromium (Cr)	0.228	0.015	0.11867	0.05	0.05
Lead (Pb) (mg/l)	0.42	0.04	0.237	0.1	0.01
Iron (Fe) (mg/l)	2.674	0.116	1.18383	0.3	0.1
Silver (Ag) (mg/l)	0.223	0.005	0.0294	0.5	0.5

The data in Table 4.4 above indicates the descriptive statistics for the chemical composition of leachates from solid wastes plant in Mbale city. The values for total phosphorus, chemical oxygen demand (COD) and lead were high for all samples in

contrast to regulatory limits (NEMA, 2020). Similarly, electrical conductivity (EC) and total nitrogen also had higher values before leachates joined the river as shown by results in Table 4.5 from sample number one (P1) to sample number (P11). However, the values kept on reducing as the leachates mixed with flowing water in River Namatala.

The total phosphorus concentration varied from 176.29 mg/l to 2367.49 mg/l. The concentration of chemical oxygen demand (COD) varied from 23.03 mg/l to 1047.2 mg/l while lead concentration varied from 0.04 mg/l to 0.42 mg/l. After being mixed with water from the River Namatala, electrical conductivity (EC) varied from high values of 6,010 s/cm to tolerable values of 282 s/cm (NEMA, 2020). Total nitrogen content in the leachate varied from 666.24 mg/l before mixing with water from the river to 0.01 mg/l.

The concentration of total nitrogen and electrical conductivity kept on reducing as the water flows downstream at the point of entry and also decreases upstream from the point of entry. This means that upstream water sources around entry point of leachates is riskier for use than downstream water sources. The 5-day biochemical oxygen demand ranged between 0.23-4.22. The results indicate that during decomposition of solid wastes, soluble salts tend to be leached out first as shown by high EC and concentrations of soluble ions. This is in line with the conclusions of (Al-Wabel et al., 2011).

In the Table 4.4 above, the pH that ranged from 6.11 - 7.98 were within the recommended National Environment Management Authority (Waste Management) regulation (2020) of 5.0 - 8.5 with mean \pm st.dev of 6.98 ± 0.62 . This could be due

to the alkaline, organic and inorganic acids formed when solid wastes decompose turning leachates to be acidic in nature (Al-Wabel et al., 2011).

The concentration of lead, copper, iron, nickel, silver, chromium ranged between (0 - 1.558 mg/l), (0.116 - 2.674 mg/l), (0.011 - 0.129 mg/l), (0.005 - 0.223 mg/l), (0.015 - 0.228 mg/l) respectively. The concentrations of heavy metals in the leachate was low apart from lead which was high above the recommended National Environment Management Authority of Uganda standards of 0.1mg/l. Al-Wabel et al., (2011) stated that the danger posed by heavy metals in leachates should not be ignored even if standards are met since solid waste composite plant leachates are the known sources of heavy metals to nearby environments. The implication of this particular result in reference to (Al-Wabel et al., 2011) suggests that cleanup of the environment around River Namatala is necessary and urgent.

4.4 Comparative analysis of leachates in upstream and downstream

Laboratory tests were done for pH, BOD₅, COD, total nitrogen, total phosphorus, electrical conductivity, and heavy metals copper, nickel, chromium, lead, iron and silver. The results P1 to P12 is for leachate flow from waste management plant to River Namatala , D13 to D24 river flow downstream and S25 to S30 upstream river flow. Table 4.5 shows the result of laboratory tests for these parameters.

Table 4. 5: Summary of results from Makerere University laboratory

Lab ID	PH	BOD ₅	COD	Total Nitrogen	Total Phosphorus	Conductivity	Heavy Metals					
							Cu (mg/l)	Ni (mg/l)	Cr (mg/l)	Pb (mg/l)	Fe (mg/l)	Ag (mg/l)
P1	7.9	1.71	914.06	203.64	1010.90	6010	0.166	0.116	0.015	0.18	2.333	0.037
P2	7.9	3.99	596.54	511.60	918.62	5790	0.142	0.103	0.061	0.1	2.202	0.048
P3	8	3.99	887.63	339.01	1050.84	5690	0.124	0.088	0.036	0.06	2.121	0.024
P4	8	1.71	1047.20	91.74	1163.77	5640	1.558	0.09	0.143	0.17	1.871	0.024
P5	7.7	1.03	626.20	113.20	1289.10	5770	0.762	0.129	0.129	0.08	2.674	0.048
P6	7.4	0.91	314.80	255.27	2367.49	5240	0.174	0.043	0.099	0.04	0.136	0.005
P7	7.8	1.25	453.41	554.10	1205.09	3530	0.348	0.029	0.114	0.04	1.311	0.014
P8	7.5	2.28	214.55	226.38	1380.00	3130	0.125	0.011	0.125	0.16	0.457	0.014
P9	7.6	2.28	180.38	600.54	1349.70	3560	0.183	0.016	0.106	0.09	0.704	0.011
P10	7.4	1.14	193.92	666.24	1323.53	3250	0.158	0.016	0.228	0.07	0.849	0.142
P11	7.5	1.71	213.26	431.60	1183.05	3230	0.032	0.015	0.121	0.12	0.766	0.223
P12	7.2	0.91	23.03	42.97	622.51	513	0.015	0.062	0.073	0.27	2.066	0.017
D13	6.5	2.97	113.75	7.47	592.22	385	0.02	0.046	0.093	0.27	0.913	0.012
D14	6.6	2.62	350	5.41	556.41	397	0.026	0.051	0.106	0.28	1.692	0.023
D15	6.6	1.48	276.32	22.77	421.44	406	0.015	0.049	0.128	0.23	2.496	0.013
D16	6.6	0.57	363.82	10.76	444.85	362	0.014	0.033	0.119	0.31	1.618	0.01
D17	6.8	0.23	260.2	11.37	592.22	372	0.014	0.042	0.152	0.28	2.631	0.022
D18	6.9	1.14	282.92	9.75	951.68	396	0.009	0.07	0.122	0.28	1.271	0.021
D19	6.6	1.71	370.95	8.49	527.49	735	0.637	0.031	0.14	0.29	0.381	0.013
D20	6.6	1.83	242.08	7.88	455.87	379	0.038	0.055	0.131	0.23	2.596	0.015
D21	6.8	4.22	390.83	1.07	498.56	520	0.095	0.037	0.135	0.31	0.386	0.019
D22	7.2	4.22	229.44	1.03	302.99	547	0.006	0.042	0.144	0.33	0.414	0.015
D23	6.5	2.85	306.25	0.21	360.84	454	0.007	0.046	0.082	0.34	0.567	0.017
D24	6.2	3.99	354.58	0.10	531.62	282	0.026	0.021	0.114	0.35	1.961	0.013
S25	6.1	3.19	379.17	0.01	506.83	805	0.003	0.057	0.126	0.34	0.116	0.012
S26	6.3	2.62	490.00	1.49	308.50	428	0.002	0.055	0.166	0.38	0.273	0.009
S27	6.4	3.65	167.43	0.02	422.81	357	0	0.078	0.155	0.42	0.192	0.014
S28	6.4	3.76	215.1	0.10	285.09	538	0.002	0.059	0.117	0.35	0.146	0.016
S29	6.2	3.88	215.10	0.02	256.17	540	0.005	0.053	0.125	0.35	0.166	0.014
S30	6.2	2.74	256.67	1.17	176.29	675	0.003	0.055	0.155	0.39	0.206	0.017

