KYAMBOGO UNIVERSITY

DIRECTORATE OF RESEARCH AND GRADUATE TRAINING

ASSESSING BIOGAS RECOVERY POTENTIAL FROM ORGANIC SOLID WASTE GENERATED FROM ACADEMIC INSTITUTIONS

(Case study: Islamic University in Uganda - Mbale City)

By:

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REG. NO: **17/U/14679/GMEW/PE**

A DISSERTATION SUBMITTED TO KYAMBOGO UNIVERSITY DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILMENT FOR THE AWARD OF A MASTER OF SCIENCE IN WATER AND SANITATION ENGINEEERING DEGREE OF KYAMBOGO UNIVERSITY

SEPTEMBER 2022

DECLARATION

I **Kayizzi Patrick with Registration number 17/U/14679/GMEW/PE** 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 the university or other institute of higher learning, except where due acknowledgement has been made in the text and reference list.

Signature ……………………

Date: 27/09/2022 ------------------------------

APPROVAL

The undersigned approve that they have read and hereby recommend for submission for examination to the School of Graduate Studies of Kyambogo University a research dissertation entitled **Assessing Biogas Recovery Potential from Organic Solid waste**, in fulfillment of the requirements for the award of a Master of Science in Water and Sanitation Engineering Degree of Kyambogo University.

Eng. Dr. Nakagiri Anne (Supervisor)

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Date: 14.10.2022

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Kayizzi Patrick.

DEDICATION

To my parents Mr. & Mrs. Lwasa, My Wife Noeline and Children Keyla, Kailey and Kelsey for always being there for me.

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AD -	Anaerobic digestion
BMP-	Biomethane Potential
C-	Carbon
CO_2 -	Carbon dioxide
dm^3 -	Cubic decimeters (liters)
Fig. -	Figure
K –	Kelvin
Kg –	Kilograms
Km -	Kilometers
kJ -	Kilojoules
MFPED-	Ministry of Finance, Planning and Economic Development
MHLUD-	Ministry of lands Housing and Urban Development
NCE-	New Climate Economy
OIC -	Organization of Islamic Cooperation
WHO-	World Health Organization
kWh -	kilowatt hours
m -	meters

ABSTRACT

Resource recovery is contingent to the circular economy and the core intention is to replace the norm of largely linear economy of take make and dispose with one where resource circulation and disposal is fostered at high value. One of the current trending strategies in waste minimization is resource recovery such as biogas given its undisputable benefits. Education institutions are considered as congregated communities that have significant social, economic and environmental impact on the environment. like local authorities, these institutions experience challenges of provision of satisfactory social services such as managing solid waste. Minimal efforts have been invested in carrying out research in waste management practices in school settings most especially establishing the potential of biogas recovery that can contribute towards reduced impact to the ecosystem. This study was therefore focused on exploring the biogas potential from solid organic waste generated from higher academic institutions in Mbale Municipality. The study first looked at solid waste management practices in sampled academic institutions and their respective main source of fuel for cooking; a checklist was prepared and 26 out of 36 sampled institutions willingly provided access to their premise. From the data gathered, 65% of the 26 institutions practiced onsite waste disposal mainly dumping in pits and burning while the other schools disposed of to the main landfill; 25 out 26 institutions utilized wood biofuels for cooking while 1 out of the 26 used electricity; none of the schools practiced resource recovery. A detailed assesssment was then undertaken at Islamic University in Uganda to establish the quantity and composition of the waste generated within two distinct periods of the semester: one at the beginning (February) that represented the dry weather conditions and at the end of the semester (November) that represented the wet season. Results indicated that foliage pruning contributed the highest percentage of waste generated followed by kitchen waste while paper waste registered the least percentage contribution by both volume and weight; It was also noted that more waste generation was experienced during the wet season; hourly waste collection indicated peak collection/ generation between 1000-1200 while least collection was between 1200-1400hr with kitchen waste dominating between 0800-1000hrs and 1600-1800 while foliage pruning dominated between 1000-1200hrs and 1200-1400hrs respectively. Biogas resource potential was investigated using a single stage biogas setup where co-digestion of the organic solid waste was used as substrate; eight sets of experiments were conducted with two identical sets per ratio for (paper, kitchen and grass) and 25% cow dung inoculant by weight of the total substrate weight under mesospheric conditions. Results indicated a high methane composition of 33% and a relatively low percentage of 13% for ratios of 1:19:7 and 1:5:7 (for paper: kitchen: grass) respectively.

The potential of biogas in solid organic waste gave an indication of a virgin opportunity to explore harnessing resources from the organic waste generated from academic institutions that will in return provide an alternative for safe solid waste disposal as well as harnessing nature gas for cooking and manure for soil stabilization for ecosystem degradation mitigation.

Key Words: Resource recovery, Biogas, Solid Organic Waste, Methane

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Uganda's urban population has rapidly grown over years and currently stands at 6 million with an average growth rate of 5% per year and expected at 20 million by 2040 (Mukama et al., 2016; Bishop et al., 2016). Mbale Municipality located in Eastern Uganda is one of the 20 top major urban areas that contributes to the urban population in Uganda. it's population has since grown from 71,130 people in 2002 to over 96,189 people in 2014, with a growth rate of 2%, it is expected to be 160,964 by the year 2040 (Bishop et al., 2016).

Generated Waste is a retrospective product of urbanization, economic development and population growth (Moqbel, 2018). As cities become more populated, more waste is generated which demands for effective and efficient waste collection, treatment and disposal (thi thu trang, 2016; Mekonnen, Haddis and Zeine, 2020). Globally, 2.01 billion tonnes of municipal solid waste is generated annually (Kaza and Yao, 2018). With the anticipated rise in population, waste generation is expected to increase to 3.40 billion tonnes by 2050, higher values up to more than three times in low income countries are however anticipated (Kaza and Yao, 2018).

Waste composition globally differs across income levels, high income countries on average generate less food and green waste estimated at 32% but generate more recyclable waste of about 51%. Middle and low income countries generate 53% and 56% food and green waste respectively (Vergara and Tchobanoglous, 2012; Kaza and Yao, 2018). In major urban centers in East Africa, bio-waste accounts for the highest percentage at 70% average of the total Municipal Solid Waste with Uganda at highest percentage of 74%. (Okot-okumu, 2012; Komakech, 2014; Ntagisanimana, Yu and Ma, 2021)

Globally, it is estimated that 40% of waste is disposed of in landfills, 19% undergoes material recovery through recycling and composting, 11% treated through modern incineration while almost 33% of waste is openly dumped with prevalence in low income countries (Kaza, et al., 2018). These trends are partly stirred by indiscriminate management of solid organic waste often sidelined for other competing priorities like water, sanitation access, health and the consequences are often experienced from their negative impact on water resource quality, health, environmental degradation as well as decreased aesthetic values of settlements (Besufekad et al., 2020).

Mbale Municipality like any other rapidly urbanizing centers in low-income countries, has seen a rise in the commercial growth in terms of trade, industrialization and institutional development both academic and administrative (Oates et al., 2019; Bishop et al., 2016). To meet the increasing demand for social services like education services in the area, many schools and institutions have been setup to meet the demand for enrolment of pupils and students (Moqbel, 2018) as reflected in Figure 1-1 below. This trend has however directly contributed to increased generation of domestic waste mostly from paper waste, food waste and many other forms of waste (Ahmed et al., 2007; Moqbel, 2018).

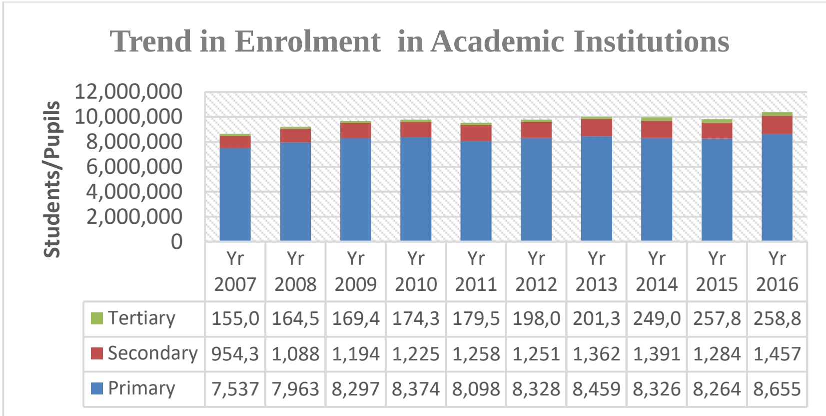


Figure 1-1: Trends of enrolment in academic institutions
Source (Ministry of Education and Sports- Uganda, 2019)

Education institutions are considered as small but rather congregated communities that have significant social, economic and environmental impact on surrounding environment (Moqbel, 2018) (Taghizadeh et al., 2012). These institutions therefore, like local authorities experience challenges related to provision of satisfactory social services such as managing solid waste (Trang, 2016; Moqbel, 2018). However, if good practices of effective solid waste are adopted in these institutions, it can informally train students and take experience back to their homes and surrounding communities (Enrique and Ortiz-hernandez, 2015).

This study was therefore focused on exploring the biogas potential from solid organic waste generated from accademic institutions in Mbale Municipality with a detailed case study at Islamic University in Uganda. This area of study was therefore considered to inform an integrated approach towards lessening environmental degradation through sustainable organic solid waste management.

1.2 Statement of the Problem

Public Authorities are mandated to oversee and undertake solid waste management in these urban areas but the responsibility of waste management has been shifted to the respective individual where academic institutions are inclusive (Coker et al., 2016). The widely adopted waste management practices in academic institutions is mostly open dumping, burning, and to a minimal level composting. (Trang, 2016; Coker et al., 2015).

Figure 1-2 shows open dumping practiced by one of the academic institutions visited.

Figure 1-2: Dumping site at Islamic University in Uganda Source:(Field survey)

Unregulated open disposal of waste has however lead to numerous environmental and health risks due to; contamination of surface (Komakech, 2014) and groundwater, ecosystem degradation and soil pollution from leachate. Every year, more than one billion people are infected and more than one million people die from vector-borne and water-borne diseases, with an estimated 438, 000 related deaths worldwide were registered in 2015 (Nor Faiza et al., 2019).

1.3 Research Objectives

1.3.1 Main Objective

The main objective of this study was to explore the biogas recovery potential from organic solid waste with a case study of academic institutions in Mbale Municipality, Eastern Uganda.

1.3.2 Specific Objectives

The specific objectives were:

- to investigate the practices of solid waste management selected academic institutions within Mbale Municipality
- to characterize waste generated at Islamic University in Uganda (IUIU).
- investigate the biogas resource potential recoverable from the generated organic solid waste.

1.4 Research questions

- What is the current practice of organic waste collection, containment and disposal in academic institutions?
- What are the characteristics of solid waste generated within academic Institutions?
- What is the biogas resource potential of solid organic waste?

1.5 Justification

The rationale of this study was to explore opportunities to replace the norm of largely linear process of waste disposal which is entirely a take make and dispose with one where resource circulation and disposal is fostered at high value with reduced residual waste, pollutants and emissions to the ecosystem. (ellenmacarthurfoundation, 2015)

One of the current trending strategies in waste minimization is through resource recovery (ADB, 2011; U.S. Environmental Protection Agency, 2012; EMF, 2015; Somanathan and Bluffstone, 2015; Agunyo et al., 2019) however, minimal efforts have been invested in carrying out research in waste management practices in school settings most especially in establishing the potential of biogas recovery that can contribute towards reduced impact to the ecosystem (Oates, et al., 2019).

Therefore, bold innovative solutions to the challenges of sustainable waste management in school settings in Uganda require propagation of reliable data to guide on Policy frameworks as well as design of biogas plants that can effectively address the problem and implementation in a manner that will inform and train students on good waste management approaches as well as rolling out to the community. (Komakech, 2014; Enrique and Ortiz-hernandez, 2015; Trang, 2016; Otoo, 2018; Moqbel, 2018).

The approach of offering the prospect of resource recovery from solid organic waste offers a paradigm shift from a linear waste management strategy of collection, transportation and disposal to collection, transportation, resource recovery and reuse of products or bi-products. This will not only offer environment conservation approaches but will also offer economic values through employment opportunity (Jacob Granit, 2016).

1.6 Significance of the research

The study reflects on several benefits as herewith listed below:

The research provides a methodology for Improved organic waste management for safe disposal in academic institutions and municipality at large

It also offers an enlightened insight on the possibility of biogas recovery from the organic solid waste generated from institutions most preferably Biogas

Potential contribution to the body of knowledge and research in solid organic waste management particularly resource recovery and reuse concept

The research will bring awareness about climate change mitigation and adaptation through minimization of green gas emission and reduction of fossil fuel demand through provision of an alternative energy source for cooking

Provide relevant insights to ignite and contribute towards policy planning and implementation of commitments in the National Development Plan by the year 2040.

1.7 Scope of the Study

1.7.1 Study area

It focused on establishing general waste management practices from sampled academic institutions in Mbale Municipality that gave a representative fraction of primary, secondary and tertiary institutions in all the divisions that makeup Mbale Municipality (Industrial Division, Wanale Division and Southern Division). Further analysis was made to quantify and characterize the organic waste as well as setting up a Biogas Potential laboratory experiment for waste generated from Islamic University in Uganda as the case study.

1.7.2 Content

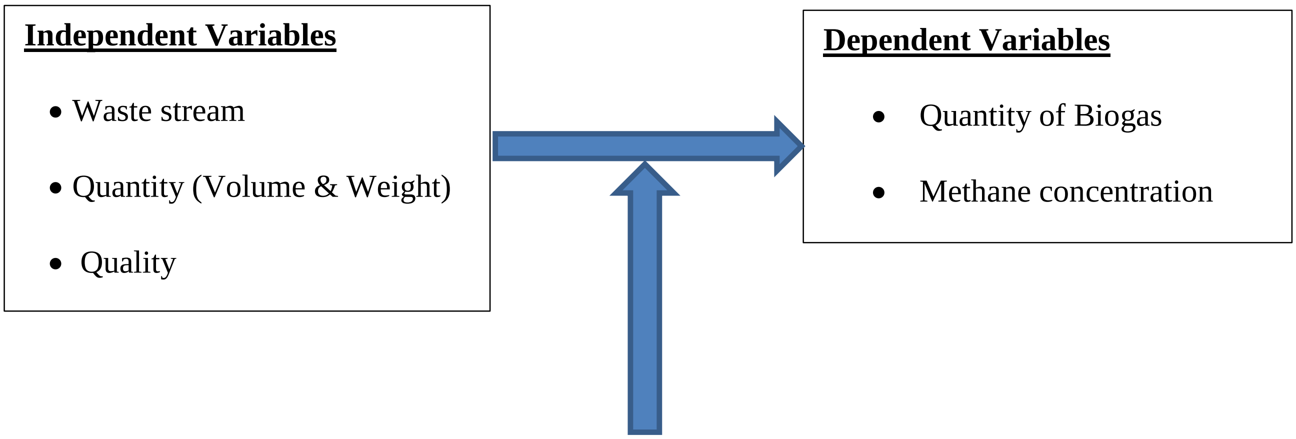
The study was intended to establish the biogas potential from organic waste generated from academic institutions.

1.7.3 Time:

The research was conducted in the period from May 2019 to January 2021.

1.8 Conceptual framework

Figure 1-3 shows the linkage between dependent and independent variables and moderating factors. The classification, quality and quantity of the organic waste in appropriate proportions determine how much quantity of biogas and methane concentration that can be realized under moderated anaerobic conditions.



Moderating factors

- Anaerobic conditions
- Inoculant

Figure 1-3: Layout of the conceptual framework

CHAPTER TWO: LITERATURE REVIEW

2.1 General overview

All non-liquid waste with the exclusion of excreta can be referred to as solid waste (Sataloff et al., 2002). Sources of solid waste may include; medical facilities, Food stores, cafeteria places, slaughter areas, warehouses, domestic areas, markets and institutions.(Sataloff et al., 2002).

(Enrique and Hernandez, 2015) delineated classification generation and composition of solid waste in three categories namely :

i. **Special management wastes** include empty print cartridges (toner and ink); used batteries; electronic articles such a computer equipment, photocopiers and scientific equipment which are generated in the university campuses, among others (Enrique and Hernandez, 2015)

ii. **Dangerous wastes** include materials with characteristics of corrosive nature, explosives, toxic nature, flammable, or containing infectious agents (Enrique and Hernandez, 2015).

iii. **Solid municipal wastes** include waste material generated during domestic activities; these may include containers or packaging such as Paper, solid organic wastes, plastics, metals, multilayer containers and other non-recoverable wastes (Kadir et al. 2016; Kaza and Yao., 2018).

(Carey et al. 2006) defined organic waste such as paper, leftover food, food peelings, fruit residue and garden waste as waste that is proficient in anaerobic or aerobic decomposition through a biological treatment process. The raw material in biogas production is therefore referred to as feedstock. An assessment undertaken by Asian Development Bank indicated that generally, 70% of domestic solid waste generated is biodegradable organic mass with high moisture content (Asian Development Bank, 2011).

Solid Waste Management involves generation, collection, containment, transportation, processing, disposal, management and monitoring of waste material in a safe manner (Coker et al., 2016). Generation is where materials become worthless to the owner and thereafter stored in an area of containment after being discarded. This can be in form of containers, polyether bags, communal deposits, Per capital waste generation can be ascertained by determination of the net weight (w/kg) of solid waste delivered at the dumping site, determination of interval of collection *(t_s)* in days and Number of people contributing to the waste *(p)* as reflected in Equation 2.1 (Coker et al., 2016).

Waste generation rate

$$Waste\ generation\ Rate\ (W_G) = \frac{w_{kg}}{p \times t_s}\ (kg/Capita/Day)\ \ldots\ldots\ldots\ldots\ \text{Equation 2.1}$$

Collection of waste involves gathering waste before it is conveyed to its point of disposal. Transportation means can either be human powered, animal powered or motorized (Management, Fronti and Poor, 1994). The final stage of solid waste management can be in four forms i.e. land application (Landfills), biological decomposition in form of aerobic decomposition (composting), anaerobic decomposition, Incineration and recycling (Sataloff et al. 2002; Kadir et al. 2016). Biological treatments comprises composting under which organic matter is broken down by micro-organisms in the presence of moisture and head (Carey et al. 2006) while Anaerobic digestion involves breakdown of organic compounds by micro-organisms in the absence of oxygen to generate methane and Carbondioxide gas (Carey et al. 2006).

Enrique and Ortiz-hernandez, (2015) indicates that strategies for effective management of the waste generated included; prevention of waste generation, decreasing of waste generation, separation of recoverable waste for reuse and recycling and then disposal from campus the waste that are not recoverable by the municipality.

Enrique and Ortiz-hernandez, (2015) further remarked that the increase in number of institutions has significantly contributed to waste in all possible physical states that further impact the environment. Additionally, (Vergara and Tchobanoglous, 2012) noted that waste generation rates are related to affluence as well as population. Richer societies are characterized by higher rates of waste generation per capita, while less affluent societies generate less waste and practice informal recycling/re-use initiatives that reduce the waste per capita to be collected at the municipal level. Solid waste generation rates therefore range from <0.1 t/cap/yr in low income countries to >0.8 t/cap/yr in high-income industrialized countries.

Coker et al., (2016; Moqbel, (2018) in their study, indicated that the increase in enrolments in this institutions has directly contributed to high rate of generation of the waste that retrospectively poses a high burden on the waste management budget. This has greatly been attributed to the lack of understanding over a diversity of factors that influence the different stages of waste management and linkages necessary to enable a streamlined system of waste management (Coker et al., 2016).

Ahmed et al., (2007); Andersson et al., (2009) noted that whereas the availability and quality of annual data are major problems for the waste management sector. Solid waste and waste water data are lacking for many countries; data quality is variable, definitions are not uniform, and internal variability is often not well quantified. However, (Kaza and Yao, 2018) explains that there have been three major approaches that have been used to estimate global waste generation and these include; data from national waste statistics or surveys, including IPCC methodologies, estimates based on population (e.g., Special report emission), and the use of a proxy variable linked to demographic or economic indicators for which national data are annually collected.

Whereas limited research has been undertaken in solid waste management in academic institutions in Uganda, elsewhere in the world, strides have been made to assess the trends of waste generation in academic institutions and other sectors. A study by (Enrique and Hernandez, 2015) for Solid Waste management in Higher Education as a Tool for Environmental Education and findings indicated that over 1,000 tonnes/year of municipal waste was generated in 2014, equivalent to about 200g/person/day. Further analysis revealed that the average composition of municipal solid waste generated in the The Autonomous Morelos State University (UAEM) constituted by weight as paper and paper board 21.36%, Tetra pack 12.7%, Metal Wraps0.77%, Wood 0.18%, acrosol Containers 0.38%, Polyethrane Terephtalate (PET) 15.33%, Toilet paper 9.84%, Film plastic 4.52%, Rigid plastics 9.12%, Organic wastes 11.84%, Garden Wastes 5.04%, Polystyrene 2.24% Glass 5.43 and Aluminium 1.16% this gave a higher total percentage of organic waste composition.

Additionally, a study by Trang, (2016) analyzed the trend of waste generation and potential recovery for solid waste generated from academic institutional sectors such as healthcare facilities, office/ government offices and education facilities, with an intention of designing and operating an appropriate solid waste management system within Hue city in Vietnam. The study carried out in kindergartens, primary schools, secondary schools, college and University and Private tutoring indicated that food residue ranged from 23.5% to 75.8%, followed by plastic, which ranged from 8.5% to 34.4%, and paper, which ranged from 1.5% to 27.5%. Food waste accounted for the highest portion at "Kindergarten" facilities (54.8%), whereas it was lowest at "Secondary school" facilities (5.2%).

A study by Moqbel, (2018) about solid waste management in education institutions with case study at University of Jordan highlighted that there was need to have recycling and greening initiatives. The study investigated the generation rate of solid waste and characteristics of the entire solid waste streams in the main campus of the University of Jordan and the variation in waste composition over the school academic calendar and main events. Findings from the study also indicated 25% compostable, 64% recyclable and 11% non-recyclable. The exercise further revealed that the University administration got an insight for potential recycling and waste reduction strategies.

In a study conducted by Komakech et al., (2014) that focused on characterization of municipal waste in Kampala, Uganda The sampling methodology focused on random selection of delivery trucks that were making trips to Kitezi (the main landfill for Kampala). The researchers characterized the municipal waste generated in Kampala as delivered to Kitezi landfill between July 2011 and June 2012, (the dry and wet months). During the wet month the waste consisted of 88.5% organic, 3.8% soft plastics, 2.8% Hard plastics, 2.2% paper, 0.9% glass, 0.7% textile and leather, 0.2% metal sand 1.0% others while during the dry months the waste consisted of 94.8% Organics, 2.4% soft plastics, 1.0% hard plastics, 0.7%papers, 0.3% glass, 0.3% textile and leather, 0.1% metal and 0.3% others. The study further analyzed the average moisture content of 71.1%, 1.89% Nitrogen content, 0.27% Phosphorus and 1.95% Potassium and gross energy potential of 17.3MJ/kg content. From the study it was also further established that there was potential of the organic waste to provide plant nutrients that are useful especially in the urban agriculture.

2.2 Impacts of poor Solid Waste management

Surface and groundwater contamination plays a significant role as a population stressor since humans are dependent on water for their existence. Waste are directly or indirectly discharged in water bodies with minimal consideration to assimilation capacities. The process is party facilitated by rainfall runoffs that transits them after dissolving (Mekonnen, Haddis and Zeine, 2020). Additionally, due to self-propelled anaerobic process, there is increased emission of harmful methane gas which not only adds to global warming and associate climate change challenges but also contributes to increased public and environmental health risks, additionally, can further lead to leachate pollution of surface and ground water thereby causing significant challenges such as eutrophication and exposure of toxic content (Sataloff et al., 2002).

(Sataloff et al., 2002; WHO, 2007; Faiza et al., 2019) further noted that, decaying Organic waste appeals vermin and flies as well as providing breeding sites for mosquitoes that are responsible for the spread of fever. For cases of accumulated dry waste in hot temperatures, this was further noted that it may lead to fire related hazards like smoke pollution and destruction to property and human life.

Therefore, bold innovative solutions to the challenges of sustainable waste management require new ways of thinking towards waste management most importantly resource recovery where various wastes can be put to productive use (Andersson et al., 2009).

including soil, air and water quality thereby reducing the health risk (African Development Bank, 2011; Komakech et al., 2014).

2.3 Waste Management and Policy framework

Internationally, the European Waste Management Policy of land fill management (1999/31/EC) has been widely adopted. It considers ranking of solid waste from most favored to least devoured from top to bottom as; prevention, minimization, Reuse, recycling, energy recovery and finally disposal (Carey et al., 2006)

The Uganda Local Government Act 1997 mandates local authorities to provide solid waste management services to urban authorities, however efforts to manage the waste are continuously being over whelmed by the rapid rate of waste production (Komakech, 2014; Oates et al., 2019).

On the other hand, it has been noted that policies about waste management are inadequately formulated which results in their poor implementation. Existing policies ignore describing the necessary safe methods of solid waste management to be adopted and guiding in detail on the appropriate disposal of the different waste streams (Coker et al., 2016).

2.4 Resource recovery potential from Organic solid waste

It is estimated that 5.2 million tons of solid waste are generated daily worldwide of which 3.8 million tons are from developing counties. As waste generation increases significantly, this also retrospectively contributes to the greater demand for both effective waste collection, containment, transportation and innovative treatment options such as resource recovery and reuse (Asian Development Bank, 2011).

The three main solid waste treatment options widely practiced especially in developing countries include; Landfilling, Composting and Incineration (United Nations Economic and Social Commission for Asia and the Pacific, 2010). All waste disposal options breakdown the organic material into simpler carbon molecules such as carbon dioxide and methane. Developed countries however, have gone a notch higher and ventured into more sustainable waste management options of resource recovery for environmental conservation, food security and energy conservation (Asian Development Bank, 2011).

(ellenmacarthurfoundation, 2015) explains that Resource recovery is contingent to the circular economy and the core intention is to replace the norm of largely linear economy of take make and dispose with one where resource circulation and disposal is fostered at high value with reduced residual waste, pollutants and emissions to the ecosystem. The concept is therefore largely based on the principles of the circular economy as reflected in

The drivers of establishment of resource recovery therefore involve establishment of prospect of feature demand for products derived from the resources as well as bringing them to the centers of demand without prohibitive economic, environmental or social costs (Andersson et al., 2009) .

Asian Development Bank, (2011) indicates that apart from resource recovery, other drivers for scaling up organic waste management include:

- Food Security through composting for improved soil organic matter and productivity,
- Global Warming through mitigation of Green House Gases (GHG) generation. Additionally, these activities are eligible for Carbon financing under the Kyoto Protocol Clean development mechanisms,
- Land Scarcity where diversion of Organic waste from dumpsites into resource recovery significantly extends the working life of such sites. Reducing the need and expenses of establishing bigger dumping facilities in future and Public health risks, where diversion organic waste lessens leachate production. This eventually reduce on the biochemical oxygen demand that is highly detectable in water ways (Mekonnen et al., 2020).

In a study conducted by (Enrique and Ortiz-hernandez, 2015), separated Paper waste was subjected to direct reutilization and recycling as a permanent strategy and it attracted 200 tons/year. food waste and green waste was gathered for composting as a treatment system to generate over 500m3/year of compost which was used for covering the needs of substrate for the green areas of the campus and an excess for commercialization.

A study by (Wickham et al., 2016) evaluated the Biomethane potential of co-digestion of sewage sludge, organic waste and hydrated algae using a customized (Bio Methane Potential (BMP) system that included an array of 1l fermentation glass and a gas collection gallery, temperature was maintained at 35±0.1^{o}C. Co-digestion with algae co-substrate with waste water sludge on a mass fraction percentage over a range of concentration from 0.15 – 9% yielded removal of total solids and volatile solids by 59% and 75% respectively with methane potential of 139L CH4/Kg of co-Substrate. Co-digestion of solid sludge and organic waste substrate increased the methane yield above that of any waste water sludge at 10% and 15% (wt/wt) with significant production of biogas of 139 Liters and substantially lower at 5%.

The digestion performance in terms of volatile solids and chemical oxygen demand (COD) removals when co-digesting with liquid wastes was generally much higher compared to solid wastes. In other words, COD, volatile solids (VS) and total solids (TS) removals of above 100% were attributed to the synergistic effect of liquid waste co-digestion.

It is however very clear that co-digestion has been widely practiced with solid organic waste and substrates like cow dung and feacal sludge for anaerobic digestion.

2.5 Biogas production

2.5.1 Anaerobic process

Biogas is produced by anaerobic digestion that degrade organic material (feedstock) and these include: substrates of farm origin such as liquid manure, feed waste, harvest waste and energy crops; Waste from private households and municipalities mainly separately organic waste; Industrial by-products such as glycerin, by-products of food processing and wastes from fat separators. This conversion is carried out by a consortium of microorganisms through a series of metabolic stages (namely, hydrolysis, acidogenesis, acetogenesis and methanogenesis) (Arthur, 2013). The anaerobic process is summarized in Fig. 2.2 (Mbohwa, 2016).

(Achinas, 2016) explains that an anaerobic digestion system normally consists of a reactor with a liquid – solid volume and a sealed gas headspace at atmospheric pressure. From Figure 2-1, The bioreactor is fed by reactants A and B which are converted through a series of biological steps into products C and D.

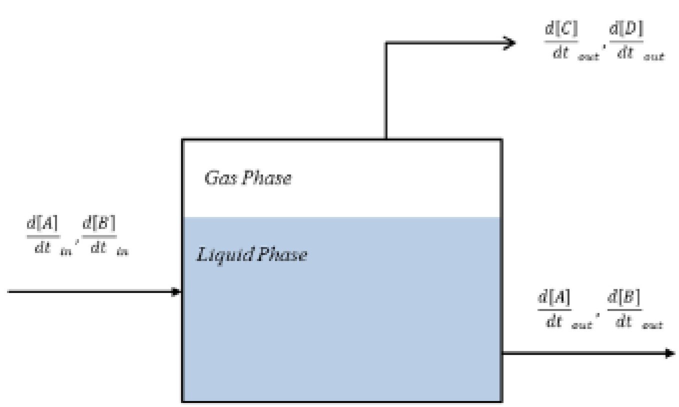


Figure 2-1: Schematic of a typical single tank reactor

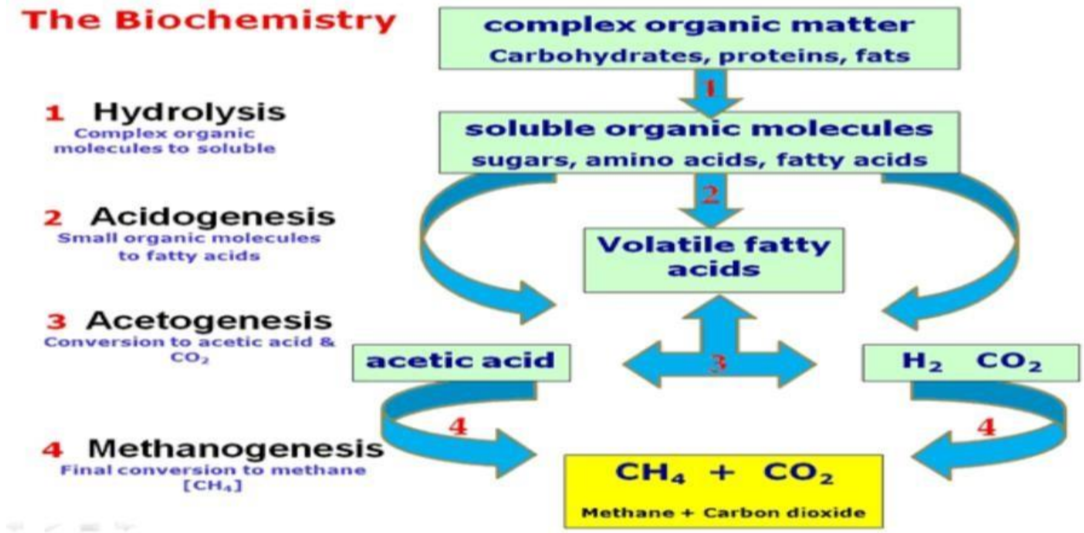


Figure 2-2: Anaerobic digestion degradation steps (source: Mbohwa, 2016)

Hydrolysis is the first step where complex organic compound such as lipids, protein and polysaccharides are converted into soluble monomers or oligomers (e.g. amino acids, long chain fatty acids, sugars and glycerol) through hydrolysis; Acidogenesis is that stage where the sugars, fatty acids and amino acids from hydrolysis are utilised to produce organic acids such as acetic, propionic, butyric and fatty acids, hydrogen and carbon dioxide by the fermentative micro-organism; Acetogenesis is where alcohols and volatile fatty acids are anaerobically oxidized by hydrogen-producing acetogenic bacteria into acetate, H_2S and CO_2. Acetate can also be formed from H_2 and CO_2 by hydrogenoxidizing acetogenic bacteria known as homoacetogens. In the final stage, acetotrophic and hydrogenotrophic methanogens transform acetate, H_2 and CO_2 into a mixture of CH_4 and CO_2; Methanogenesis is where Methane and carbon dioxide are formed by mainly hydrogen/carbon dioxide. In the final stage of methanogenesis, methane is produced by two groups of methanogenic bacteria. (Arthur, 2013; Mbohwa, 2016).

The main constituents of biogas include: - The flammable methane (CH_4) which fluctuates between 50% to 75%, the second main component is Carbon dioxide (CO_2) with a share between 25% to 50%. other components are Water (H_2O), Oxygen (O_2), Sulfur (S_2) and Hydrogen sulfide (H_2S) (Mbohwa, 2016).

Anaerobic digestion usually takes place within three temperature ranges namely: thermophilic between (50-58) ^oC, Mesopheric that ranges between (25-45) ^oC and Psychrophilic that ranges between (10-25) ^oC (Huber, 2019). Temperature affects anaerobic digestion in a way that the higher the temperature, the faster the degradation and the shorter the retention time. It is further noted that the higher the temperature, the better the pathogen inactivation; but on the other hand very high temperatures transform Ammonium (NH_4) into ammonia (NH_3) which increases the risk of microbial inhibition. Very low temperatures require a very long retention time though they are not energy intensive therefore, Moderate temperatures of mesospheric range are recommended (Arthur. W, 2013).

2.5.2 Stoichiometry of biogas production

Arthur, (2013); Achinas, (2016) explained that With the knowledge of the chemical composition of a waste (feedstock) the quantity of methane can be predicted from the stoichiometric formula developed by Buswell and Hatfield in 1936. The basic elementary formula by Buswell can be adopted as shown in Equation 2.3.

(Achinas and Euverink, 2016) note that biogas can be predicted from theoretical modals on assumption that a reaction goes to completion. It was further noted that the purpose is not to create a model that takes all factors into account and predicts biogas output to very high level of precision but rather a modal that provides balance between simplicity and effective biogas prediction. This however requires knowledge on the biodegradation of organics. a schematic biochemical process stages of anaerobic digestion (Achinas and Euverink, 2016).

Buswell formula 1936

$$C_nH_aO_b + \left(n - \frac{a}{4} - \frac{b}{2}\right) H_2O \rightarrow \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4}\right) CH_4 + \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4}\right) CO_2 \text{ ....Equation 2.2}$$

The chemical reaction of Boswell and Mueller (1952) was modified by Boyle as indicated in **Error! Reference source not found.**. this modification included nitrogen and sulfur to obtain the fraction of ammonia and hydrogen sulfide in the produced biogas (Achinas and Euverink, 2016).

Modified Buswell formula 1952

$$\mathrm{C_nH_aO_bN_dS_e} + \left(\mathrm{n} - \frac{\mathrm{a}}{4} - \frac{\mathrm{b}}{2} + \frac{3\mathrm{d}}{4} + \frac{\mathrm{e}}{2}\right) \mathrm{H_2O} \rightarrow \left(\frac{\mathrm{n}}{2} + \frac{\mathrm{a}}{8} - \frac{\mathrm{b}}{4} - \frac{3\mathrm{d}}{4} - \frac{\mathrm{e}}{2}\right) \mathrm{CH_4} +$$

$$\left(\frac{\mathrm{n}}{2} - \frac{\mathrm{a}}{8} + \frac{\mathrm{b}}{4} + \frac{3\mathrm{d}}{8} + \frac{\mathrm{e}}{4}\right) \mathrm{CO_2} + \mathrm{dNH_3} + \mathrm{eH_2}S \text{ ....Equation 2.3}$$

or in simplistic form

$$\mathrm{A} + \mathrm{C_1B} \rightarrow \mathrm{C_2C} + \mathrm{C_3D} + \mathrm{C_4E} + \mathrm{C_5F}$$

$$\mathrm{A, B} \rightarrow \text{reactants}$$

$$\mathrm{C, D, E, F} \rightarrow \text{products}$$

(Arthur. W, 2013) noted that “ In 1967, Bryant and co-workers showed that the M.Omelianski culture contained two bacteria species; One converted ethanol (CH_4CH_2OH) to (CH_3COOH) and hydrogen (H_2) the other converted Carbon dioxide (CO_2) and (CH_4). Contributions from three separate species would be required, as

Species 2; $CH_3CH_2OH + H_2O = CH_3COO^- + H^+ + 2H_2 \quad + 5.95 \Delta G\ (kJ/reaction)$ ……………………………..… Equation 2.4

Species 4.1; $2H_2 + 0.5CO_2 = 0.5CH_4 + H_2O \quad - 65.45\ \Delta G (kJ/reaction)$ …………………….………… Equation 2.5

Species 4.2; $CH_3COO^- + H^+ = CH_4 + CO_2 - 28.35\ \Delta G (kJ/reaction)$ ….Equation 2.6

Net, $CH_3CH_2OH = 1.5CH_4 + 0.5CO_2 \quad - 87.85\ \Delta G (kJ/reaction)$ ………Equation 2.7

- Species 2: The Obligate Proton - Reducing (OPR) acetogenic bacteria. The standard free energy of the reaction (ΔG) is positive. Thus, for this reaction to occur, the hydrogen partial pressure has to be lowered. This is explained by Le Chatelier’s principle, which states that if some stress (in this case a reduction in the concentration of the products) is brought to bear on a system in equilibrium a reaction occurs which displaces the equilibrium in the direction which tends to undo the effect (towards the product).
- Species 4.1: Hydrogen trophic methanogenic bacteria form a syntrophic association with the acerogenin bacteria. The standard free energy of the reaction is relatively high in the negative direction, indicating the affinity of the methanogen to hydrogen.