Source: Makerere University Biochemistry Laboratory

4.4.1 Analysis of pH in river flow

Samples obtained from upstream river flow and downstream river flow showed a pH below 7. The pH of leachate flowing from solid wastes plant was slightly above 7 (Figure 4.5). The leachate flow, downstream river flow, and upstream river flow all complied with the required pH standards and were consistent with findings from Xaypanya et al. (2018) that showed the pH values remaining within the range of (7.07 to 8.2) in dry season and (7.0 to 8.3) in wet season . The upstream river flow had a mean \pm st.dev pH of 6.27 ± 0.139 while downstream river flow had a mean \pm st.dev pH of 6.633 ± 0.149 . However, there was a statistically noteworthy difference between the averages of pH from upstream and downstream river flow ($p = 0.000000000176$ or $p < 0.05$). The pH of the river was nearer 7 compared to the leachates. Water with pH less than seven ($\text{pH} < 7$) is taken as acidic and one with pH greater than seven ($\text{pH} > 7$) is taken as alkaline. Acidic water can lead to natural phenomena and while heavy metals can lead to diarrhea, nausea and vomiting, suppression of the immune system and organ damage (USEPA, 2004). Table 4.6 (a) and (b) that follows shows the analysis for pH and single factor analysis respectively.

Table 4. 6 (a): Analysis of pH

Pairing Two Samples for Means (t-Test)			Pairing Two Samples for Means (t-Test)		
	<i>downstream</i>	<i>Upstream</i>		<i>downstream</i>	<i>Upstream</i>
Average	6.63333	6.2733	Average	6.63333	6.27333
Variance	0.02231	0.0193	Variance	0.02231	0.01931
Observations	6	6	Observations	6	6
Pearson Correlation	0.7347		Pearson Correlation	0.7347	
Theoretical Mean Difference	0		Theoretical Mean Difference	0	
df	5		df	5	
t Stat	8.3623		t Stat	8.3623	
P(T<=t) one-tail	0.0002		P(T<=t) one-tail	0.0002	
t Critical one-tail	2.0150		t Critical one-tail	2.0150	
P(T<=t) two-tail	0.0004		P(T<=t) two-tail	0.0004	
t Critical two-tail	2.5706		t Critical two-tail	2.5706	

Table 4.6 (b): Single Factor (Analysis of Variance)

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Leachate	6	46.45	7.741667	0.032417
Downstream	6	39.8	6.633333	0.022307
Upstream	6	37.64	6.273333	0.019307

<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	7.028011111	2	3.514006	142.402	0.000000000176	3.68232
Within Groups	0.37015	15	0.024677			
Total	7.398161111	17				

Summary for pH

	Mean	variance	t stat	t from the table	Decision
Downstream	6.633	0.022	8.362	2.571	Reject
Upstream	6.273	0.019	8.362	2.571	Reject

4.4.2 Analysis of copper in river flow

The concentration of copper in the downstream river flow, upstream river flow and leachate were less than the maximum permitted value of 0.5mg/l (Figure 4.1). Although the quantities of copper in the upstream of river Namatala (0 - 0.005 mg/l) were less than the downstream of river Namatala and leachate flow (0.007 - 0.637 mg/l) and (0.015 - 1.558 mg/l) respectively. The total copper ions in the upstream river flow had mean \pm st.dev. of 0.0025 ± 0.0016 mg/l whereas downstream river flow had mean \pm st.dev. of 0.018 ± 0.012 mg/l. The averages of copper concentration varied statistically significantly between the upstream and downstream river flows ($p= 0.013303$ or $p < 0.05$). Some water sources where copper ore deposits are mined can have some copper traces found in them. The amount of copper in treated water system increases during treated water transmission and distribution more especially in the system carbonated beverages with a pH that is acidic or alkaline. A high copper percentage in treated drinking water has a detrimental effect on human health (Aaseth and Norseth, 1986). Small quantities of copper, however, have no appreciable impact on human health, although they do impart unpleasant tastes to drinking water (Onyutha et al., 2022). Table 4.7 (a) and (b) that follows shows the analysis for copper and single factor analysis respectively.

Table 4. 7(a): Analysis of copper

Pairing Two Samples for Means (t-Test)			Pairing Two Samples for Means (t-Test)		
	<i>Flow downstream</i>	<i>Upstream</i>		<i>Flow downstream</i>	<i>Upstream</i>
Average	0.018	0.0025	Average	0.018	0.0025
Variance	0.0001428	0.0000027	Variance	0.0001428	0.0000027
Observations	6	6	Observations	6	6
Pearson Correlation	0.275009549		Pearson Correlation	0.275009549	
Theoretical Mean Difference		0	Theoretical Mean Difference		0
Df		5	Df		5
t Stat	3.271323741		t Stat	3.271323741	
P(T<=t) one-tail	0.011083041		P(T<=t) one-tail	0.011083041	
t Critical one-tail	2.015048372		t Critical one-tail	2.015048372	
P(T<=t) two-tail	0.022166082		P(T<=t) two-tail	0.022166082	
t Critical two-tail	2.570581835		t Critical two-tail	2.570581835	

Table 4.7 (b): Single Factor

SUMMARY						
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
Leachate flow	6	1.615	0.269167	0.06889777		
Downstream	6	0.108	0.018	0.0001428		
Upstream	6	0.015	0.0025	0.0000027		
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	0.268872	2	0.134436	5.84138304	0.013303	3.68232
Within Groups	0.345216	15	0.023014			
Total	0.614088	17				

Summary for Copper

	Mean	variance	t stat	t from the table	Decision
Downstream	0.018	0.000	3.271	2.571	Reject
Upstream	0.0025	0.000	3.271	2.571	Reject

4.4.3 Analysis of iron in river flow

The concentration of iron in the upstream river flow, downstream river flow and leachate flow were less than the maximum permitted value of 3.5mg/l (0.116 - 0.273 mg/l) , (0.381 - 2.496 mg/l) and (0.136 - 2.674 mg/l) respectively. The iron ions in the upstream river flow had mean \pm st.dev of 0.183 ± 0.055 mg/l while downstream river flow had mean \pm st.dev of 1.345 ± 1.002 mg/l. The averages of iron concentration varied statistically significantly between the upstream and downstream river flows ($p = 0.00489$ or $p < 0.05$). Onyutha et al., (2022) stated that a high iron content in water results in a brownish color, changes the taste of water, and is harmful to human health. Groundwater and various types of surface water, naturally contain iron and drinking water may occasionally contain iron as it passes through rusted steel or cast-iron pipes (Choudhury et al., 2022). Table 4.8 (a) and (b) that follows shows the analysis for iron and single factor analysis respectively.