- Species 4.2: Aceticlastic methanogenic bacteria. The standard free energy of the reaction is less negative than for its hydrogen trophic relation, indicating the lower affinity of methanogens for acetate.

In the theoretical degradation of ethanol two thirds of the methane comes from acetate and one third comes from hydrogen.

2.5.3 Digester sizing

(Huber, 2019) notes that common approaches to decide the size of a digester is to consider available quantities of daily added feedstock, retention time RT that is largely dependent on operation temperature and the suitability of the produce biogas. …………Equation 2.8 was therefore adopted for the sizing of the dome digester

Digester sizing

$$V_D = \frac{RT(V_{OW} + V_W)}{0.75}$$ ……………… …………Equation 2.8

Where: V_D is the volume of the digester, V_{OW} is volume of addeded feedstock, V_W as volume for dilution incase of solid organic waste. It was further noted from previous assumptions of mesophilic conditions for biogas yield calculation that a hydraulic retention time (RT) of 45 days was subjected for the sizing; the occupied digester volume by the active slurry was adopted as 75% of the total digester volume.

2.5.4 Biomethane Potential Evaluation

(Arthur. W, 2013) explains that Biochemical methane potential (BMP) tests are mainly used to determine the possible methane yield of a feed stock.

Standardized anaerobic degradation tests are given in EN 11734, DIN 38 414 (S8) and VDI 4630. However, The BMP test presented in the study was mainly based on DIN 38 414 (S8) and is slightly simplified. To make the test more practical, the expensive eudiometer gas measuring devices are replaced by simple water displacement bottles. In addition, a bottle with an alkaline solution is placed after the digester vessel in order to absorb the produced carbon dioxide and to allow direct methane measurement.

Evaluation of the BMP test

$$V_O = \frac{V.P.T_O}{P_O T}$$ …………………………… Equation 2.9

Where T_o = 273K and P_o = 1013hPa. Therefore, the ambient pressure (P) and the ambient temperature (T) – temperature of the gas in the displacement bottle has to be known. 10cm may be added on the hydrostatic pressure.

Summary of literature review on resource recovery from organic solid waste

Table 2-1: Citation summary

Citation	Nature of Study	Condition	Location	Remarks
(Enrique and Ortiz-hernandez, 2015)	Classification, composition and management of waste	Academic Institutional Solid waste	Mexico	Research paper focused on improved waste management strategy chain from collection to disposal
(Coker et al., 2016)	Survey and appraisal of existing waste management facilities and patterns	Academic Institutional Solid waste	Covenant University, Nigeria	0.3 and 0.4 kg/capita/day was generated, biodegradable waste accounted for 29% by weight which gave a high significance for resource recovery
(Moqbel, 2018)	Classification, composition and management of waste	Academic Institutional Solid waste	University of Jordan -	The results show that at least 87% of the waste generated on campus was recyclable.
(Trang, 2016)	Waste generation and it's potential of recovery	Municipal Solid Waste	Hue city, Vietnam	Results indicated resource potential from the organic waste. Of the 93.1 and 13.1 tons/day commercial and institutional waste, respectively, The composting potential accounted for 23 % and the recycling potential accounted for 17% of total waste generation from commercial and institutional in Hue.
(Agunyo et al., 2019)	Exploring the environmental feasibility of integrated	integrated sanitation systems using Life cycle	Uganda Christian University-	The results indicated that resource recovery contributed to the environmental feasibility of these sanitation

Citation	Nature of Study	Condition	Location	Remarks
	sanitation systems	assessment framework	Mukono - Uganda	systems. The more resources that were recovered from the sanitation systems, the lower the environmental impact.
(Ariunbaatar, 2015)	Enhancement methods under Anaerobic digestion of food waste	Two stage test anaerobic digestion	Paris-Est Mongolea	The results of the study indicated an MBR being very resilient system for the treatment of high rate AD of FW. HRT of 20 d was reduced to 1 day successfully in only 100d. The biological part of the system was fully stabilized after more than 2 weeks, and it was able to convert 50-76% of the influent COD into biogas with up to 70% methane content.
(Wickham et al., 2016)	Co-digestion of sewage sludge and organic waste	Single stage Laboratory BMP system	Sydney, Australia	Maximum co-digestion ratios were identifiable for most solid co-substrates including algae (6% wt/wt), undiluted food waste (5% wt/wt), bakery waste (5% wt/wt), and diluted commercial food waste (10% wt/wt). On the other hand, the maximum co-digestions ratio of beverage reject and sewage sludge was 10% (wt/wt).
(Mbohwa, 2016)	AD of Fruit and Vegetable Waste	Single stage AD	Johannesbu rg,	The optimum pH for AD of FVW ranges from 6.5-7.5. Two stage digestion was found to be ideal and

Citation	Nature of Study	Condition	Location	Remarks
		Under Both mesophilic and thermophilic temperatures	South Africa	co-digestion with either chicken, cattle or pig manure is advisable for enhanced biogas and methane productivity.
(Huber, 2019)	Anaerobic Digestion of organic waste	Wet AD digester in a fixed dome model	Ghazir village, Lebanon	The research looked at design, operation and maintenance of a Small scale biogas production from organic waste and application in mid income countries

It can generally be noted that while emphasis has been put on the characterization of organic waste in schools, resource recovery of Biogas from organic waste seems a divalent approach over composting for the option of resource recovery as a waste disposal option.

2.6 Shortfalls associated with resource recovery

Solid waste management has been studied well in the past decades and matured in many technical aspects in the waste management streams however, in many developing counties resource recovery for solid waste disposal still possess several limitation as reflected.

Whereas there are various opportunities envisaged, there are also associated challenges in the process of resource recovery and reuse of organic waste to mention;

There are potential health and environmental problems related to the presence of both toxic chemicals and pathogen microorganisms when resources are reused.

For an end – product to be interesting to customers, it is important that quality and quantity is constant over time. This therefore calls for continuous technical innovation, going from pilot to full scale as well as reinvestment.

There is limited publicity about environmental awareness for generating alternative solutions that include resource recovery from waste.

The lack of individual ability and farm communities to adopt and sustain post treatment risk mitigation options as well as culturally rooted attachments against resource recovery and reuse of organic waste.

Resource recovery requires much stronger governance and an active public sector working across sectors with incorporation of behavior change programs

Initial investment capital in relation to the cost benefit analysis may be crucial to providing support to the higher initial investments that may be required for improved resource management and recovery.

Lack of reliable information about solid waste management attributed to limited research.

2.7 Long term considerations and sustainable development

GHG emissions from waste can be effectively mitigated by current technologies. Many existing technologies are also cost effective; for example, landfill gas recovery for energy use can be profitable in many developed countries. However, in developing countries, a major barrier to the diffusion of technologies is lack of capital increasingly being implemented for landfill gas recovery projects, provides a major incentive for both improved waste management and GHG emission reductions. For the long term, more profound changes in waste management strategy are expected in both developed and developing countries, including more emphasis on waste minimization, recycling, re-use and energy recovery (Bogner, 2007).

Anaerobic for either wastewater or selected wastes (high moisture), is expected to continue in the future as part of the mix of mature waste management technologies.
In general, anaerobic digestion technologies incur lower capital costs than incineration; however, in terms of national GHG mitigation potential and energy offsets, their potential is more limited than landfill CH4 recovery and incineration. When compared to composting, anaerobic digestion has advantages with respect to energy benefits (biogas), reduced process times and reduced volume of residuals (Bogner, 2007)

The global environmental crisis demands the development and application of new paradigms in environmental degradation mitigation by the different sectors of the society (Ferronato and Torretta, 2021). Whereas there has been potential of biogas recovery from solid organic waste, it’s best implication cannot just be transferred from what has just been done in other settings into a school setting. Since academic institutions contribute tremendously as institutions of behavior change patterns that positively impact to the society (Enrique and Ortiz-hernandez, 2015), the study was therefore hinged on this prospect.

CHAPTER THREE: METHODOLOGY AND MATERIALS

3.1 Introduction

This chapter describes the approach that was adopted in undertaking the research objectives and it also included materials for data collection, analysis, interpretation and publication.

3.2 Approach

The research entails both cross sectional and longitudinal studies regarding organic solid waste generated from different institutions found in Mbale Municipality. The academic institutions visited include; - Primary schools, secondary schools, Tertiary Institutions and Universities.

Selection of academic institutions within Mbale Municipality for the study was relayed on “Bellagio Principles” that considers managing sanitation challenges within a sizeable domain (Agunyo et al., 2019). Figure 3.1 shows the location of the study area.

3.3 Study area

Mbale Municipality is located in Mbale district with GIS referencing of 1°04'50.0"N, 34°10'30.0"E (Latitude:1.080556; Longitude:34.175000), it is approximately 245 kilometers by road, Northeast of Kampala on an all-weather tarmac highway, mbale city, then a municipality can be accessed through kumi 50km, 30km from pallisa district in the north west, 50km from namutumba on the west and 17km from manafwa in the far east.

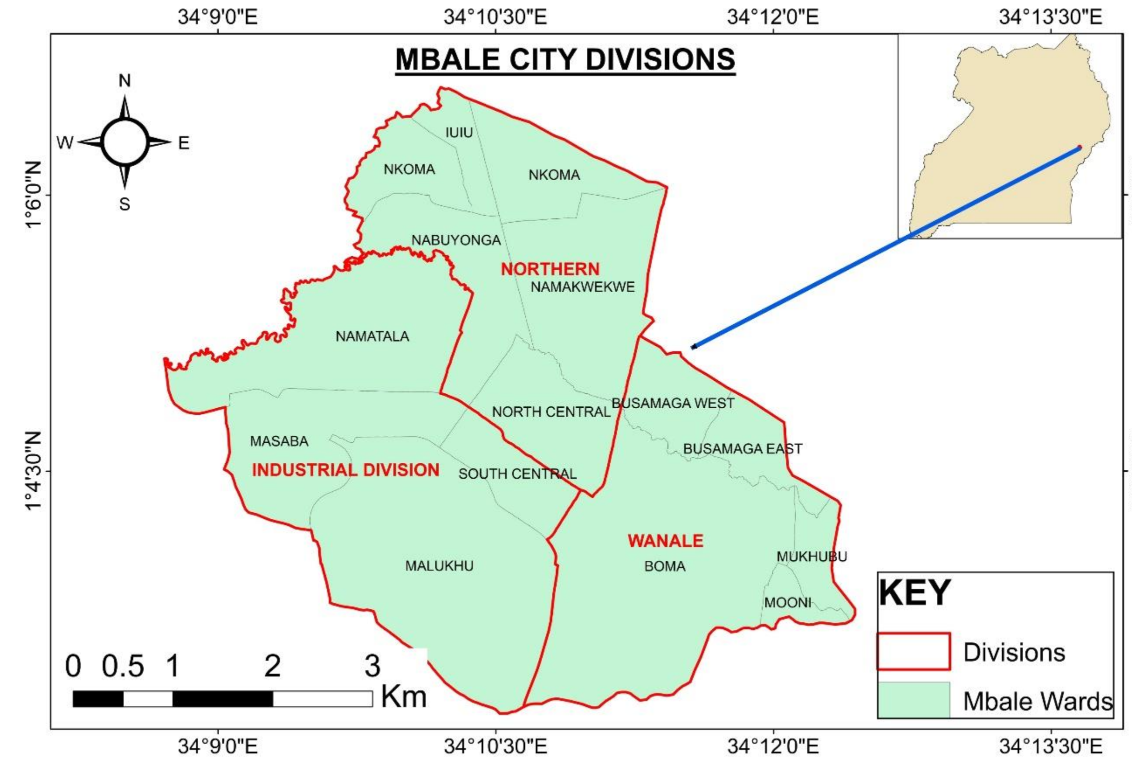


Figure 3.1: location map and geographical coverage of the Mbale city

3.4 General practices of solid waste management

3.4.1 General

The study was conducted in selected academic Institutions in their respective categories within Mbale Municipality. The categories included; Primary schools, Secondary Schools and Tertiary Institutions/ Universities. Mbale Municipality has 3 divisions that is to say Wanale Division, Northern Division and Industrial division respectively. selection of institutions from each of the divisions was done as a representative sample adequate for data collection from the various categories of institutions using systematic and cluster sampling approach.

3.4.2 Sampled schools and institutions

A systematic and cluster sampling was adopted to have corrective assessment and collection of adequate information relevant to the study (thi thu trang, 2016).

A list of all academic institutions was obtained from Mbale Municipality Education Department, (a copy is attached in Appendix B.3).

Clustering of the institutions under their respective categories (Pre-primary, Primary, Secondary, Tertiary/ university), area of location based on the three divisions within Mbale municipality, population and classification based on whether it is a government aided school or privately owned school was done. It was upon this classification and ranking that a representative sample of schools were selected for administering of the questionnaires. Figure 3.2 below shows the classification of schools and institutions within Mbale municipality

Based on systematic ranking approach based on population of the schools and institutions and location in terms of divisions, a total of 36 schools/ institutions were sampled out of 96 in total located in Mbale Municipality. This gave a general sampling ratio of 37.5%. this percentage was adequately representative based on the classification and ranking approach used.

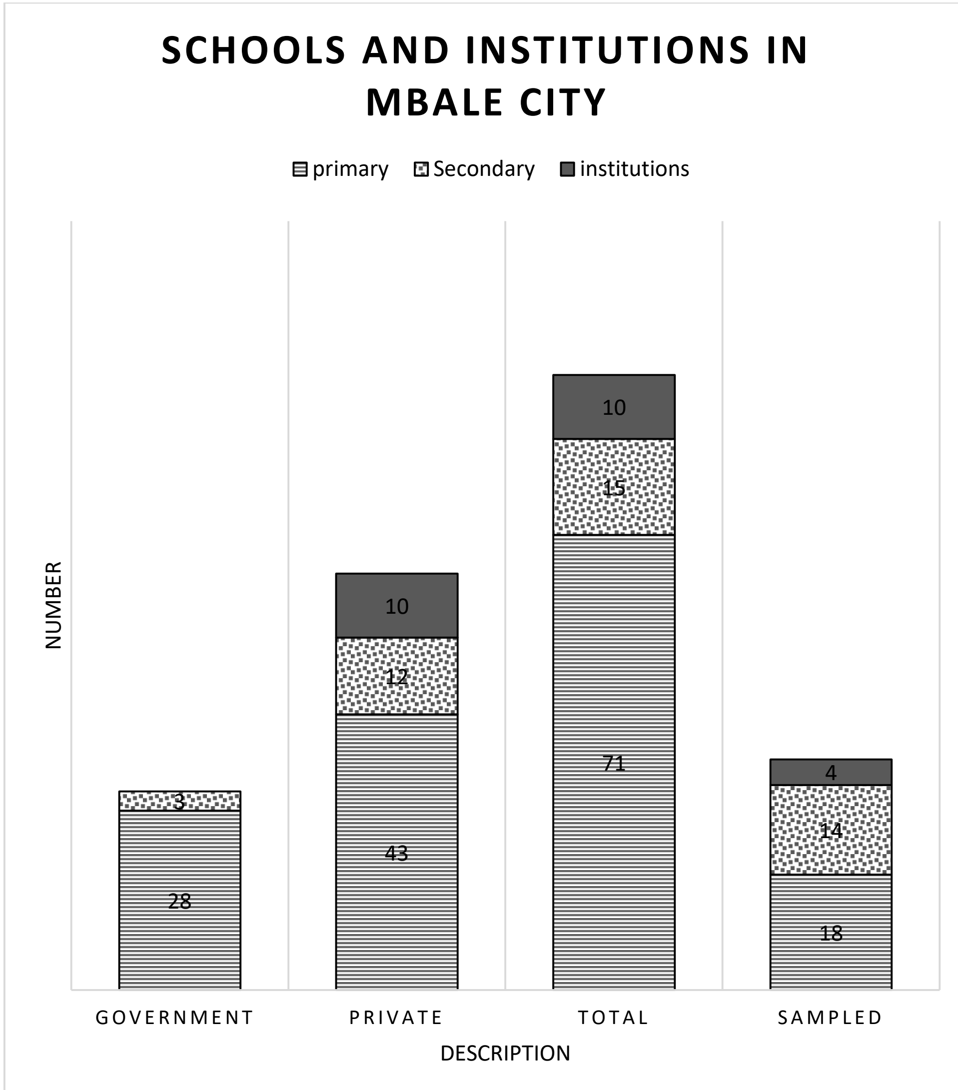


Figure 3.2: Schools and Institutions in Mbale Municipality (Source: Field survey)

3.4.3 Mapping out academic institutions and data capture on waste management

Various approaches for mapping out school and collection of relevant data were utilized to collect both qualitative and quantitative data.

The data collection methodology embraced during general inspection of schools included;

a) Checklist A

Well-structured check list was prepared and adopted for data collection, interviews, guide surveys, observations as well as physical measurements for either weight or volume for quantitative analysis were also deployed. Information on perceptions and practices was obtained from designated staff of the respective institutions as well as the head of the institutions. This exercise was supplemented by spot checks around the institution premises.