Table 4. 8 (a): Analysis of iron

Pairing Two Samples for Means (t-Test)			Pairing Two Samples for Means (t-Test)		
	<i>Down stream</i>	<i>upstream</i>		<i>Down stream</i>	<i>upstream</i>
Average	1.345166667	0.183166667	Average	1.345166667	0.183166667
Variance	1.004151767	0.002971367	Variance	1.004151767	0.002971367
Observations	6	6	Observations	6	6
Pearson Correlation	-0.610158		Pearson Correlation	-0.610158	
Theoretical Mean Difference	0		Theoretical Mean Difference	0	
df	5		df	5	
t Stat	2.746780377		t Stat	2.746780377	
P(T<=t) one-tail	0.020232333		P(T<=t) one-tail	0.020232333	
t Critical one-tail	2.015048372		t Critical one-tail	2.015048372	
P(T<=t) two-tail	0.040464666		P(T<=t) two-tail	0.040464666	
t Critical two-tail	2.570581835		t Critical two-tail	2.570581835	

Table 4.8 (b) Single Factor

Summary						
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
Leachate	6	10.559	1.759833333	0.54582377		
Down stream	6	8.071	1.345166667	1.00415177		
upstream	6	1.099	0.183166667	0.00297137		
<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
	8.0161404					3.6823
Between Groups	44	2	4.008070222	7.74283439	0.004897	2
Within Groups	7.7647345	15	0.517648967			
	15.780874					
Total	94	17				

Summary for Iron

	Mea n	variance	t stat	t from the table	Decision
Downstream	1.345	1.004	2.747	2.571	Reject
Upstream	0.183	0.003	2.747	2.571	Reject

4.4.4 Analysis of chromium in river flow

The concentration of chromium in the upstream river flow, downstream river flow and leachate flow were less than the highest allowable amount of 0.5mg/l for discharges into the river (0.117 - 0.166 mg/l), (0.093 - 0.152 mg/l) and (0.015 - 0.228 mg/l) respectively (NEMA, 2020). The chromium ions in the upstream river flow had mean \pm standard deviation of 0.140 ± 0.02 mg/l whereas downstream river flow had mean \pm standard deviation of 0.124 ± 0.024 mg/l. The averages of iron concentration varied statistically significantly between the upstream and downstream river flows ($p = 0.0203$ or $p < 0.05$). Wael et al., (2023) and Banks et al., (2006) stated that although a series of intricate reactions including oxidative stress, chromosomal and DNA damage, and mutagenesis, human exposure to Cr(VI) resulted into both carcinogenic and non-carcinogenic health impacts. Chromium in water bodies enters them naturally by leaching from topsoil and rock (Robles-Camacho and Armienta, 2000). Table 4.9 (a) and (b) that follows shows the analysis for chromium and single factor analysis respectively.

Table 4. 9 (a): Analysis of Chromium

Pairing Two Samples for Means (t-Test)			Pairing Two Samples for Means (t-Test)		
	<i>Down stream</i>	<i>upstream</i>		<i>Down stream</i>	<i>upstream</i>
Average	0.124333333	0.140166667	Average	0.124333333	0.140166667
Variance	0.000562667	0.000398967	Variance	0.000562667	0.000398967
Observations	6	6	Observations	6	6
Pearson Correlation	-0.078655057		Pearson Correlation	-0.078655057	
Theoretical Mean Difference	0		Theoretical Mean Difference	0	
Df	5		df	5	
t Stat	-1.204850526		t Stat	-1.204850526	
P(T<=t) one-tail	0.141086125		P(T<=t) one-tail	0.141086125	
t Critical one-tail	2.015048372		t Critical one-tail	2.015048372	
P(T<=t) two-tail	0.28217225		P(T<=t) two-tail	0.28217225	
t Critical two-tail	2.570581835		t Critical two-tail	2.570581835	

Table 4.9(b): Single Factor

Summary

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Leachate	6	0.497	0.0828333	0.00212696
Down stream	6	0.746	0.1243333	0.00056266
upstream	6	0.841	0.1401666	0.00039896

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	0.01052	2	0.0052600	5.10916488	0.020315	3.6823
Within Groups	0.015443	15	0.0010295	6		2
Total	0.025963	17				

Summary for Chromium

	Mean	variance	t stat	t from the table	Decision
Downstream	0.124	0.000	1.205	2.571	do not reject
Upstream	0.140	0.000	1.205	2.571	do not reject

4.4.5 Analysis of nickel in river flow

The concentration of nickel in the upstream river flow, downstream river flow and leachate flow were less than the maximum permitted value of 0.5 mg/l allowed to be discharged into water body. The values were (0.053 mg/l - 0.078 mg/l), (0.021 - 0.051 mg/l) and (0.011 - 0.116 mg/l) respectively. The nickel ions in the upstream river flow had mean \pm standard deviation of 0.0595 ± 0.0093 mg/l while downstream river flow had mean \pm standard deviation of 0.0418 ± 0.007 mg/l. The means of nickel concentration did not differ statistically significantly between the upstream and downstream river flows ($p = 0.4025$ or $p > 0.05$). A high nickel absorption in water poses a risk to human health (Singh, 2022). Plants may be harmed by high amounts of nickel in sandy soils and in surface water inhibits the growth of microorganisms and algae (El-Naggar et al., 2021). Table 4.10 (a) and (b) that follows shows the analysis for nickel and single factor analysis respectively.

Table 4. 10 (a): Analysis of nickel

Pairing Two Samples for Means (t-Test)			Pairing Two Samples for Means (t-Test)		
	<i>Down stream</i>	<i>upstream</i>		<i>Down stream</i>	<i>upstream</i>
Average	0.0418333	0.0595	Average	0.041833333	0.0595
Variance	4.5367E-05	0.000086	Variance	4.53667E-05	0.0000863
Observations	6	6	Observations	6	6
Pearson Correlation	-0.8134745		Pearson Correlation	-0.81347451	
Theoretical Mean Difference	0		Theoretical Mean Difference	0	
df	5		df	5	
t Stat	-2.8321601		t Stat	-2.83216009	
P(T<=t) one-tail	0.0182908		P(T<=t) one-tail	0.01829087	
t Critical one-tail	2.0150483		t Critical one-tail	2.015048372	
P(T<=t) two-tail	0.0365817		P(T<=t) two-tail	0.036581741	
t Critical two-tail	2.5705818		t Critical two-tail	2.570581835	

Table 4. 10 (b): Single Factor

SUMMARY						
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
Leachate	6	0.393	0.0655	0.0026843		
Down stream	6	0.251	0.04183	4.537E-05		
upstream	6	0.357	0.0595	8.63E-05		
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	0.00182	2	0.00091	0.9675777	0.4025	3.68232
Within Groups	0.01408	15	0.00094			
Total	0.0159	17				

Summary for Nickel

	Mean	variance	t stat	t from the table	Decision
Downstream	0.042	0.000	2.832	2.571	Reject
Upstream	0.059	0.000	2.832	2.571	Reject

4.4.6 Analysis of Lead in river flow

The concentration of Lead (Pb) in the upstream river flow, downstream river flow and leachate flow were above the maximum permitted value of 0.1 mg/l (0.34 - 0.42 mg/l), (0.23 - 0.35 mg/l) and (0.04 - 0.27 mg/l) respectively. The Lead ions in the upstream river flow had mean \pm standard deviation of 0.372 ± 0.031 mg/l while downstream river flow had mean \pm standard deviation of 0.288 ± 0.039 mg/l. The averages of lead concentration varied statistically significantly between the upstream and downstream river flows ($p = 0.0000002403$ or $p < 0.05$). Lead is rarely found in naturally occurring water sources; instead, it enters drinking water through the corrosion of Lead pipes, solder, faucets, cisterns, and other plumbing fixtures (LU et al., 2022). Aaseth et al. (1986) and LU et al. (2022) reported that high lead contamination generally affects human health and retards academic growth in children. Table 4.11 (a) and (b) that follows shows the analysis for lead and single factor analysis respectively.