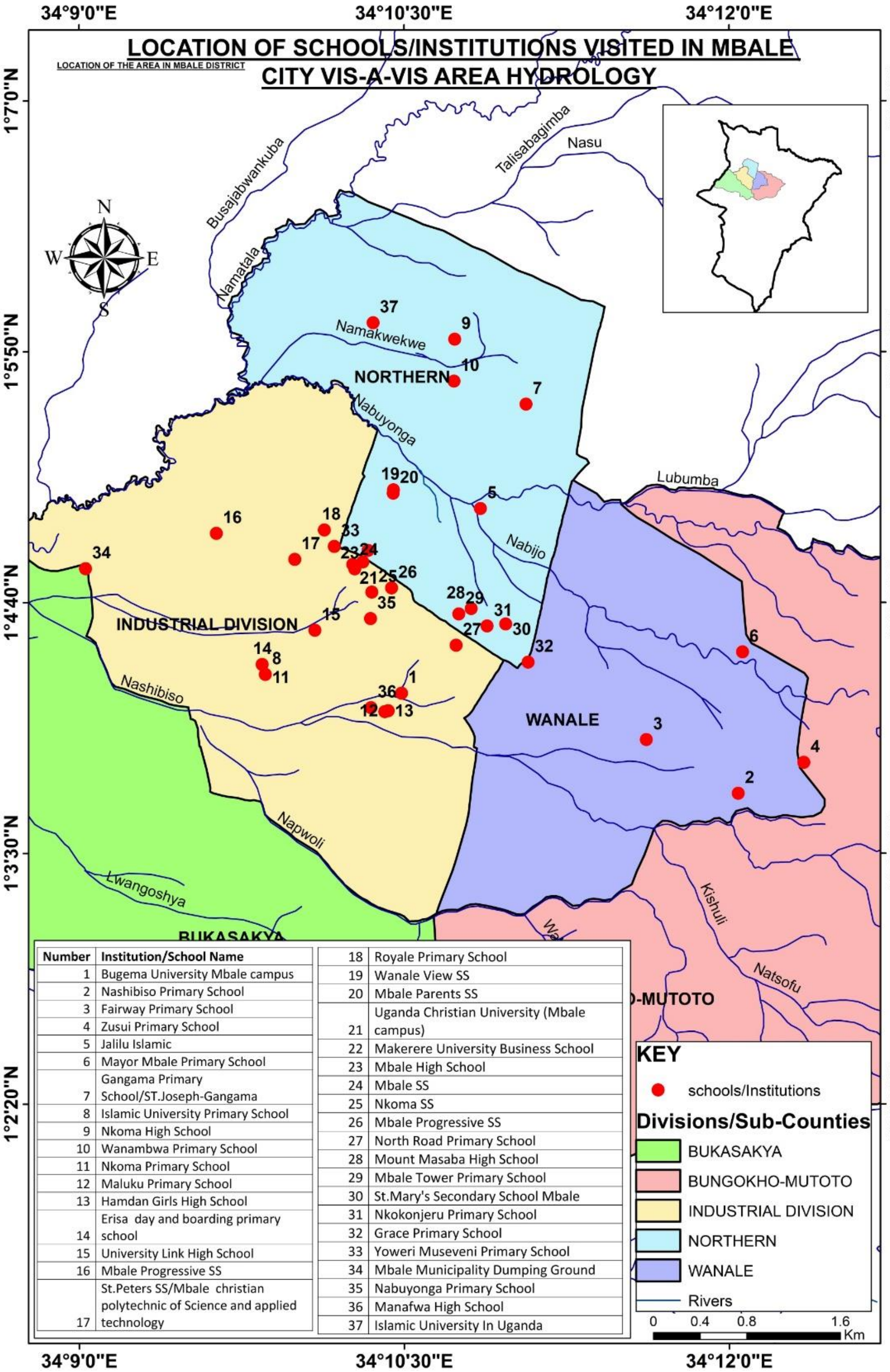
This design of the questionnaire was adopted from (UNESCAP, 2010) in sections as per the details below and a copy of the same is enclosed in Appendix B.1.

i. Section 1; Date, Interviewers name, respondents name, position and contact
ii. Section 2; General information that captured name of the school/ Institution, location, coverage, population. During inspection of the schools, Geo - referencing points were picked
iii. Section 3; Waste management this section of the questionnaire focused on establishing the waste management stream from point of Generation, collection, conveyance, containment up to the point of disposal
iv. Section 4; Source of fuel for cooking, this section was included to have a snapshot of biomass utilization which is one of the identified major factors that directly impacts the environment and climate on a wider perspective

b) Observation

By visiting the various sites and moving around these sites, a number of conditions contributing to the waste were seen by the researcher and captured accordingly

Figure 3-3 indicates the location of the schools visited during the study



Number	Institution/School Name	Number	Institution/School Name
1	Bugema University Mbale campus	18	Royale Primary School
2	Nashibiso Primary School	19	Wanale View SS
3	Fairway Primary School	20	Mbale Parents SS
4	Zusui Primary School	21	Uganda Christian University (Mbale campus)
5	Jalilu Islamic	22	Makerere University Business School
6	Mayor Mbale Primary School	23	Mbale High School
7	Gangama Primary School/ST.Joseph-Gangama	24	Mbale SS
8	Islamic University Primary School	25	Nkoma SS
9	Nkoma High School	26	Mbale Progressive SS
10	Wanambwa Primary School	27	North Road Primary School
11	Nkoma Primary School	28	Mount Masaba High School
12	Maluku Primary School	29	Mbale Tower Primary School
13	Hamdan Girls High School	30	St.Mary's Secondary School Mbale
14	Erisa day and boarding primary school	31	Nkokonjeru Primary School
15	University Link High School	32	Grace Primary School
16	Mbale Progressive SS	33	Yoweri Museveni Primary School
17	St.Peters SS/Mbale christian polytechnic of Science and applied technology	34	Mbale Municipality Dumping Ground
		35	Nabuyonga Primary School
		36	Manafwa High School
		37	Islamic University In Uganda

Figure 3-3: Location of sampled schools and Institutions (Source: field survey)

3.5 Classification and Quantifying of organic solid waste

3.5.1 Overview

This section expounds on the methodology and tools deployed to collect data on waste generation quantities in the respective organic waste streams for the waste generated in academic institutions.

The study for quantification, characterization and investigation of resource recovery potential was restricted to Islamic University in Uganda in Mbale. Given it's nature of being autonomous in the region with a population of over 7000 people, a diversified range of organic waste was anticipated in relation to the activities at the university. On the other hand, among all institutions visited it had a relatively well laid waste management strategy that included a designated waste management contractor responsible for waste management undertakings within the University premises. Higher institutions of learning are esteemed by communities as a models for adopting best practices (Coker et al., 2016) hence expected to have the capacity to accommodate innovations which can ably be castigated to other communities after being properly institutionalized(Coker et al., 2016).

Islamic University in Uganda is located about 2km from Mbale town, along Mbale – Soroti Road. The university was established by the Organization of Islamic Cooperation (OIC) under a bilateral agreement between the Government of Uganda (GOU) and the OIC. It was opened on 10th February 1988 with 80 students and two degree programs. Currently, it offers 72 courses in 7 Faculties offering at certificate, diploma, undergraduate and postgraduate levels and has a student population of average 7,000 coming from 21 different countries and has cumulatively graduated 25,000 students from various disciplines since inception.

3.5.2 Waste generation mapping

A checklist (a copy enclosed in Appendix B.2) was designed and adopted for detailed data collection for waste management at Islamic University in Uganda. (UNESCAP, 2010). GIS coordinates were used to map out various university structures including: - hostel facilities, administration offices, lecture rooms, libraries, a staff hostel, staff quarters, a police station, a mosque, cafeterias, a sports facility, a bank outlet and a medical facility that contribute to generation of organic waste such as paper waste, food waste, food peelings, vegetable waste and fruit waste. Population and occupancy of the various university facilities mapped out was also captured. Total population for the University was established and projected population for over 15 years was computed as illustrated in Equation 3.31 and Equation 3.42 respectively.

Total population

$$P_O = \sum_i P_i \text{ ………………………….. Equation 3.1}$$

Population projection

$$P_n = P_O \times (1 + r)^n \text{ ……………..…… Equation 3.2}$$

Where: P_n is the projected population, P_o is the current population, r is the growth rate and n is the number of years projected.

Conditions contributing to the waste generation were also gathered through physical observation by visiting the various sites. Some photographs were also taken to portraying the conditions prevailing at these specific point under study. It was noted from the estates office that 60% of the currently developed land is covered by lawn and trees that contribute to organic waste from falling leaves, weeds, pruning of the hedge plants and grass mowing.

Figure 3-4 shows a google image of the mapped out waste generation points at IUIU; a detailed GIS map is enclosed in Appendix B.4

Figure 3-4: Satellite view of IUIU layout and key waste collection points

3.5.3 Classification and quantification of Solid organic waste

Sorting of waste into various stream and respective weighing of the same was done at the central waste dumping ground. (volume using a stand known volume and weight using an electronic weighing scale) Whereas the best option was to sort and weigh the waste at the generation point, the approach of undertaking this exercise at the dumping site was instead adopted to allow for close supervision for accuracy as well as complying with the University requirements as issued at the outset of having a minimal number of research assistants that was limited to 5 members all in total.

Each waste container delivered was emptied, waste was then sorted hipped in their respective categories that included:- a) Paper waste, b) Food Waste, c) Fruit waste, d) Leaves/ grass clippings and pruning e) Food peeling and Vegetables (Enrique and Hernandez, 2015; Trang, 2016).

The volume (V_i) and respective weight (W_i) of the categorized waste was established and recorded on the data sheet. This exercise was conducted for two days per week for a period of four weeks in two semester periods i.e. in November towards the end of 1^{st} semester that also occurred during the wet weather conditions and in February at the beginning of 2^{nd} semester that also occurred during the dry weather conditions. Data was captured with customized recording sheets as adopted from (UNESCAP, 2010). Copy of the detailed data captured is enclosed in Appendix B.6. From Equation 3.3 and Equation 3.4 Total Weight (W_T) and Volume (V_T) were computed.

Total waste in Kgs

$$W_T = \sum_n W_i \text{ .... Equation 3.3}$$

Total waste in m^3

$$V_T = \sum_n V_i \text{ .... Equation 3.4}$$

Where n is number of days

Percapita waste production was also computed as in **Error! Reference source not found.** a nd **Error! Reference source not found.**.

Percapita waste generated in Kgs

$$W_{PP} = \frac{W_T}{P_O} \qquad \text{……………………………. Equation 3.5}$$

Percapita waste generated in m^3

$$V_{PP} = \frac{V_T}{P_O} \qquad \text{……………………………. Equation 3.6}$$

Where W_{PP} is the waste in Kgs generated per person per day, V_{PP} is the waste generated in m^3 per person per day.

3.6 Biogas potential Analysis

3.6.1 Single stage anaerobic digestion laboratory test

Solid Organic waste was evaluated using a customized Single stage Biomethane Potential system adopted from (Arthur, 2013) it comprised of an array of 3 ltr plastic containers as digesters and 2ltr plastic bottles as gas collection galleries. 9 sets of the experiment were arranged where 8 of them contained a substrate and the inoculant while the 9th set contained only the inoculant. All the digesters were air tight and connected with a rubber tubbing that delivered gas into the gas collection container. i.e. a digester and a gas collection container inverted in a water bath. The setup was made inside a material preparation room of the Regional Water Quality Laboratory hence temperatures for the setup were relied on the internal temperature of the room which ranged between 28^{o}C-

35^{o}C. Prior to commencement of the setup, all the apparatus was flushed with hot water at 100^{o}C.

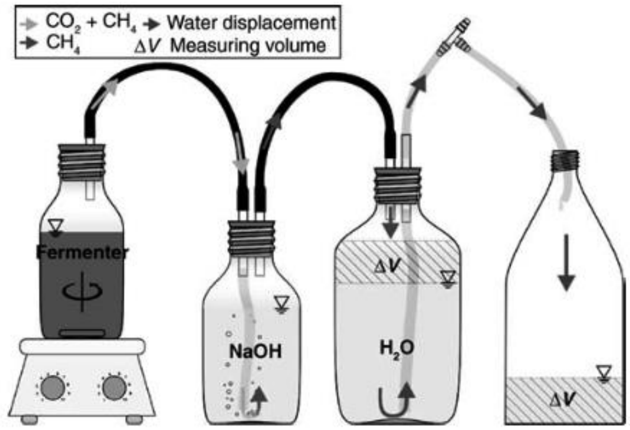


Figure 2-5: A biogas set up to determine methane concentration (Source: (Arthur, 2013)

Evaluation of the BMP test was based on the daily gas production against the inoculant based on the ideal gas equation.

Ideal gas equation

$$V_O = \frac{V.P.T_O}{P_O T}$$ ………………………………. Equation 3-7

Where T_o = 273K and P^o=1013hPa. Therefore, the ambient pressure (P) and the ambient temperature (T) – temperature of the gas in the displacement bottle has to be known. 10cm may be added on the hydrostatic pressure.

Since the BMP test presented in the study was mainly based on DIN 38 414 (S8) and was slightly simplified where the expensive eudiometer gas measuring devices were replaced by simple water displacement bottles with an alkaline solution in order to absorb the produced carbon dioxide and to allow direct methane measurement, the measured volume was considered as the net biogas yield.

3.6.2 Substrate preparation

The materials considered for the experiment included:

- Paper waste
- Kitchen Waste (Fruit waste, Food peelings and vegetables)
- Leaves and grass clippings

After Sorting and weighing of the respective organic waste per day, the respective weights per category was used to formulate mix ratios based on the respective direct weight generated as presented in Table 3-1 below.

Table 3-1: Adopted ratios for the experimental setup derived from data collected

	Substrates		
Experimental setups	**Grass**	**Kitchen**	**Paper**
1	107	235	200
2	107	235	200
3	107	972	50
4	350	235	50
5	380	972	200
6	107	972	50
7	350	972	200
8	350	235	50

Mechanical pre-treatment by shredding was done in their respective clusters to further reduce the sizes in order to increase surface area and ultimately improved biogas yield.

Considering the 3 liters containers that were used as digesters, the quantity of substrate was derived based on the digester sizing formula Equation 2.8 .

$$V_D = \frac{RT(V_{OW} + V_W)}{0.75}$$ …………..……………. Equation 3-9

The generated quantities as digestate are here with presented in the table Table 3 -2 below

Table 3 -2: Derived quantities for the digestate based on the three liters digester

Setups	Grass (g)	Kitchen (g)	Paper (g)	Total weight (g)	Inoculant (g)
1	267.5	587.5	500	1355	338.750
2	267.5	587.5	500	1355	338.750
3	267.5	2430	125	2822.5	705.625
4	875	587.5	125	1587.5	396.875
5	950	2430	500	3880	970.000
6	267.5	2430	125	2822.5	705.625
7	875	2430	500	3805	951.250
8	875	587.5	125	1587.5	396.875

Digested Cow dung slurry from a biogas digester was used as an inoculant. 25% (Paritosh *et al.*, 2017) by weight of the substrate was adopted as the inoculant composition. The slurry from the digester was used to boost seeding anaerobic organisms for the substrate.

<table>
<tr><td>Shredding and mixing of the substrates</td><td>Weighing of the substrate was done using and electronic digital weighing scale</td></tr>
<tr><td>
</td><td></td></tr>
<tr><td colspan="2">Samples of ready prepared substrates leaves and grass clippings, kitchen waste and Paper</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Samples of ready prepared and mixed substrates leaves and grass clippings, kitchen waste and Paper</td><td>Lab setup of the digesters and the gas collection containers</td></tr>
</table>

Figure 3-6: Preparation of substrates and laboratory setup

3.6.3 Biogas collection and measurement

For collection and measurement of the biogas produced, the air tight 3litre digester were interconnected with a rubber tube to an inverted 2 litres gas bottle containing water. As the gas bubbled into the inverted gas bottle immersed into a water bath, the water in the bottle was displaced into the water bath.

Since the gas collection containers were not the standard measurement apparatus, correlation of the readings on the gas containers was done with the aid of standard 100mls measuring cylinder. 100mls of water were cumulatively poured in the bottle and the water levels were cumulatively marked per every 100mls of water and displacement marks. Readings for the water levels were taken off using a measuring tape and were later used for calibration. This exercise was repeated to have average readings as per the table of results below.

Table 3-3: Calibration of gas collection container

Standard Volume of measuring cylinder (Milliliters)	Calibrated Volume (1)	Calibrated Volume (2)	Average Calibrated Volume (mm)	Intervals per 100 mls (mm)
100	22	23	22.5	23
200	35	34	34.5	12
300	45	47	46.0	12
400	57	59	58.0	12
500	70	72	71.0	13
600	85	86	85.5	15

Standard Volume of measuring cylinder (Milliliters)	Calibrated Volume (1)	Calibrated Volume (2)	Average Calibrated Volume (mm)	Intervals per 100 mls (mm)
700	100	100	100.0	15
800	114	114	114.0	14
900	127	128	127.5	14
1000	140	140	140.0	13
1100	152	152	152.0	12
1200	162	164	163.0	11
1300	175	176	175.5	13
1400	187	187	187.0	12
1500	199	200	199.5	13
1600	211	212	211.5	12
1700	223	224	223.5	12
1800	236	237	236.5	13
1900	250	252	251.0	15
2000	273	274	273.5	23

Daily monitoring of the setups was done and the change in the water displaced was recorded been ongoing and recorded, by the fourth day the set up without NaOH had already displaced 1.5 litres of water while the other 3setups with NaOH had not reflected any significant change in water displacement.

Daily recording for the gas produced was done and analysis was there after done at the time when there was no further production of the gas. A copy of the data collection sheet is captured in Appendix B.7.

3.6.4 Establishment of methane concentration in the biogas generated

100mls of the collected gas sample from the respective setups was transferred into an inverted measuring cylinder immersed into a 3M NaOH solution.

The setup was left to stand for 12 hours until a constant level of the NaOH had been achieved in the measuring cylinder. A reading was then taken off for each respective setup. This process was repeated for the rest of the other biogas setups and the collected reading were tabulated for further analysis.

Figure 3-7 shows the setup for establishment of methane concentration per 100mls of biogas.

	
Preparation of the 3M NaOH solution	**Lab setup to establish methane percentage**

Figure 3-7: Establishment of methane concentration

3.7 Methodology summary

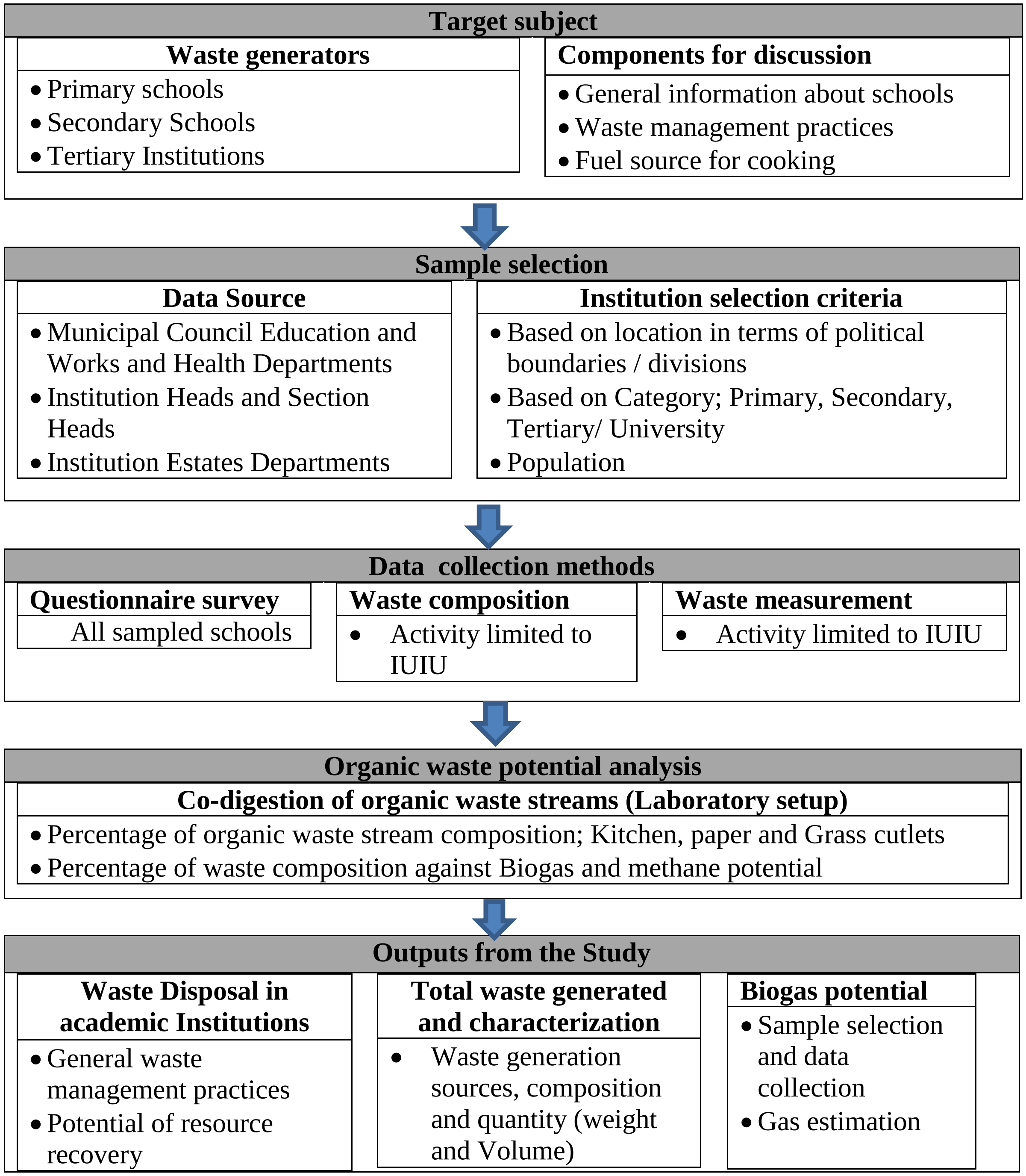


Figure 3-8: Schematic framework of the entire research

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter gives findings from the field survey carried out in the sample schools and institutions visited in relation to waste management and the lab experiment results for the most viable resource recoverable from organic waste from academic institutions. It therefore captures data collected, analysis and interpretation.

4.2 Solid waste management practices in sampled academic institutions

4.2.1 General information

a) Population in the sampled academic institutions

Figure 4-1 below shows the population in all the schools visited and willingly offered to respond to the questionnaire. The figure indicates that Secondary schools were observed with the highest population compared to primary school. This could have been attributed to the relatively law number of secondary schools that are only 15 compared to 71 primary schools. This could be attributed to the very few secondary schools in the municipality. Information obtained from the city found 15 secondary schools compared to 71 primary schools.

The high number of students noted in some school, for example Nkoma SS with over 7550 students could be attributed to good performance at both UCE and UACE in addition to being among the Universal Secondary Education schools in the area and this has enabled it to attract a relatively high number of entrants. North road primary school registered the highest number of pupils of over 2,020 pupils, it is one of primary schools under UPE but with a good ranking in PLE performance while Islamic University in Uganda registers the highest enrolment (7,209) among Universities and institutions as it is one of the oldest University in Uganda and Mbale is its main branch.

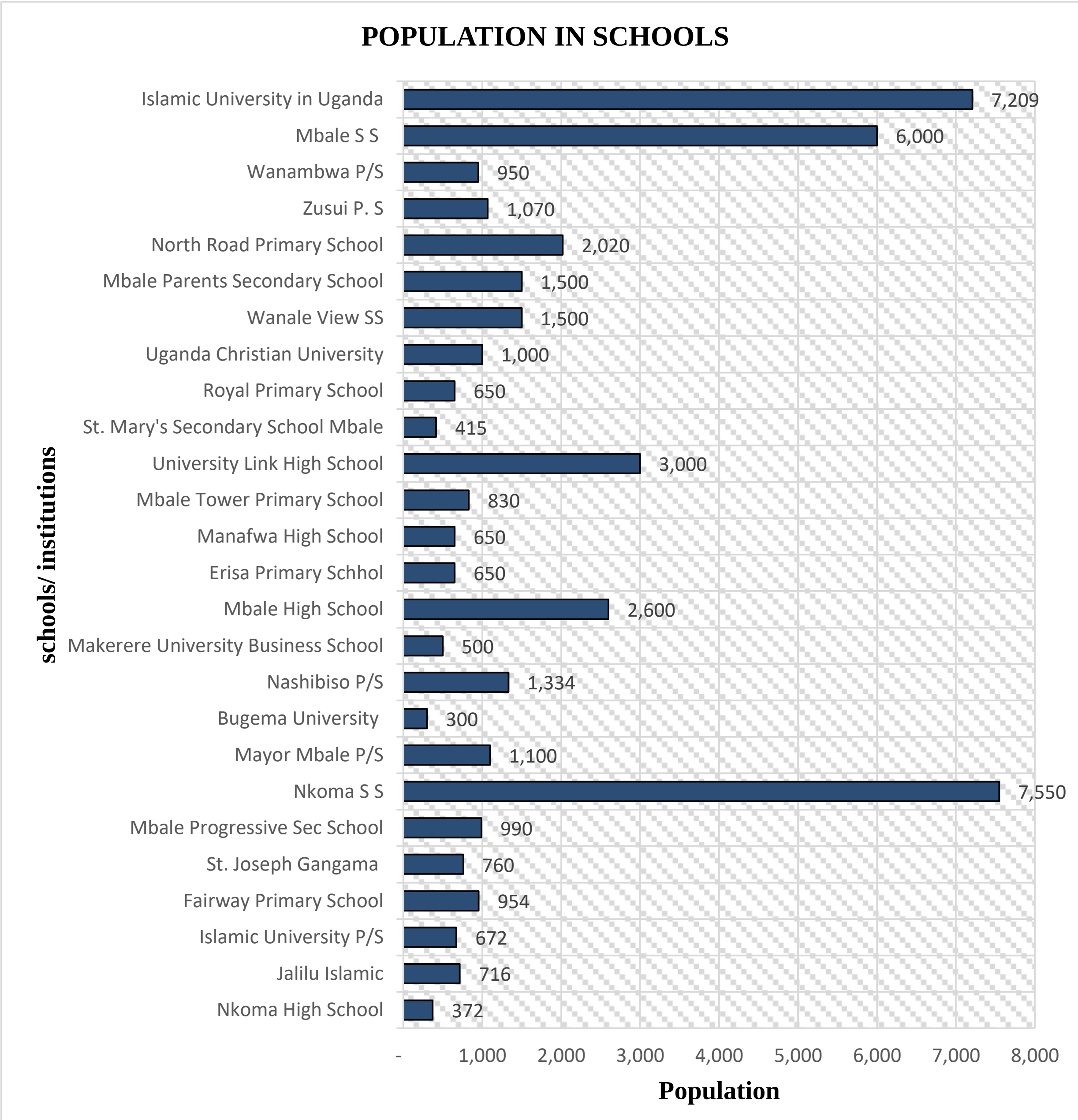


Figure 4-1: Population for the visited schools

4.2.2 Relationship between land coverage and Population

The average land coverage of primary schools was 3.1 Acres with a maximum of 4 acres and minimum of 0.5 acres, while that of secondary was averagely 3.25 Acres with a maximum of 10 acres and a minimum of 1 acre, Islamic University in Uganda had an exceptional land coverage of over 200 acres. It was observed that Schools with average population of 1000 students occupied on average 1.5 Acres of land. It should however be noted that most schools land coverage follows below average of the recommended land coverage of 6 - to 11.6 acres (MLHUD, 2011).

Figure 4-2 shows the relationship between land coverage and school population

Both primary and secondary schools were generally practicing onsite waste disposal however this was more prevalent with government schools.

4.2.3 Waste streams from the sampled schools

From the field findings, it was generally observed from the findings that waste from schools was dominated by paper waste, food waste and vegetable waste. There was also a relative contribution of food waste and paper waste from several institutions

Day schools were characterized by mainly paper waste, leaves and landscape waste with a relative contribution from vegetable waste.

Figure 4-3 reflects organic solid waste composition in the respective academic institutions visited, it clearly indicated that over 7 No. academic institutions had their solid waste comprised of paper, fruit and vegetables and food waste. Two schools indicated each

Paper, Fruit and vegetable and leaves and landscaping, 5 schools indicated generation of paper and food waste.

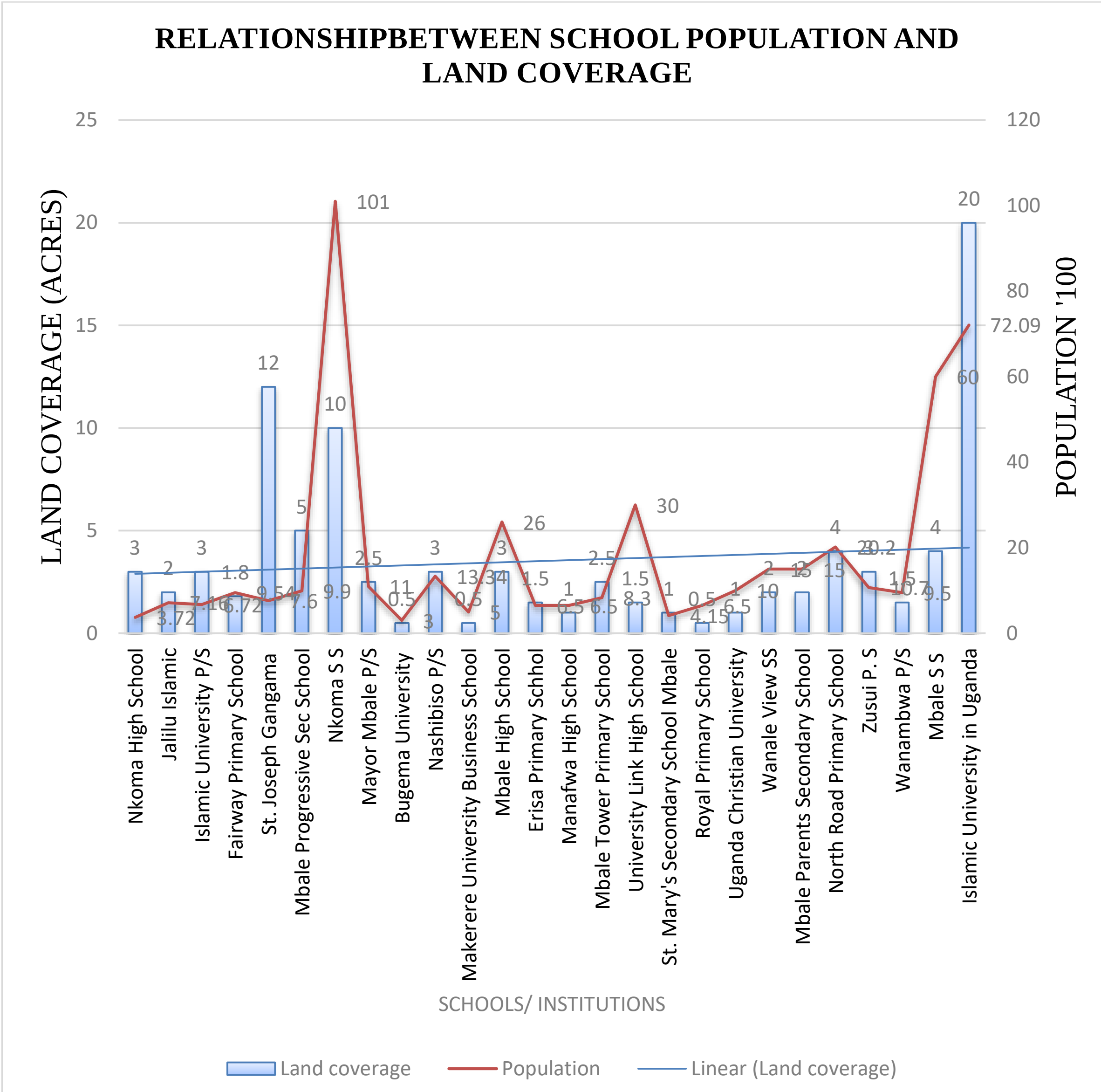


Figure 4-2: Relation between school population and land coverage

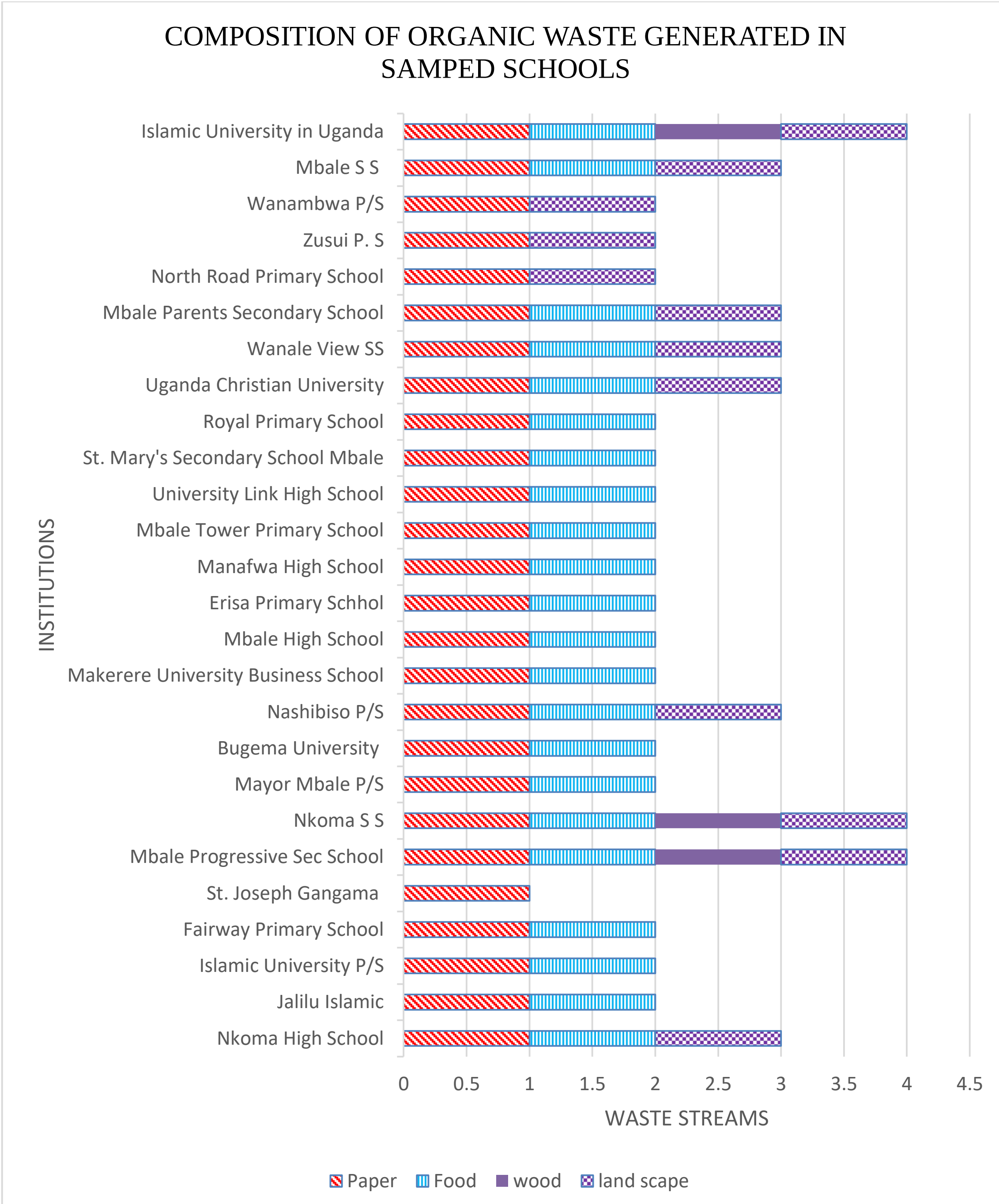


Figure 4-3: Organic waste streams generated from institutions

4.2.4 Waste collection and disposal

It was observed from the field findings, that the key players in waste process are students and pupils especially in secondary and primary schools under direct supervision of designated staff. Figure 4-4 reflects the responsibility holders for waste management in the sampled schools

Every morning and in the evening, students and pupils do either hand picking or sweeping of the compound and drop the collected waste in designated dumping areas (Rubbish pits). Additionally, schools have also procured rubbish bins which they have located in strategic places like classrooms, canteen areas and cafeteria places where students occasionally drop papers, polythene bags and left over food to avoid littering.

From Figure 4-4 it is reflected that most schools tap into free labor from students and pupils to collect, transport and dispose waste.

Field findings as reflected in Figure 4-5, also revealed that over 16 schools out of the 26 visited practice onsite waste disposal mainly by burning.

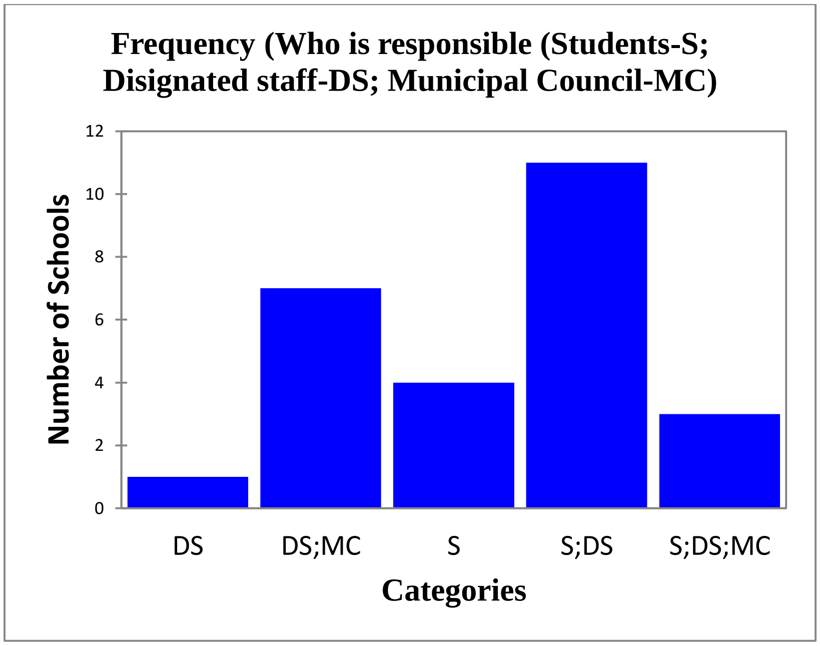


Figure 4-4: Key players in waste collection and disposal

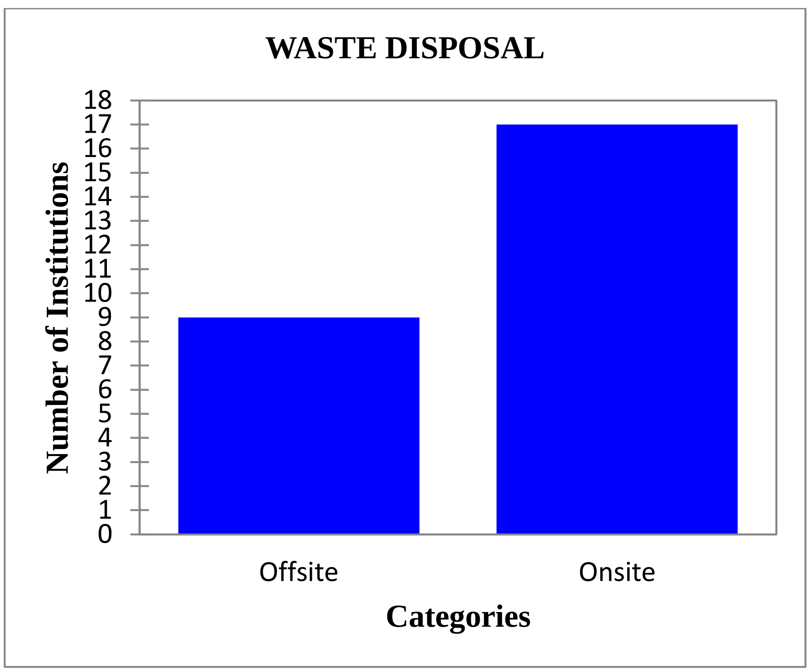


Figure 4-5: Waste disposal

4.2.5 Enabling environment

From information gathered from the field as reflected in Figure 4-6, it was established that atleast more than half of the schools visited had an established strategy for managing waste and had atleast allocated some funds to effectively manage waste generated within their premises. The school administration further confirmed that there was however no Policy by the local authority to guide on appropriate methods of waste management in schools. However, some City Councils have made some strides in formulating guidelines in waste management. In 2000, Kampala Capital City Authority - Uganda (KCCA) then referred to as Kampala City Council (KCC) issued a solid waste management ordinance to regulate storage, collection, transportation, processing and disposal of solid waste in Kampala where it described the roles of the different stakeholders i.e. Local Authority, private Sector Operators and the communities. The Ordinance capitalized on establishment and operation of solid waste disposal facilities mainly landfills, and hence never looked in the direction of possibilities of resource recovery. (Pillai and Mutono, 2010).