Table 4. 11(a): Analysis of Lead

Pairing Two Samples for Means (t-Test)			Pairing Two Samples for Means (t-Test)		
	<i>Down stream</i>	<i>upstream</i>		<i>Down stream</i>	<i>upstream</i>
Average	0.2875	0.371667	Average	0.2875	0.3716667
Variance	0.0014975	0.000937	Variance	0.0014975	0.000937
Observations	6	6	Observations	6	6
Pearson Correlation	-0.07177001		Pearson Correlation	0.071770005	-
Theoretical Mean Difference	0		Theoretical Mean Difference	0	
df	5		Df	5	
t Stat	-4.04		t Stat	-4.04	
P(T<=t) one-tail	0.004961365		P(T<=t) one-tail	0.004961365	
t Critical one-tail	2.015048372		t Critical one-tail	2.015048372	
P(T<=t) two-tail	0.009922729		P(T<=t) two-tail	0.009922729	
t Critical two-tail	2.570581835		t Critical two-tail	2.570581835	

Table 4.11(b): Single Factor

Summary

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
Leachate	6	0.645	0.1075	0.004158		
Down stream	6	1.725	0.2875	0.001497		
upstream	6	2.23	0.371667	0.000937		
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	0.218536	2	0.109268	49.73009	0.00000024031	3.68232
Within Groups	0.032958	15	0.002197			
Total	0.251494	17				

Summary for Lead

	Mean	variance	t stat	t from the table	Decision
Downstream	0.288	0.001	4.040	2.571	Reject
Upstream	0.372	0.001	4.040	2.571	Reject

4.4.7 Analysis of silver in river flow

The concentration of silver in the upstream river flow, downstream river flow and leachate flow were less than the highest allowable amount of 0.5 mg/l for discharges into river. The silver concentration values are (0.009 - 0.017 mg/l), (0.01 - 0.023 mg/l) and (0.005 - 0.223 mg/l). The silver ions in the upstream river flow had mean \pm standard deviation of 0.014 ± 0.003 mg/l while the downstream river flow had mean \pm standard deviation of 0.016 ± 0.004 mg/l. The means of silver concentration did not differ statistically significantly between the upstream and downstream river flows ($p = 0.195972$ or $p > 0.05$). Silver species are easily able to penetrate biological membranes and alter organisms physiology, leading to hazardous effects (Courtois et al., 2019). Silver has harmful effects on both healthy cells and pathogenic organisms. (Antsiferova et al., 2022). Silver concentrations in soil and surface water that are naturally occurring do not have any negative effects on the environment (WHO,2002). Table 4.12 (a) and (b) that follows shows the analysis for silver and single factor analysis respectively.

Table 4. 12 (a): Analysis of silver

Pairing Two Samples for Means (t-Test)			Pairing Two Samples for Means (t-Test)		
	<i>Down stream</i>	<i>upstream</i>		<i>Down stream</i>	<i>upstream</i>
Average	0.01566667	0.01366667	Average	0.01566667	0.0136667
Variance	0.0000159	0.0000082667	Variance	0.0000159	0.0000083
Observations	6	6	Observations	6	6
Pearson Correlation	-0.2386627		Pearson Correlation	-0.2386627	
Theoretical Mean Difference	0		Theoretical Mean Difference	0	
df	5		Df	5	
t Stat	0.900450		t Stat	0.900450	
P(T<=t) one-tail	0.2045767		P(T<=t) one-tail	0.2045767	
t Critical one-tail	2.0150484		t Critical one-tail	2.0150484	
P(T<=t) two-tail	0.40915		P(T<=t) two-tail	0.40915	
t Critical two-tail	2.57058183		t Critical two-tail	2.570581835	

Table 4. 12 (b): single factor analysis (analysis of variance)

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
leachate	6	0.357	0.0595	0.0066107
Down stream	6	0.094	0.015667	0.00001586667
upstream	6	0.082	0.013667	0.00000826667

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	0.008052111	2	0.004026	1.820417494	0.195972	3.68232
Within Groups	0.033174167	15	0.002212			
Total	0.041226278	17				

Summary for Silver

	Mean	variance	t stat	t from the table	Decision
Downstream	0.016	0.000	0.900	2.571	do not reject
Upstream	0.014	0.000	0.900	2.571	do not reject

4.4.8 Analysis of total nitrogen in river flow

The concentration of total nitrogen in the upstream river flow (0.01 - 1.49 mg/l) was less than the maximum permitted value of 10 mg/l. The concentration of total nitrogen in the downstream river flow (0.10 - 22.77 mg/l) and leachate flow (42.77 - 666.24 mg/l) was higher than the maximum permissible value of 10 mg/l allowed to be discharged into the water body (NEMA,2020). The total nitrogen in the upstream river flow had mean \pm standard deviation of 0.4683 ± 0.676 mg/l whereas the downstream river flow had mean \pm standard deviation of 8.563 ± 8.208 mg/l. There were statistically significant variations in the means of total nitrogen concentration between the upstream and downstream river flows ($p = 0.00003438$ or $p < 0.05$). Total nitrogen (TN) is composed of nitrates, nitrites, ammonia, and organic nitrogen (Huckleberry et al., 2009). The growth of aquatic plants and algae is encouraged by high total nitrogen levels, which can suffocate water intakes, reduce dissolved oxygen as they break down, and block sunlight from penetrating deeper waters (Mishra and Tripathi, 2023). Table 4.13 (a) and (b) that follows shows the analysis for total nitrogen and single factor analysis respectively.

Table 4. 13 (a): Analysis of total nitrogen

Pairing Two Samples for Means (t-Test)			Pairing Two Samples for Means (t-Test)		
	<i>down stream</i>	<i>upstream</i>		<i>down stream</i>	<i>upstream</i>
Average	8.5633333	0.468333	Average	8.5633333	0.4683333
Variance	67.367147	0.456777	Variance	67.3671467	0.45677667
Observations	6	6	Observations	6	6
Pearson Correlation	-0.43137		Pearson Correlation	-0.43137	
Theoretical Mean Difference	0.0000000		Theoretical Mean Difference	0.0000000	
df	5.0000000		Df	5.0000000	
t Stat	2.3269933		t Stat	2.3269933	
P(T<=t) one-tail	0.0337317		P(T<=t) one-tail	0.0337317	
t Critical one-tail	2.0150484		t Critical one-tail	2.0150484	
P(T<=t) two-tail	0.0674633		P(T<=t) two-tail	0.0674633	
t Critical two-tail	2.5705818		t Critical two-tail	2.5705818	

Table 4. 13(b): single factor analysis (analysis of variance)

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
leachate	6	2242.090	373.682	37067.401
down stream	6	51.380	8.563	67.367
upstream	6	2.810	0.468	0.457

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	545330.2	2	272665.1	22.02748	0.00003438	3.6823
Within Groups	185676.1	15	12378.41			
Total	731006.4	17				

Summary for Total Nitrogen

	Mean	variance	t stat	t from the table	Decision
Downstream	8.563	67.367	2.327	2.571	do not reject
Upstream	0.468	0.457	2.327	2.571	do not reject