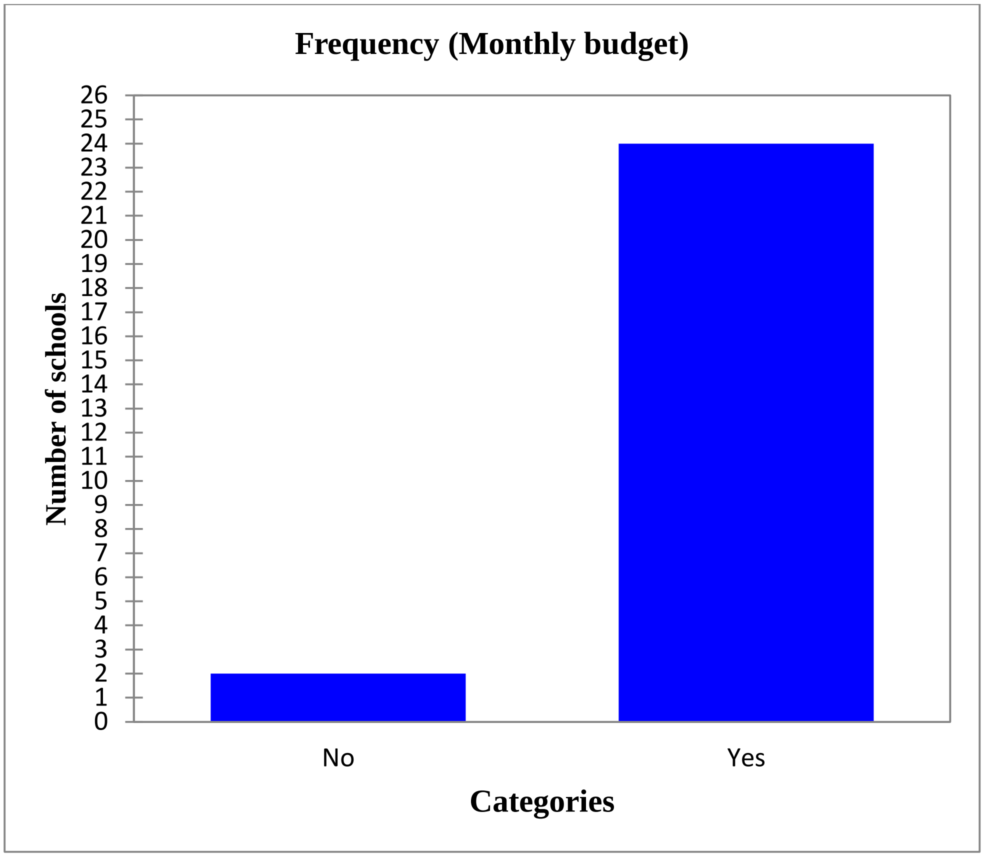


Figure 4-6: Monthly budget for waste management

4.3 Quantifying and Classification of organic waste generated with case study of Islamic University in Uganda (IUIU)

4.3.1 University demography

The University has an average population of 7000 people that occupy and utilize the various structures as well as conducting various activities at the premises.

There are over 8 male and 3 female hostels with a total occupancy of 2,251 resident students. The university has an average population 2,453 non- resident students.

The University has a total of 370 staff members, among whom, 234 are resident staff members.

The University also has a health center with an average outpatient turnover of 100 students and 20 in-patients, 3 cafeterias, a police station with 10 police quarters, a mosque, a main administration block with 20 offices with average square area of $400m^2$, a Library area, 4 office blocks with average square area of $50m^2$ each and 40 lecture rooms of average $150m^2$ floor area.

Table 4-1, shows the available structures at the premises, the related population that utilizes the facilities that ultimately contribute to waste generation at the University.

Table 4-1: University population summary

Institution	Description	Category	Population
IUIU	Staff	Non Residents	136
		Residents	234
	Students and Staff	Non Residents	2,453
		Residents	2,251
	Health Centers	Non Residents	100
		Residents	20
	Other Institutions		2,197
Total			7,391

4.3.2 Classification and quantifying of organic Waste stream

a) General overview

Having established a high potential of organic waste generated in institutions, further analysis was conducted on the institution with the highest number prevalence of waste generation and that Was Islamic university in Uganda.

The University had a laid out strategy of waste management by engaging a designated service provider (M/s Joblink Ltd) to oversee and partake cleaning and managing of associated waste from point of generation to disposal under direct supervision of the

University Estates Engineer. The service provider does the cleaning of the entire university premises from the daily sweeping of the compound lecture rooms, hostels and administration blocks as well as gardening and land scaping.

Waste from the various generation points was loaded into waste collection bins and or carts and then transported to the main designated dumping ground. Figure 4-7 illustrates the service provider staff delivering waste to the main dumping point.

Figure 4-7: Modes of delivery of Waste to the Universitye dump site

From the study as reflected in Figure 4-8 below, it was observed that there was minimal level of separation of waste both at generation, containment and main dumping facility. Noticeably, at hostels all waste both bio-degradable and non-biodegradable was being put in one single container ready for dumping at the designated dumping ground.

However, at cafeteria places, there was some level of separation of waste mostly food waste and food peelings that were usually given to farmers as animal feeds.

Generally, all waste collected was carried in buckets either by head or carts and dumped at the main dumping site in Hips together with organic, non-organic and medical waste. It was however noted that as a step towards solid waste management at the dumping site, the university had considered constructing a concrete paved collection facility measuring 10m x 5m to improve on waste management at the dumping point.

Figure 4-8:Mixup of both biodegradable and non-biodegradable at the university dumping ground

This mode of waste collection therefore gave an indication that there was need to further strength the existing management strategy to include waste separation at source to facilitate in appropriate waste reuse and recycling of recyclable waste.

a) Monthly organic waste generated

From Figure 4-12 below, it was noticeable that more waste of 5000m^3 average by volume was generated in the month of November as opposed to the Month of February with an average waste generation of 3500m^3. The trend of organic waste generation from the date indicated a dependence on the semester calendar activities i.e during the last week of

November (Wk2), it was an examination period for end of semester while in Wk4 – Mid February students were doing tests. On the other hand, these periods received considerable rains with reasonable wind hence contributing to rapid growth of the University hedges, grass within the greeneries hence continuous pruning and grass cutting.

The month of November is a rainy season month hence higher weights of waste are anticipated due to high moisture content as compared to the weights in February which is a dry month. With minimal sunlight for self-drying of the open dumped waste, rapid accumulation of the waste at the dumping point is anticipated. Successively bad odour due to decomposition of the organic waste is anticipated.
Additionally, due to stagnant water within the waste as well as thawing of leachate into the environment by rain waters, water born and vector borne diseases are anticipated to be prevalent during the month of November 2019.

It was observed from the data collected that highest waste collected was 1,492Kgs that translated in 7.246m^3 by volume. This occurred during the last week of November 2019, While the lowest waste collected was 625Kgs that also translated into 3.057m^3 by volume that occurred in the first week of February 2020. The indication of high spikes in waste generation provides for better planning for adequate waste collection amenities to ensure effectiveness within a day's collection. Additionally, this also provides for better planning of the workforce such that staff don't work for very long hours beyond the stipulated time This also gave 962Kgs and 4.669m^3 in average of waste generated by weight and volume respectively.

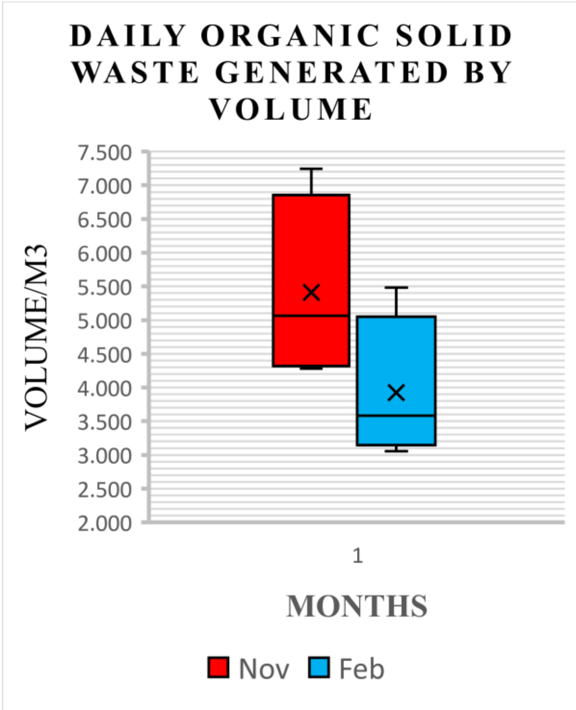


Figure 4-9: Box plot for Monthly Total weight by volume of Organic waste

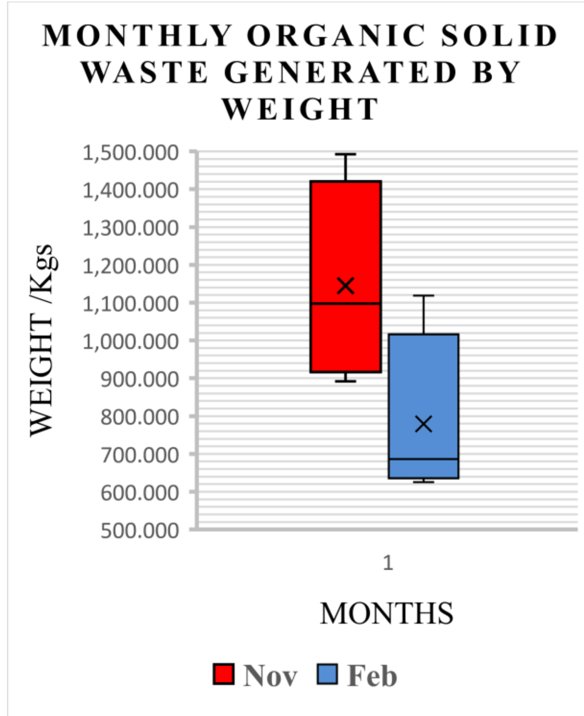


Figure 4-10: Box plot for Monthly Total weight by weight of Organic waste

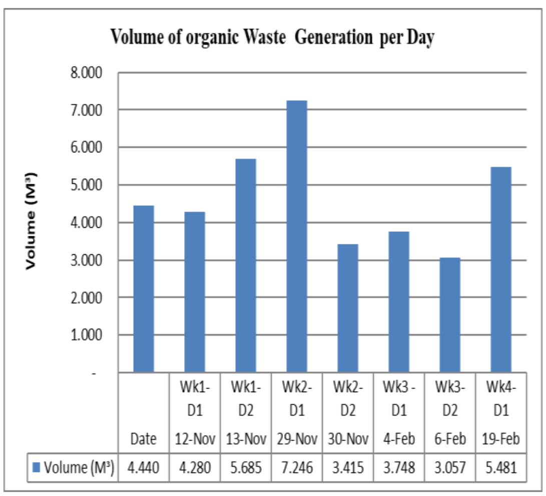


Figure 4-11: Daily Total volume of Organic waste

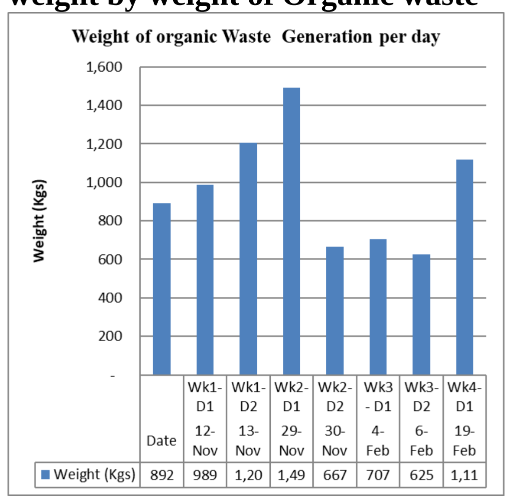


Figure 4-12: Daily Total weight of Organic waste

b) Daily organic waste composition

Figure 4-13: Daily organic waste composition by volume and Figure 4-14 below for volume and weight respectively, it was observed that leaves, grass clippings and hedge pruning formed a bigger volume/ weight of the waste collected per day of 1.4m3 average. There was also considerable contribution from food waste, paper and food peelings & vegetables of average volume $0.987m^3$, $1.05m^3$ and $1.1m^3$ respectively then with fruits with the least contribution of $0.119m^3$. As per the analysis, it is therefore imperative to adequately plan for suitable mechanisms for substrate preparation for the respective waste streams such that best yields of biogas are realized.

Additionally, food peelings weighed most in terms of weight despite it’s volume being relatively lower than that of leaves/grass clippings and pruning. This could relatively be attributed to the high moisture content in the food peelings. Paper was however noted to contribute relatively lower weight inversely proportional it’s high volume contribution. The inverse representation of weight to volume was largely attributed to the higher percentage of voids and the moisture content.

It’s therefore important to correlate the volume and weight while designing the waste treatment facilities to ensure adequate mass balancing, PH and moisture content within the digester.

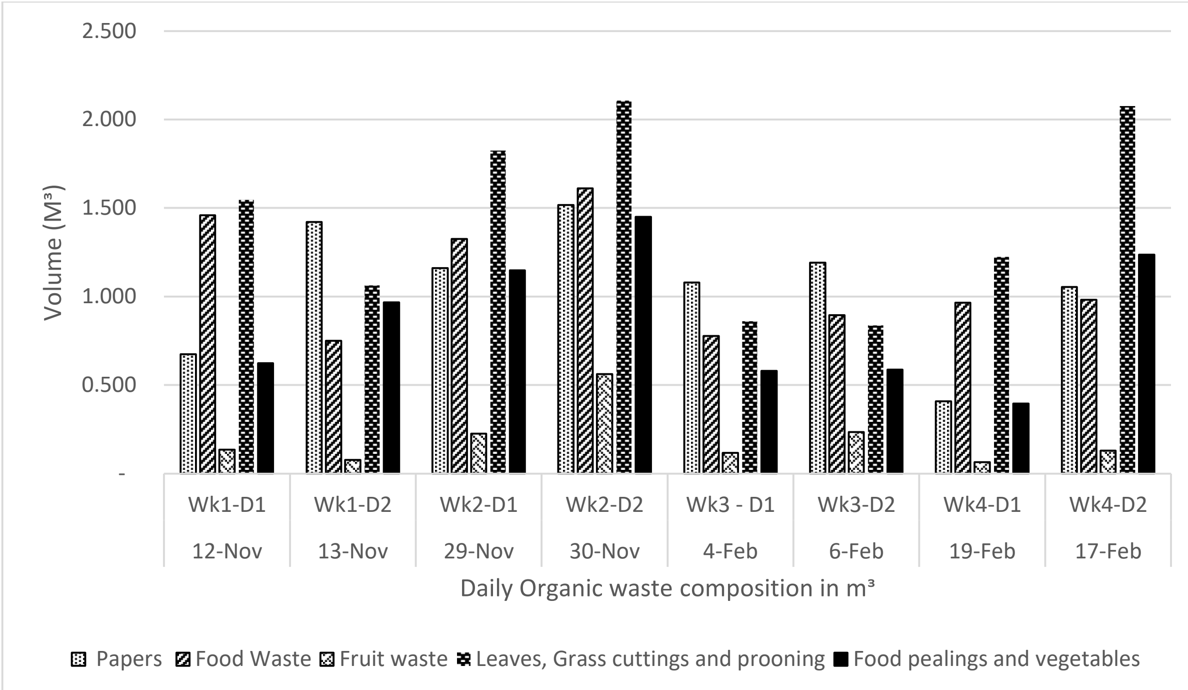


Figure 4-13: Daily organic waste composition by volume

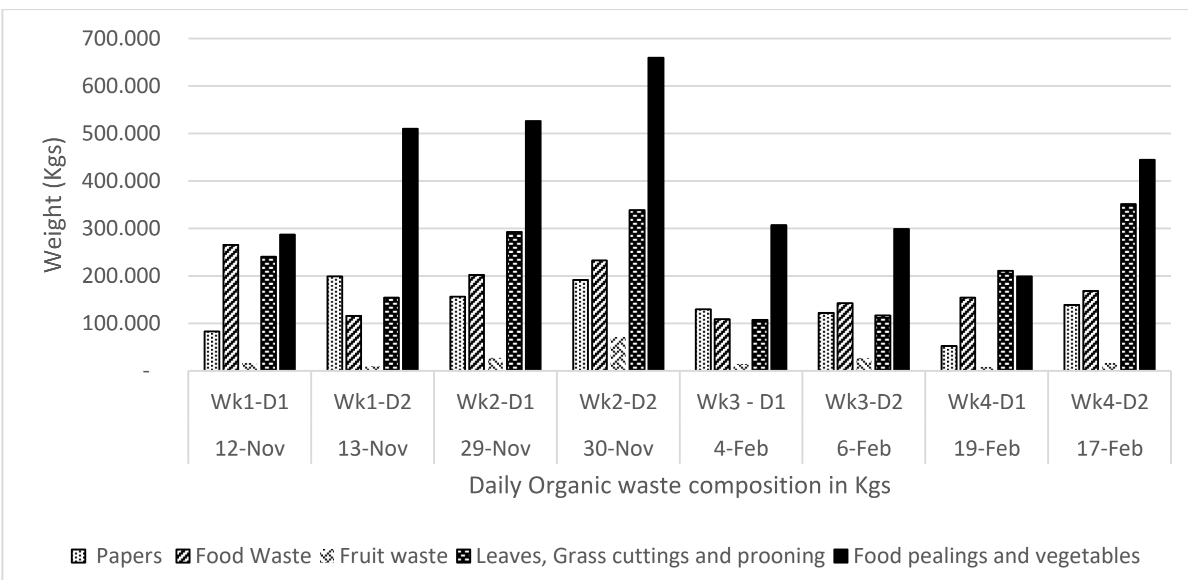


Figure 4-14:Daily waste composition by weight

c) Trends in daily hourly collection

From daily data collected, further analysis of the waste generation for average hourly intervals per day were considered for further analysis.

From Figure 4-15, it was observed that more organic waste of up to 33% was collected between 1000-1200hrs while lest waste was collected between 1400-1600hrs.