4.4.9 Analysis of total phosphorus in river flow

The concentration of total phosphorus in the upstream river flow (531.62 mg/l - 176.29 mg/l), downstream river flow (592.22 - 360.84 mg/l) and leachate flow into the river (1010.9 - 622.51 mg/l) was higher than the maximum permitted value of 5 mg/l allowed to be discharged into the river. The total phosphorus in the upstream river flow had mean \pm standard deviation of 325.948 ± 119.449 mg/l while the downstream river flow had mean \pm standard deviation of 498.795 ± 93.054 mg/l. There were statistically significant variations in the means of total phosphorus concentration between the upstream and downstream river flows ($p = 0.000000004$ or $p < 0.05$). Apart from its environmental effects, total phosphorus has no unique direct human health consequences (Xiu-Xiu et al., 2022). Blue-green algal blooms are always caused by high amounts of total phosphorus, which can impact human health by contact or intake of water or food, particularly fish, taken from water (Ngatia and Taylor, 2019). Eutrophication is caused by high total phosphorus levels in water bodies (Vaclav, 2000). Table 4.14 (a) and (b) that follows shows the analysis for total phosphorus and single factor analysis (analysis of variance) respectively.

Table 4. 14 (a): Analysis of total phosphorus

Pairing Two Samples for Means (t-Test)			Pairing Two Samples for Means (t-Test)		
	<i>down stream</i>	<i>upstream</i>		<i>down stream</i>	<i>upstream</i>
Average	498.795	325.9483	Average	498.795	325.9483
Variance	8659.060	14268.17	Variance	8659.060	14268.17
Observations	6	6	Observations	6	6
Pearson Correlation	-0.622051		Pearson Correlation	-0.622051	
Theoretical Mean Difference	0		Theoretical Mean Difference	0	
df	5		Df	5	
t Stat	2.208381		t Stat	2.208381	
P(T<=t) one-tail	0.039132		P(T<=t) one-tail	0.039132	
t Critical one-tail	2.015048		t Critical one-tail	2.015048	
P(T<=t) two-tail	0.078264		P(T<=t) two-tail	0.078264	
t Critical two-tail	2.570582		t Critical two-tail	2.570582	

Table 4. 14 (b): Single factor analysis

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
leachate	6	7088.68	1181.447	17320.85
down stream	6	2992.77	498.795	8659.06
upstream	6	1955.69	325.9483	14268.17

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	245553	2	1227767	91.5149	0.000000004	3.68232
Within Groups	201240.	15	13416.03			
Total	265677	17				

Summary for Total Phosphorus

	Mean	variance	t stat	t from the table	Decision
Downstream	498.795	8659.060	2.208	2.571	do not reject
Upstream	325.948	14268.170	2.208	2.571	do not reject

4.4.10 Analysis of electrical conductivity in river flow

The electrical conductivity of the upstream river flow (357 - 805 $\mu\text{s/cm}$), downstream river flow (282 - 735 $\mu\text{s/cm}$) were less than the maximum permissible value of 1,000 $\mu\text{s/cm}$. The electrical conductivity of leachate flow (1,460 – 6,010 $\mu\text{s/cm}$) was higher than the maximum permissible value of 1,000 $\mu\text{s/cm}$ (NEMA,2020). The electrical conductivity in the upstream river flow had mean \pm standard deviation of 557.167 ± 162.923 $\mu\text{s/cm}$ while the downstream river flow had mean \pm standard deviation of 478.667 ± 136.715 $\mu\text{s/cm}$. There were statistically significant variations in the means of electrical conductivity concentration between the upstream and downstream river flows ($p = 0.000000095$ or $p < 0.05$). Water quality and the wellbeing of aquatic ecosystems may be impacted by the electrical conductivity of water, which rises with the quantity of dissolved salts and minerals (Meride and Ayenew, 2016). Table 4.15 (a) and (b) that follows shows the analysis for electrical conductivity and single factor analysis respectively.

Table 4. 15 (a): Analysis of electrical conductivity

Pairing Two Samples for Means (t-Test)			Pairing Two Samples for Means (t-Test)		
	<i>down stream</i>	<i>upstream</i>		<i>down stream</i>	<i>upstream</i>
Average	478.667	557.167	Average	478.667	557.166'
Variance	18691.067	26543.767	Variance	18691.067	26543.766'
Observations	6	6	Observations	6	
Pearson Correlation	-0.633085		Pearson Correlation	-0.633085	
Theoretical Mean Difference	0		Theoretical Mean Difference	0	
df	5		Df	5	
t Stat	-0.70956		t Stat	-0.70956	
P(T<=t) one-tail	0.25484		P(T<=t) one-tail	0.25484	
t Critical one-tail	2.01505		t Critical one-tail	2.01505	
P(T<=t) two-tail	0.50969		P(T<=t) two-tail	0.50969	
t Critical two-tail	2.57058		t Critical two-tail	2.57058	

Table 4. 15 (b): Single factor analysis (analysis of variance)

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
leachate	6	27790	4631.6666	1728496.667
down stream	6	2872	478.66666	18691.06667
upstream	6	3343	557.16666	26543.76667

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	67710243	2	33855121.5	57.260845	0.000000095	3.68232
Within Groups	8868657.5	15	591243.833			
Total	76578900.5	17				

Summary for Electrical conductivity

	Mean	variance	t stat	t from the table	Decision
Downstream	478.66 7	18691.06 7	0.710	2.571	do not reject
Upstream	557.16 7	26543.76 7	0.710	2.571	do not reject

Table 4. 16(b): Single Factor

SUMMARY						
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
Leachate	6	3274.94	545.8233	102315.6		
Downstream	6	1718.295	286.3825	9808.904		
Upstream	6	1723.47	287.245	15052.01		
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	268346.1	2	134173	3.165044	0.071325	3.68232
Within Groups	635882.5	15	42392.16			
Total	904228.5	17				

Summary for Chemical Oxygen Demand

	Mean	variance	t stat	t from the table	Decision
Downstream	286.383	9808.904	0.011	2.571	do not reject
Upstream	287.245	15052.01	0.011	2.571	do not reject

4.4.12 Analysis of biochemical oxygen demands in river flow

The biological oxygen demands of the upstream river flow (2.62 - 3.88 mg/l), downstream river flow (0.23 - 4.22 mg/l) and biological oxygen demands of leachate flow (0.91 - 3.99 mg/l) were less than the highest allowable amount of 50 mg/l (NEMA,2020). The biochemical oxygen demands in the upstream river flow had mean \pm standard deviation of 3.306667 ± 0.540 mg/l while the downstream river flow had mean \pm standard deviation of 2.243 ± 1.395 mg/l. The means of biochemical oxygen demand concentration did not differ statistically significantly between the upstream and downstream river flows ($p = 0.108367$ or $p > 0.05$). Table 4.17 (a) and (b) that follows shows the analysis for 5-day biochemical oxygen demand and single factor analysis (analysis of variance) respectively.

Table 4. 17 (a): Analysis of biochemical oxygen demands

Pairing Two Samples for Means (t-Test)			Pairing Two Samples for Means (t-Test)		
	<i>Downstream</i>	<i>Upstream</i>		<i>Downstream</i>	<i>Upstream</i>
Average	2.243333333	3.306666667	Average	2.243333333	3.306666667
Variance	1.944786667	0.291666667	Variance	1.944786667	0.291666667
Observations	6	6	Observations	6	6
Pearson Correlation	0.078568172		Pearson Correlation	0.078568172	
Theoretical Mean Difference	0		Theoretical Mean Difference	0	
df	5		Df	5	
t Stat	1.789662508		t Stat	1.789662508	
P(T<=t) one-tail	0.066761508		P(T<=t) one-tail	0.066761508	
t Critical one-tail	2.015048372		t Critical one-tail	2.015048372	
P(T<=t) two-tail	0.133523017		P(T<=t) two-tail	0.133523017	
t Critical two-tail	2.570581835		t Critical two-tail	2.570581835	

Table 17 (b): Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Leachate	6	11.97	1.995	1.14199
Downstream	6	13.46	2.243333	1.944787
Upstream	6	19.84	3.306667	0.291667

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	5.825633	2	2.912817	2.586531	0.108367	3.68232
Within Groups	16.89222	15	1.126148			
Total	22.71785	17				

Table for Biochemical Oxygen Demand s

	Mean	variance	t stat	t from the table	Decision
Downstream	2.243	1.945	1.790	2.571	do not reject
Upstream	3.307	2.230	1.790	2.571	do not reject

4.5 Comparative analysis of percentage removal of Lead (II) ions using avocado seeds

Determination of the treatment options for Lead (II) ions using avocado seeds answers specific objective number four. The line graphs, bar graphs and descriptive statistics (mean, coefficient of determination R^2 -regression) was used to describe the removal of lead using avocado seeds.

4.5.1 Analysis of percentage removal of Lead (II) ions using raw avocado seeds

The effectiveness of raw avocado seeds in removing Lead (II) ions from wastewater is shown in figure 4.9 (a) and (b), which shows the Lead (II) ions removal rate increases with increasing contact time and dosage of raw avocado seeds. At each contact time in table 4.24, higher dosages of raw avocado seeds tend to result in higher Lead (II) ions removal rates. At 5 minutes contact time, the Lead removal rate increased from 66.7% for 1 gram to 75.98% for 5 grams, indicating that the removal rate increased with increasing dosage. The adsorption of Lead (II) ions is improved by a greater adsorbent dosage because there are more adsorption sites available. (Naeema 2014). The increase in dosage and contact time had positive correlation coefficient with least correlation coefficient of 0.977 and the highest as 0.998 at 1g and 5g dosage respectively.

The findings are consistent with findings of Ukpong et al.,(2024) on the use of avocado seeds for removal of Lead (II) ions from wastewater. Similarly, Montañez et al.,(2023) showed that Lead (II) ions percentage removal increases with time as the dosage of avocado seeds increases. Figure 4.8 (a) and (b), summarizes the percentage increase in removal of Lead (II) ions with increase in dosage and time.

Table 4. 18: Summarizes percentage removal of Lead using raw avocado seeds

Time/Pb Dosage (g)	1g	2g	3g	4g	5g
Contact Time (min)	Percentage removal	Percentage removal	Percentage removal	Percentage removal	Percentage removal
5	66.715	68.6	70.406	74.32	75.98
10	70.52	72.801	75.89	79.922	81.894
15	78.75	80.869	84.77	86.575	88.846
20	80.965	86.458	89.733	90.533	93.969

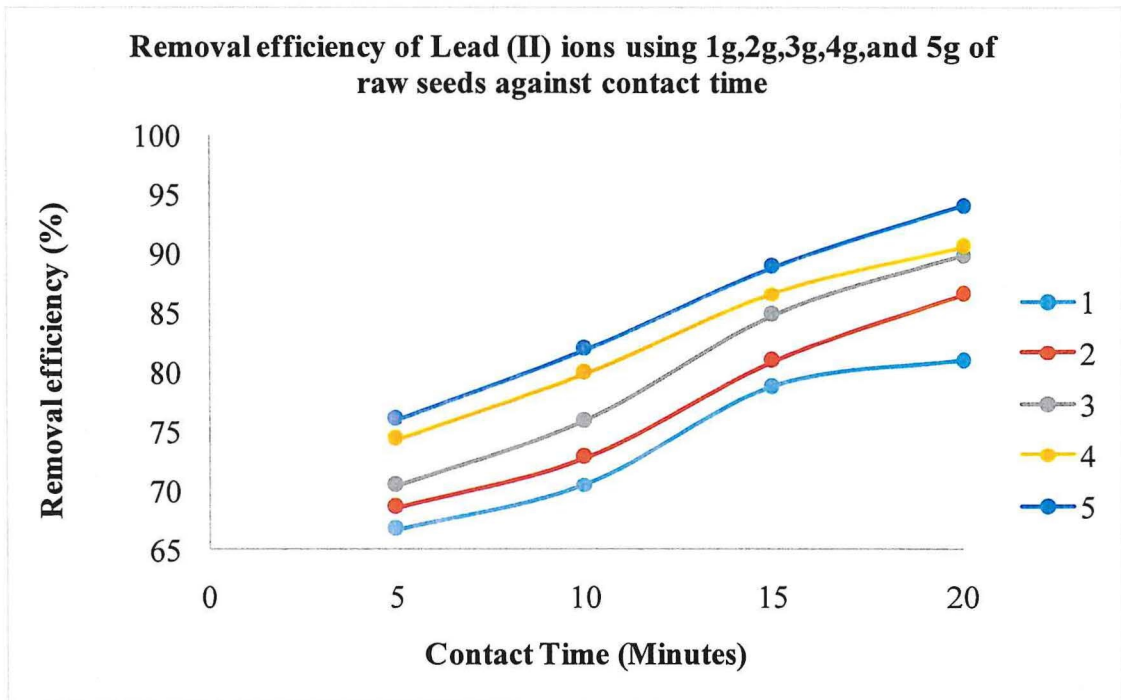


Figure 4.9 (a)

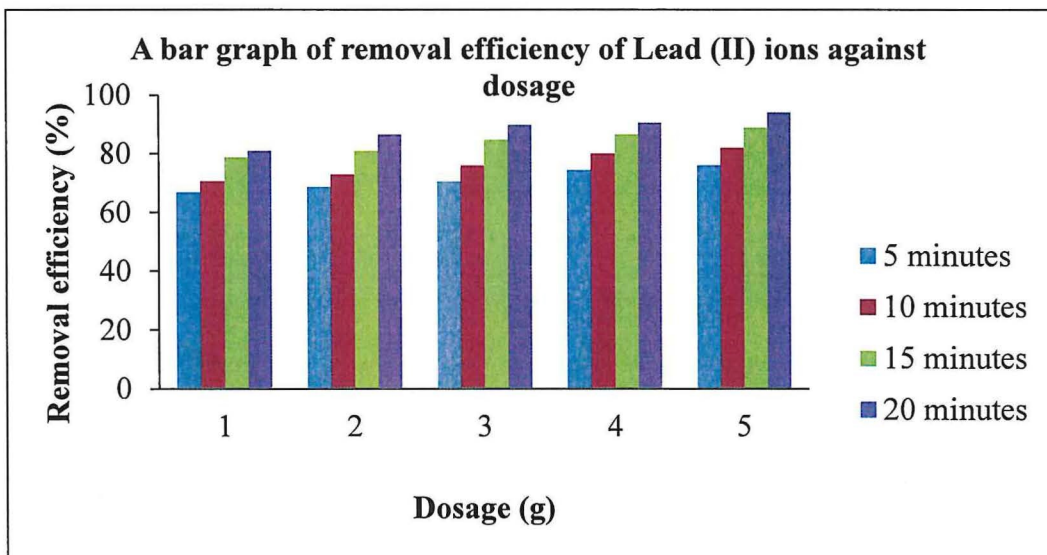


Figure 4.9 (b)