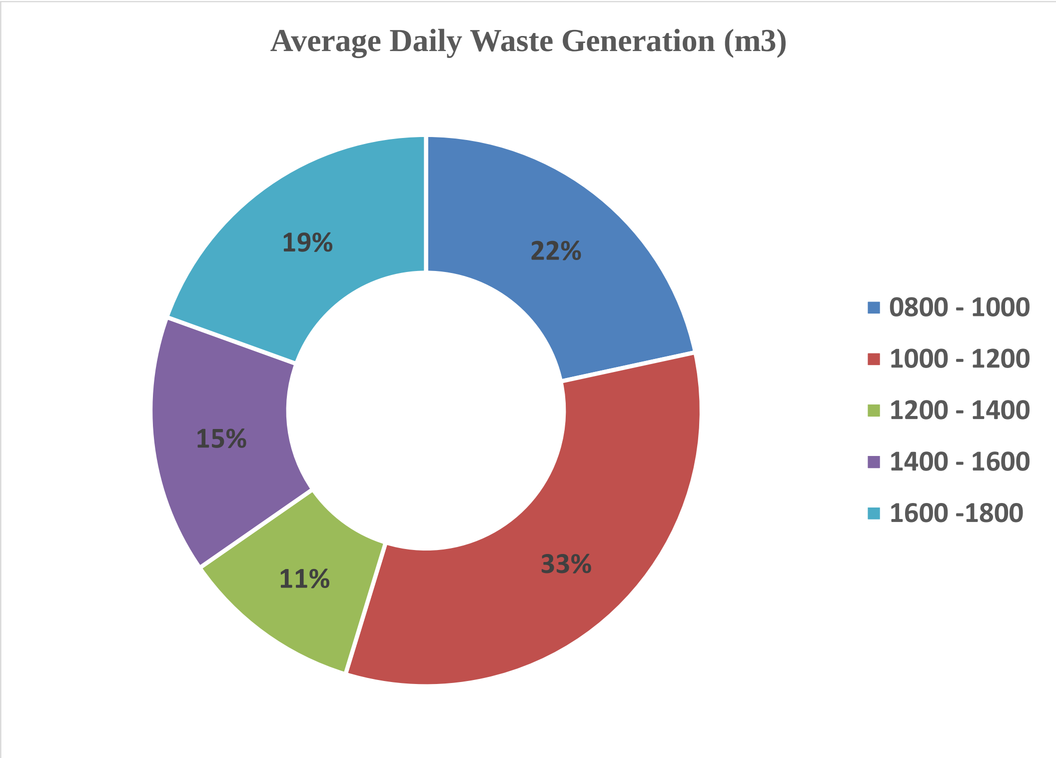


Figure 4-15: Trend of daily waste collection by volume

Further analysis into hourly trends was undertaken to understand the specific waste stream composition per hourly intervals. Figure 4-16, Figure 4-18, Figure 4-19, Figure 4-19, Figure 4-20, and Figure 4-17 elaborates waste generations from 0800-10000hrs, 10000-1200hrs, 1200-1400hrs, 1400-1600hrs and 1600-1800hrs respectively.

Between 0800-1000hrs and 1600-1800hrs as per Figure 4-16and Figure 4-17 respectively food waste was registered highest with over 48% and 50% respectively The high food waste was attributed to the food waste generated overnight in residential halls the previous day and lunch time that day for the afternoon.

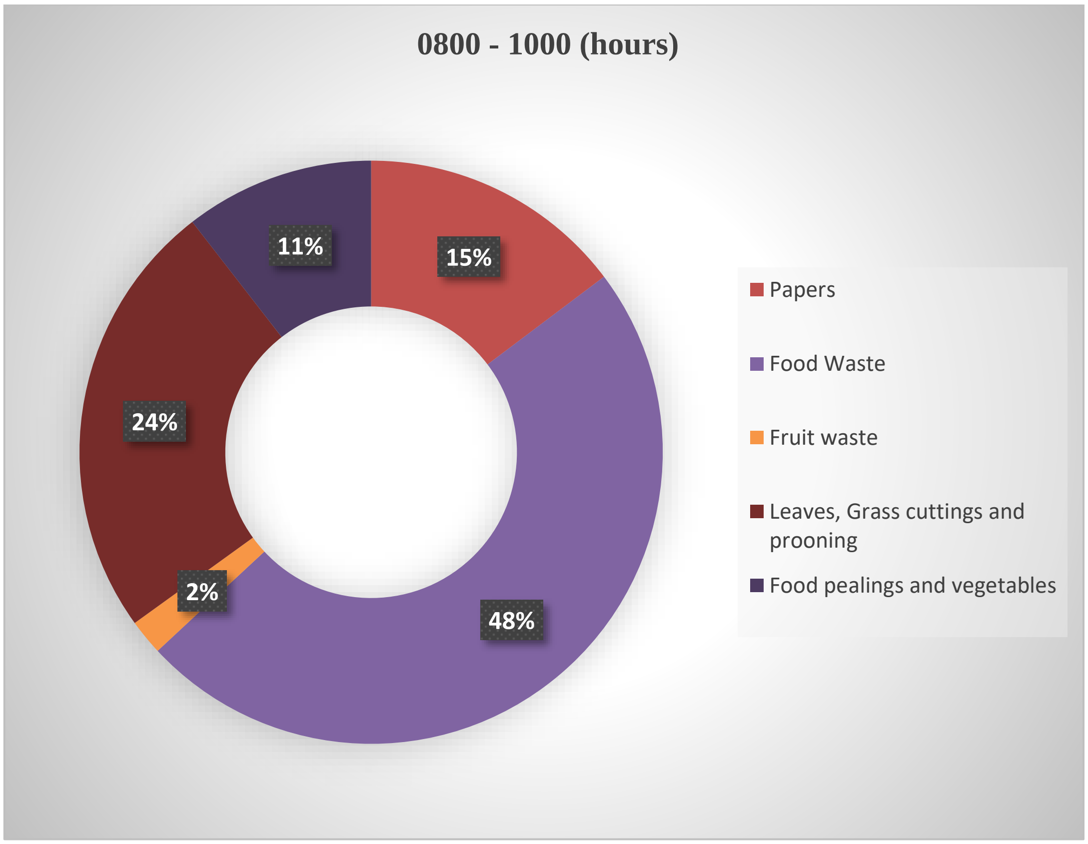


Figure 4-16: Trend of daily waste collection by volume from 0800-1000hrs

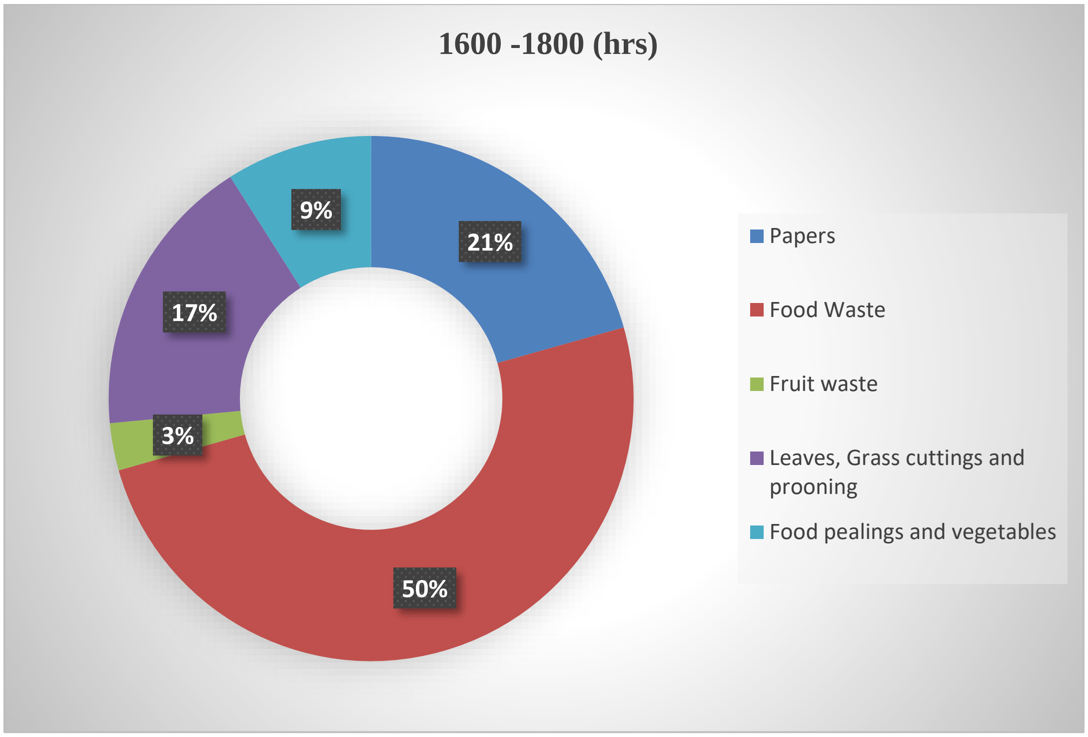


Figure 4-17: Trend of daily waste collection by volume from 1600-1800hrs

The high percentage of leaves, grass cuttings registered between 1000-1200hrs as reflected in Figure 4-18, Figure 4-19 and Figure 4-20 respectively, it was attributed to the intensified cleaning of the lawn and the compound. In relation to the daily overall waste generation where leaves contribute over33% of the daily average waste generated, adequate planning for transportation of the waste to the main point of disposal is very paramount.

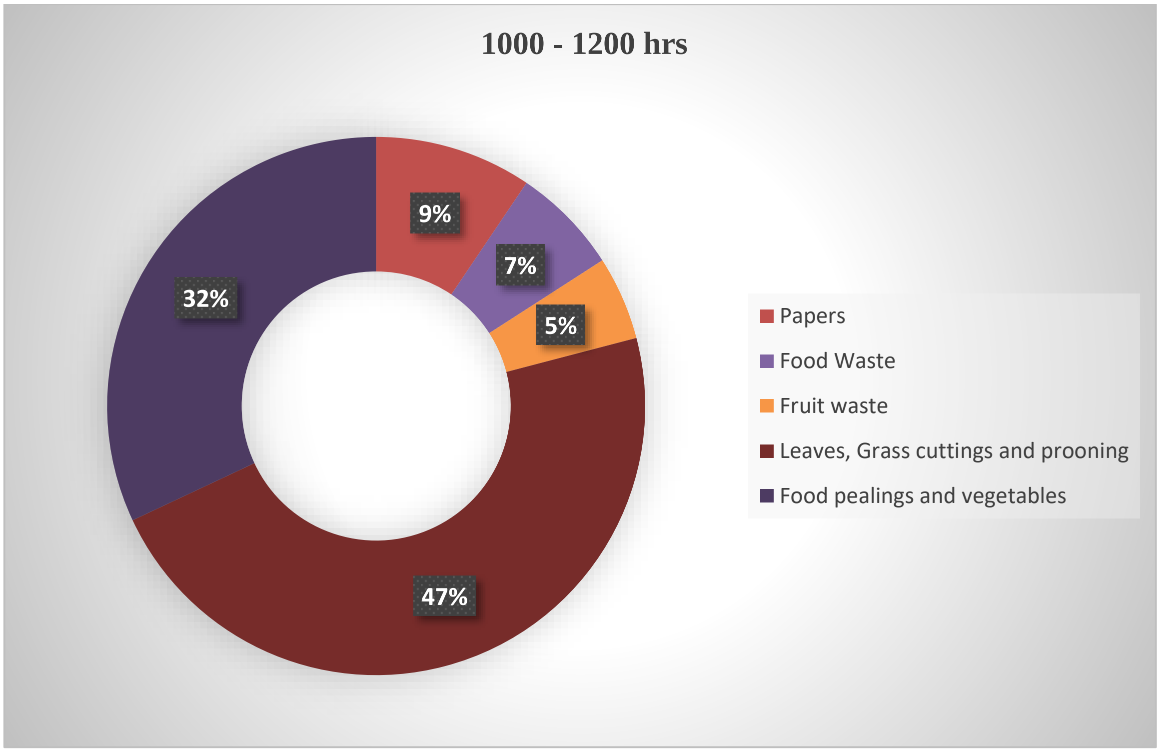


Figure 4-18: Trend of daily waste collection by volume from 1000-1200hrs

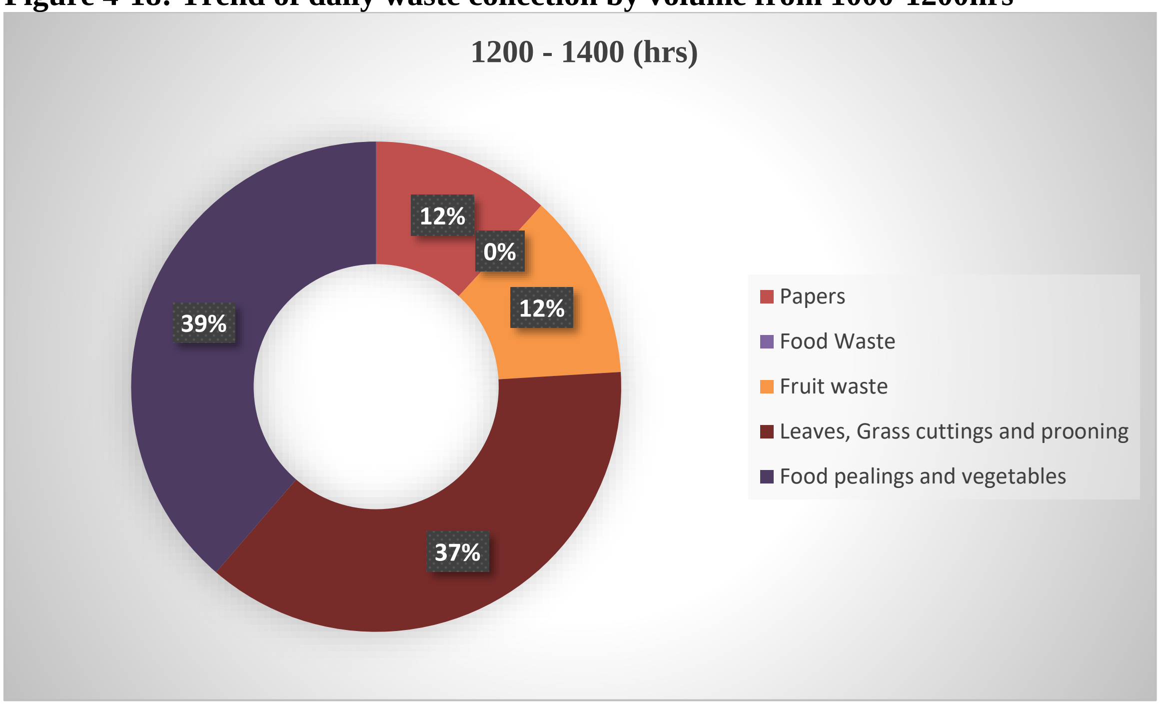


Figure 4-19: Trend of daily waste collection by volume from 1200-1400hrs

Figure 4-21, reflected an averagely high generation of paper waste of 31%, Leaves and grass cuttings at 31% and food waste at 21% respectively between 1400-1600hrs, this therefore reflected intensified activities at cafeteria places, lecture rooms as well as cleaning of the lawn and compound.

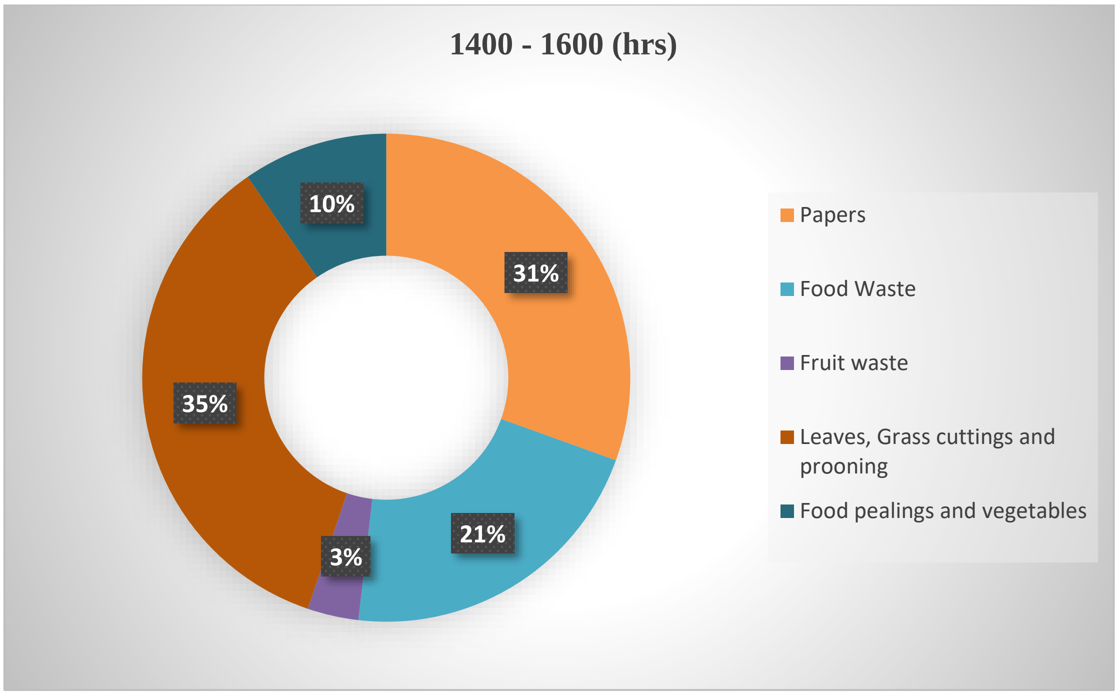


Figure 4-20: Trend of daily waste collection by volume from 1400-1600 hrs

The general average hourly analysis therefore guided well on the anticipated areas of waste generation during specific time intervals and hence strategic allocation of waste management resources in terms of human resource, waste collection containers and tools could adequately be allocated.

4.4 Biogas potential

From the Biogas digesters, bubbling of the gas was observed after 5 days from the time of the setup. Data collection for the gas produced daily is here with presented below. The cumulative recordings for the gas produced was graphically analyzed for the daily cumulative and total gas produced as follows.

Figure 4-22, reflects the respective daily biogas produced. From the figure it was observed that setup 3, 5, 6 and 7 registered early production of biogas ranging between 40 –200 mls. They further registered the highest daily biogas production that ranged between 250mls to 600mls, with the longest production period of averagely 19 days. This performance could have been attributed to the high percentage of kitchen waste and intermediate quantity of grass.

Setup 1 registered it's first production on the 6th day while setups 2,4 and 8 registered their first production after 10 days. The late start with relatively minimal biogas generated could have been attributed to the relatively high percentage of grass and paper waste in relation to kitchen waste.

It was also observed that the setup 3,5 and 7 registered progressive prolonged production of the gas with setup 5 registering the highest of 876mm of cumulative water displacement equivalent to 6,633.76mL of biogas for a relatively period of 19 days.

There was also negligible water displacement registered in the cow dung inoculant setup.