Figure 4. 8 (a) and (b) shows increase in removal efficiency (%) of Lead II ions with increase in dosage and time

4.5.2 Analysis of percentage removal of Lead (II) ions using activated avocado seeds

The effectiveness of activated avocado seeds in removing Lead (II) ions from wastewater is shown in figure 4.10 (a) and (b), which shows Lead (II) ions removal rate increases with increasing contact time and dosage of activated avocado seeds. At each contact time in table 4.25, higher dosages of activated avocado seeds tend to result in higher Lead (II) ions removal rates. At 5 minutes contact time, the Lead removal rate increased from 42.05% for 1 gram to 68.98% for 5 grams, indicating that the removal rate increased with increasing dosage. The increase in dosage and contact time had positive correlation coefficient with least correlation coefficient of 0.973 and the highest as 0.994 at 2g and 5g dosage respectively.

The findings are consistent with findings of Boeykens et al., (2019) on the use of activated avocado seeds for removal of Lead (II) ions from wastewater where the removal efficiency of 80% was reached with 0.15g. Similarly, Muthuraman et al.,(2021) showed that Lead (II) ions percentage removal increased with time as the dosage of avocado seeds powder was also increased. Table 4.19 Summarizes percentage removal of Lead (II) ions using activated avocado seeds.

Table 4. 19:Summarizes percentage removal of Lead using activated avocado seeds.

Time/Pb Dosage (g)	1g	2g	3g	4g	5g
Contact Time (min.)	Percentage removal	Percentage removal	Percentage removal	Percentage removal	Percentage removal
5	42.05	61.75	63.32	66.6	68.98
10	55.835	68.005	70.922	72.801	76.894
15	62.695	78.405	81.77	83.575	84.846
20	69.479	80.367	84.533	86.969	89.738

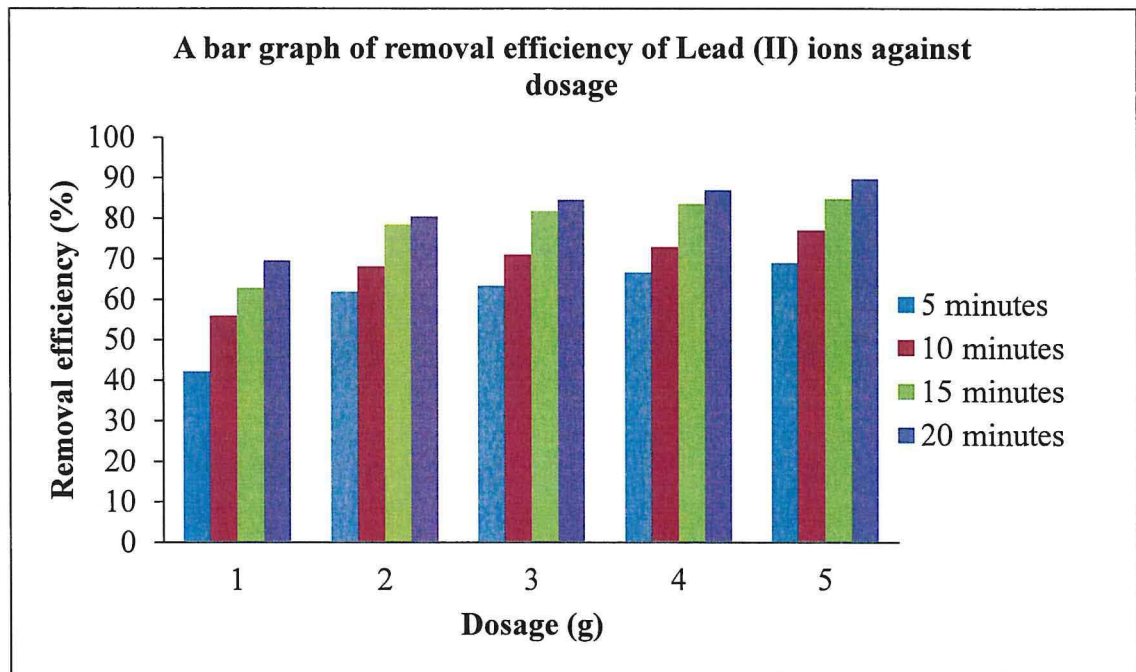
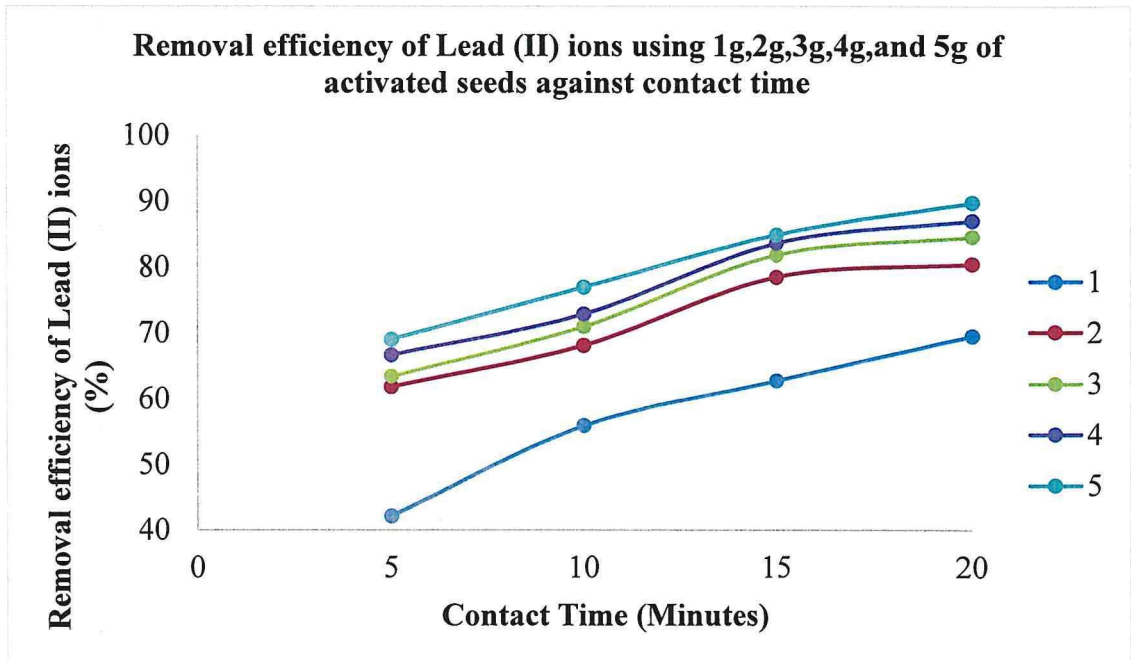


Figure 4. 9: (a) and (b) shows increase in removal efficiency (%) of Lead II ions with increase in dosage and time

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The following conclusions are made based on the results from specific objectives and research questions.

5.1.1 Characteristics of solid wastes generated in Mbale City

The 15.6% non-biodegradable wastes are plastics, construction materials, metals, glasses and others which are not affected so much by weather conditions. 84.4% are biodegradable wastes that are affected by weather and these include papers and agricultural products such as bananas (commonly known as *Matooke*), irish potatoes, cabbages, watermelon, carrots and pineapples.

5.1.2 Concentrations of water pollutants from leachates

The following parameters; 5 day biochemical oxygen demand, chemical oxygen demand, total nitrogen, total phosphorus, electrical conductivity, copper, lead, nickel, chromium and iron tested had concentrations above the recommended limits of World Health Organisation and National Environment Management Authority. Only pH and silver had concentrations below recommended standards of World Health Organisation and National Environment Management Authority

5.1.3 Effect of leachates on River Namatala water quality

T- test showed that copper, pH, iron, chromium, lead, total nitrogen, total phosphorus, electrical conductivity are affecting the River Namatala water quality whereas silver chemical oxygen demand, 5 day biochemical oxygen demand and nickel do not have effect on River Namatala water quality.

5.1.4 Treatment of Lead from leachate using avocado seeds

When Lead (II) ions were treated from leachate using powdered raw and activated avocado seeds, the proportion of Lead (II) ions removed rose as dosage and duration were increased. Therefore with increase in time and dosage raw avocado seeds powder removed 93.97% of Lead (II) ions compared to activated avocado seeds powder which removed 89.74% of Lead (II) ions.

5.2 Limitations

- i) The study was based on the effect of leachate from solid waste management plant on surface water quality of River Namatala and therefore the research focused only on the surface water quality of the river.
- ii) The study does not give the effect of the solid wastes on the surrounding environment living organisms, the soil conditions and underground water in this area as results of this solid waste management plant being in the area.
- iii) The funding implications in doing the tests could not allow the researcher to test all the parameters in the general chemicals and micro-biological discharge and also inorganic substance effluent discharge under National Environment Management Authority regulation,2020.

5.3 Recommendations

The following recommendations have been made as a result of this research:

5.3.1 Policy

- i) Mbale city should make use of solid waste pickers in the informal sector to separate the biodegradable from non-biodegradable wastes so that the

production of leachate are reduced since biodegradable wastes are turned in manure and non-biodegradable sold for recycling.

- ii) Modern solid waste management system should be developed to impede seepage and contamination of surrounding water sources. Mbale city council can partner with private sector to bring in improved technology that can reduce the solid wastes into agricultural manure and also source of energy.
- iii) Mbale city should sensitize households on the need and importance of solid wastes separation into biodegradable and non-biodegradable for ease of management at the waste plant.
- iv) Policy should be developed making it mandatory for every urban dwelling in cities to pay for waste disposal and also the wastes should be sorted in biodegradable and non- biodegradable.
- v) Mbale city should adopt physicochemical approaches in treating leachate being produced from the solid waste plant before disposing into the environment. The physicochemical approaches should include adsorption method and coagulation/flocculation method.

5.3.2 Further research

Recommendations for further research are as below:

- i) Treatment for other pollutants identified other than Lead using low cost technology should be explored.

- ii) The effect of leachate during the dry season should be investigated. This is expected to highlight on the effect of seasonality on the water quality under pollution from leachate.

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APPENDIX

A1: Letter of introduction from Kyambogo University to Mbale city



February 11, 2020

The Town Clerk,
Mbale Municipal council,
Mbale, Uganda.

Dear Sir/Madam,

S.E.D
Offer our best to the students
Dr. Charles Onyutha

RE: INTRODUCTION LETTER FOR DENIS ALUNYU

Mr. Denis Alunyu is a student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Building Engineering. He is conducting a research study on "Assessing the effect of Leachate from Solid Waste Management Plant on Surface Water Quality in Mbale Municipal Council". The researcher is being supervised and co-supervised by Dr. Charles Onyutha and Eng. Dr. Anne Nakagiri, respectively.

In his research, Denis Alunyu will require support on a number of occasions for the various specific objectives of his study (see next page). Both primary and secondary data from the study area shall be required. The purpose of this letter is to request your office to assist the researcher with necessary information on solid wastes, leachate and allow him collect the necessary samples to be tested and analyzed for the research.

I shall be grateful for any assistance rendered to Mr. Denis Alunyu to allow him conduct his research study timely.

Yours Sincerely,

Dr. Lawrence Mwanuzi
**THE HEAD OF DEPARTMENT
CIVIL AND BUILDING ENGINEERING
KYAMBOGO UNIVERSITY**
Head of Department of Civil and Building Engineering

Cc. Dean, School of Graduate Studies, Kyambogo University

Dr. Charles Onyutha - Department of Civil and Building Engineering, Kyambogo University

Eng. Dr. Anne Nakagiri - Department of Civil and Building Engineering, Kyambogo University

The specific objectives of this study are;

- To determine the characteristics of solid wastes being introduced into the solid wastes' treatment plant within municipality.
- To determine the characteristics of leachate being produced from solid waste management plant in Mbale municipality.
- To determine the effect of leachate on water quality of River Namatala.

A2: Letter of introduction to Makerere University



Department of Civil and Building Engineering

P. O. BOX 1, KYAMBOGO – P. O. BOX 7181 KAMPALA, UGANDA

Website: www.kyu.ac.ug, Email: civil@kyu.ac.ug
TEL: +256-41-4287340, FAX: +256-41-4289056/4222643

February 11, 2020

Head - Department of BioChemistry,
Makerere University,
P.O. Box 7062,
Kampala, Uganda.

Dear Prof./Dr./Sir/Madam,

RE: INTRODUCTION LETTER FOR DENIS ALUNYU AND REQUEST FOR SUBSIDIZING RATES FOR LABORATORY TESTS TO BE CONDUCTED

Mr. Denis Alunyu is a student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Building Engineering. He is conducting a research study on "Assessing the effect of Leachate from Solid Waste Management Plant on Surface Water Quality in Mbale Municipal Council". The researcher is being supervised and co-supervised by Dr. Charles Onyutha and Eng. Dr. Anne Nakagiri, respectively.

In his research, Denis Alunyu will require support on a number of occasions for the various specific objectives of his study (see next page). Both primary and secondary data shall be required for this research. The researcher wishes to test his samples in the laboratory of your department. Because there will be several samples to be tested, I hereby write to your office requesting for subsidizing of the laboratory tests. The necessary support to enable the researcher timely conduct the laboratory tests and complete his research will be duly acknowledged in the dissemination of the results.

I shall be grateful for any assistance rendered to Mr. Denis Alunyu to allow him conduct his research study timely.

Yours Sincerely,

Dr. Lawrence Muhwezi
Head of Department of Civil and Building Engineering

Cc. Dean, School of Graduate Studies, Kyambogo University

Dr. Charles Onyutha - Department of Civil and Building Engineering, Kyambogo University

Eng. Dr. Anne Nakagiri - Department of Civil and Building Engineering, Kyambogo University

The specific objectives of this study are;

- a) To determine the characteristics of solid wastes being introduced into the solid wastes' treatment plant within municipality.
- b) To determine the characteristics of leachate being produced from solid waste management plant in Mbale municipality.
- c) To determine the effect of leachate on water quality of River Namatala.