Table 4.2, defines the series setup reflected on the graphs as prepared in the laboratory

Table 4-2: Experiment set up and legend

Setups	Grass (grams)	Kitchen (grams))	Paper (grams)	Total weight (grams)	Inoculant (grams)	Legend
1	267.5	587.5	500	1355.0	338.750	Setup 1
2	267.5	587.5	500	1355.0	338.750	Setup 2
3	267.5	2430.0	125	2822.5	705.625	Setup 3
4	875.0	587.5	125	1587.5	396.875	Setup 4
5	950.0	2430.0	500	3880.0	970.000	Setup 5
6	267.5	2430.0	125	2822.5	705.625	Setup 6
7	875.0	2430.0	500	3805.0	951.250	Setup 7
8	875.0	587.5	125	1587.5	396.875	Setup 8

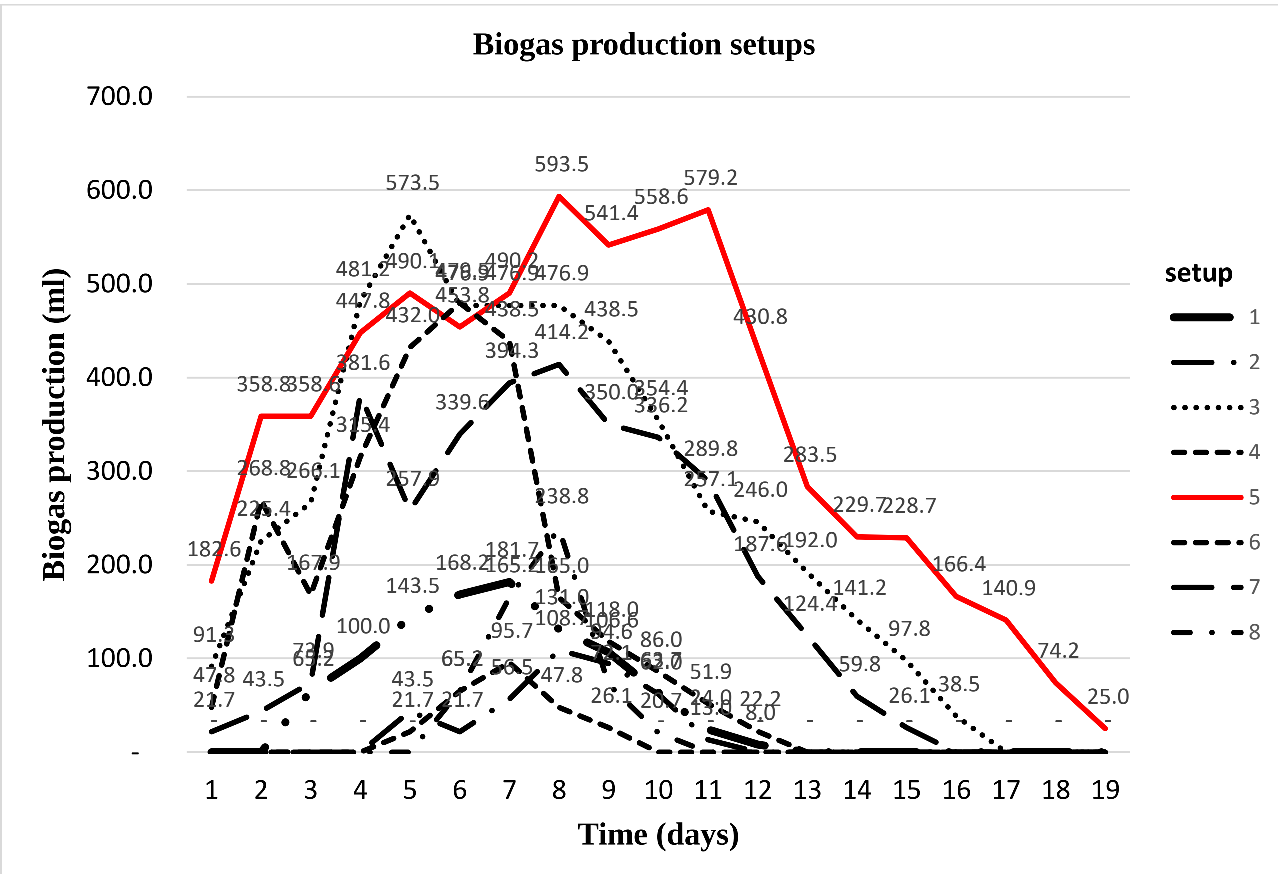


Figure 4-21: Daily Biogas production plotted against time

From Figure 4-22, setup 1 registered the highest and longest biogas production of upto 876mls. For the longest period of 19 days, while setup 4 registered the least of only 41mls. Which leveled off within 4days. Additionally, there was consistent production of biogas registered from setups 3, 5,6 and 7 respectively which gave an indicator that the ratios considered in these setups were relatively ideal for optimal biogas production.

From Figure 4-23, for methane concentration, it was further observed that there was relatively high methane concentration from setups 3, 5, 6 and 7 ranging between 26 to 33 respectively. This therefore gives prospects of good energy recovery from the organic solid waste.

From the methane concentration evaluation, setup 3 registered the highest concentration of 33% while setup 8 registered the least percentage of 13%methane concentration

Biogas setups 3, 5, 6, 7 with a relatively high percentage of kitchen waste, registered a high percentage concentration of methane gas while Setups with a higher percentage of grass clippings (4&8) registered the least methane gas.

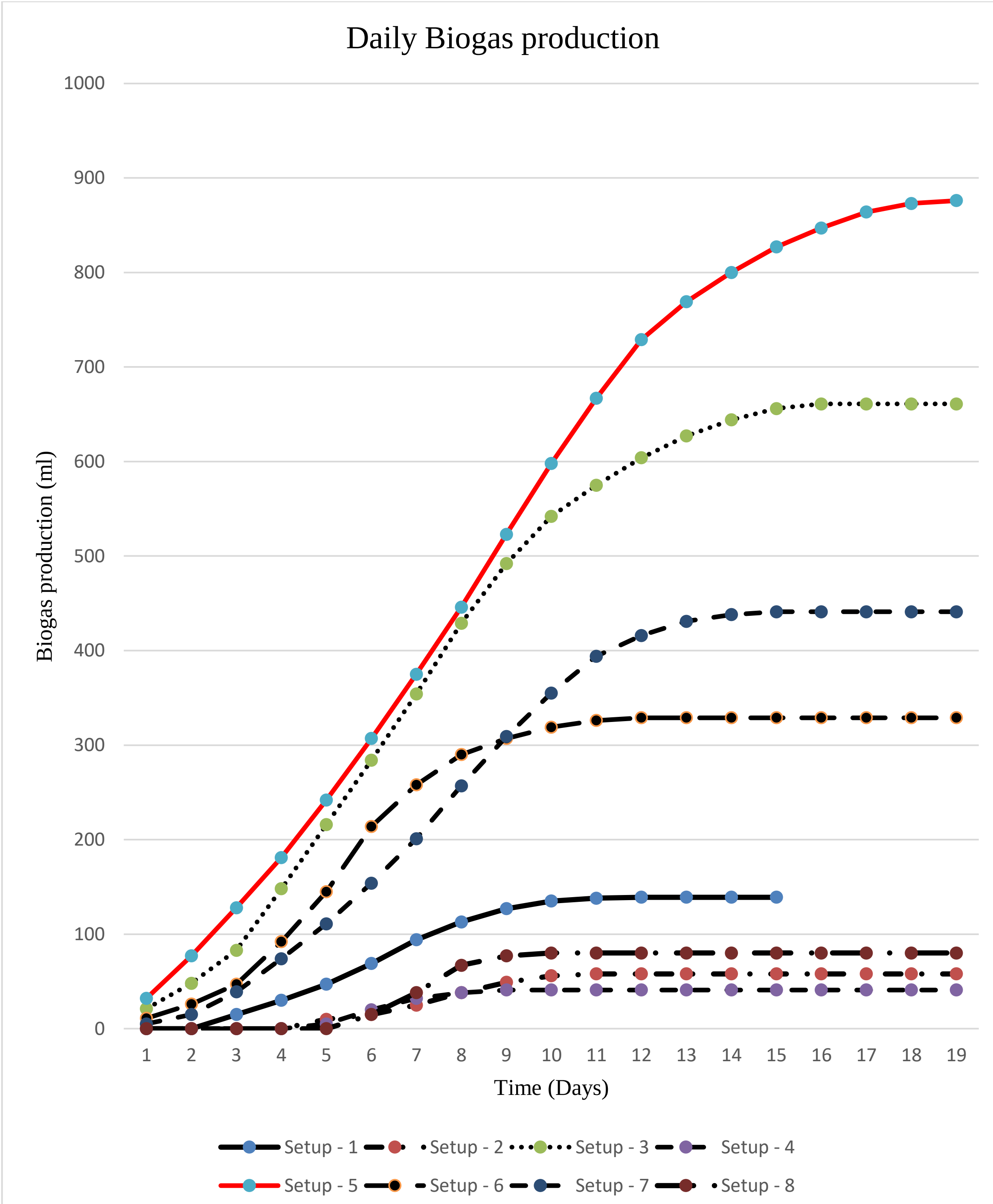


Figure 4-22: Cumulative biogas production(mm) plotted against time

Table 4-3:Substrate ratios

Setups	Grass	Kitchen	Paper
1	2	5	4
2	2	5	4
3	2	19	1
4	7	5	1
5	8	19	4
6	2	19	1
7	7	19	4
8	7	5	1

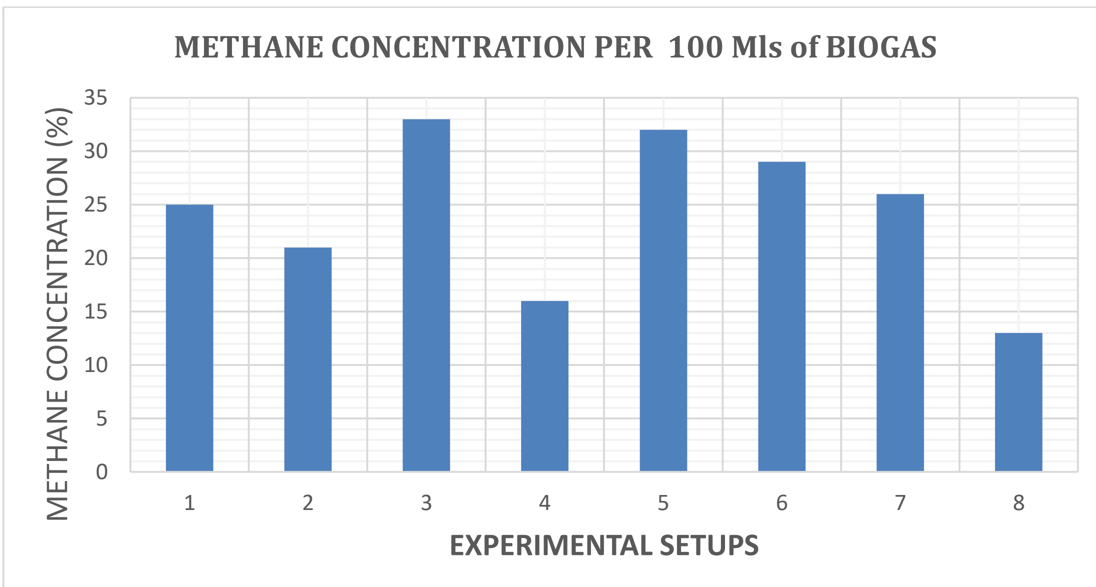


Figure 4-23: Methane concentration

Table 4-4: Total methane concentration evaluation

Setups	methane per 100 (Mls)	Biogas per lab Setup ratios (mm)	Methane per Total lab setup (mm)	Methane (%)	Total Substrate (g)	Substrate in the ratio (1:400) (g)	Total Biogas (Ltrs)	Total Methane (Ltrs)
1	25	992.0	248.0	25%	542,000	1,355	396.80	99.20
2	21	400.0	84.0	21%	542,000	1,355	160.00	33.60
3	33	4833.7	1595.1	33%	1,129,000	2,823	1,933.46	638.04
4	16	256.5	41.0	16%	635,000	1,588	102.61	16.42
5	32	6633.8	2122.8	32%	1,552,000	3,880	2,653.51	849.12
6	29	2593.0	752.0	29%	1,129,000	2,823	1,037.21	300.79
7	26	3300.6	858.2	26%	1,522,000	3,805	1,320.23	343.26
8	13	562.1	73.1	13%	635,000	1,588	224.83	29.23

From the data collected from IUIU, the average daily volume and weight of organic waste generated was 4.669m^3/day and 961.984kgs/day respectively.

Therefore, implied that the total average waste generation in a semester of 3 months would translate to:

By volume;

$$= Average\ daily\ waste\ generated \times \text{days in a month} \times \text{month in a semester}$$

$$= 4.669 \times 30 \times 3$$

$$= 420.21\ \text{m}^3/\text{semester}$$

Likewise, by weight;

$$= 961.984 \times 30 \times 3$$

$$86{,}578.56\ \text{kgs/semester}$$

With the daily average waste generation of 4.669m^3/day and an average of 962kgs in weight, this translated into 420.21m^3 cumulative volume and 86,578.56 kgs cumulative weight per semester.

Average Total biogas per semester = $\frac{\text{Average Biogas produced}}{\text{Average weight of the organic waste}} \times \text{Total waste}$

$$= \frac{978.581}{960{,}750} \times 86{,}578{,}560$$

$$= 88{,}185.41\ \text{Ltrs of Biogas per semester}$$

4.5 General Discussion

This section gives a general concept of the findings from the field survey carried out in the sampled schools and institutions visited, the case study for characterization and quantification of organic waste as well as an experimental simulation of anaerobic digestion of organic waste. The following were therefore conceptualized;

4.5.1 Solid waste management practices in academic institutions

The schools in Mbale Municipality registered a relatively high number of students/ pupils at an average of 1000 pupils for primary and 4,500 students in secondary schools compared to the land coverage of an average of 1.5 acres. This land coverage however falls below the recommended range of 6 - to 11.6 acres (MLHUD, 2011)

The high number of students in Secondary schools as compared to the population in primary school is first of attributed the very few secondary schools (15) compared to (71) primary schools which is even less than ¼ by ratio. On the other hand, the municipality has only 3 government aided schools, hence, these tend to enrollee a relatively high number to meet the demand for UCE services both within the municipality and outside in the neighboring districts.

70% of the schools sampled were practicing solid waste disposal on site hips or pits in designated locations where self-decomposition took course. Mbale Municipality is populated with surface water resources mainly streams and rivers hence, there is a likelihood of seepage of leachate from several onsite disposal points during heavy rains in the numerous academic institutions in the area.

It was further observed that most schools had a monthly budget for waste management but this was not sufficient to offset the acceptable safe waste disposal but rather only cover wages for the laborers and buying and repairing of waste bins and carts for transportation of waste.

It was also observed that there were no regulations and policies to guide on the practice of separation of waste at generation points. The nonexistent of policies at school level, local level and National level has further promoted laxity to enforce separation of waste (Biodegradable, on biodegradable and Toxic/ medical waste.

Only 25 out of the 26 schools visited were using wood biofuel as the main source of energy for cooking. On average boarding schools were using an average of 6 Tata trucks of firewood per term for coking while Day schools were using an average of 2 Tata trucks. This directly reflected on the enormous contribution to environmental degradation by academic institutions in pursuit for cooking energy. formed the major source of energy for cooking in academic institutions.

4.5.2 Quantifying and characterization of the organic solid waste

From the case study at (IUIU), institutions produce significant quantities of waste but do not practice separation of waste at source. Hence, collection and disposal of biodegradable, Non – biodegradable and medical waste is done in one single place with no separation. This therefore poses a risk of seepage of leachate to the environment thus contributing to pollution to the underlying water resource. Additionally, at the point of disposal, the lack of separation of waste contributes to ineffective treatment process for the waste that eventually contributes to accumulation of waste in these areas. Additionally, One of the worlds' underlying challenge is climate change that has retrospectively affected the eco-system more especially drying up of water resource like rivers, streams, springs and boreholes, but this has been greatly attributed to cutting down of trees (Vergara and Tchobanoglous, 2012).

The current waste management practiced is the linear approach of "collect transport and dispose" this kind of approach deprives us of the underlying opportunities like nutrient recovery, recycling and reuse. Academic Institutions are rich in recyclable material like paper Ref. Figure 4-14 which can be reused, recycled or utilized as a raw to generate other resource like compost and natural gas (Andersson et al., 2009).

4.5.3 Biogas potential and methane concentration

The experimental simulation for anaerobic digestion indicated that organic waste from institutions have a potential for production of Methane. Whereas the methane concentration was low about 30% concentration. It's enhancement to reasonable percentages can also be achieved up to as high as 65% through improvement on the operating conditions, substrate pretreatment and inoculant quality (Ariumbaatar, 2015).

The quality and quantity of the resource recoverable from anaerobic digestion greatly relies on the quality of the substrate. This will therefore call for sensitization of the institutions to practice source separation of waste at point of generation. The mixing of non-biodegradable waste and toxic waste greatly affects the effective performance of the anaerobic process. (Dieter, et al., 2017).

The recovery of anaerobic digestion reduces the risk of the Green House Gas emission to the atmosphere and can instead be used for cooking or processed further for generation of heat and electricity. Additionally, the Digestate can also be put to use as manure for improved agriculture production (Andersson et al., 2009).

Currently the world is faced with the challenge of global warming due to accelerated environmental degradation and this has in return affected the quality and quantity of water resources. Anaerobic digestion for organic solid waste can therefore be one of the key tools for mitigation and control of the negative effects posed by the current linear waste management of collection, containment, transportation and disposal. This will in return guarantee the sustainability of water resources (Enrique and Ortiz-hernandez, 2015).

4.6 Key assumptions and limitations

4.6.1 Waste generation

Organic waste streams generated from Islamic University in Uganda were considered as inputs with mechanical pretreatment by grinding and shredding

Temperatures within the tropical regions were considered adequate for anaerobic conditions hence the setup in the lab was considered adequately.

4.6.2 Biogas composition

Biogas composition was assumed as follows

parameter	Farm scale AD plant	Centralized AD Plant
CH_4 (Vol %)	55-60	60-70
H_2 (Vol %)	0	0
N_2 (Vol %)	<1-2	2-6
CO_2 (Vol %)	35-40	35-40
O_2 (Vol %)	<1	0.5 – 1. 6

Composition of biogas from dedicated anaerobic digestion (Arthur. W, 2013)

4.6.3 Limitation

Waste characterization and quantification at generation points could not be undertaken due to access restrictions laid out at the outset by the university Administration. Possibility to undertake a full scale Anaerobic digestion laboratory setup complete with a methane analyzer with temperature, PH controls could not be achieved due to financial constraints however a basic setup to serve the purpose was adopted from.

CHAPTER FIVE: CONCLUSIONS AND RECOMENDATIONS

5.1 Conclusions

The study focused on assessing the biogas recovery potential from organic solid waste in academic institutions within Mbale Municipality. The research looked at investigating the practices of solid waste management in academic institutions within Mbale Municipality where academic institutions were sampled and assessed. The study further assessed the quantity in terms of mass and respective volume as well as the composition of the waste generated within academic institutions where a case study at Islamic University in Uganda was considered, further analysis was undertaken to investigate the biogas potential recoverable from the generated organic solid waste using the lab scale single stage anaerobic digester. The results of the study therefore included the following: -

Generally, there was potential of organic solid waste composition in academic institutions majorly; paper waste, food waste, fruit and vegetable, landscape clippings and leaves. This was however dependent on the category and nature of school, school calendar and environmental conditions.

High potential of Organic Waste generation in academic institutions was further verified and was noted to be dependent on the semester calendar activities. In the month of November which represented the end of the semester a relatively high generation of waste of 5000m3 while in the month February that represents the beginning of the semester a relatively lower organic solid waste of 3500m3 was generated. The last week of November 2019 the highest organic solid waste of 1,492Kgs that translated in 7.246m^3 by volume while the lowest organic solid waste of 625Kgs that also translated into 3.057m^3 by volume was generated in the first week of February 2020.

The indication of high spikes in waste generation provides for better planning for adequate waste collection amenities to ensure effectiveness within a day's collection. Additionally, this also provides for better planning of the workforce such that staff don't work for very long hours beyond the stipulated time.

It was also observed that there was no separation of waste in the waste management stream right from point of generation, collection, transportation and disposal.

Resource recovery has been anchored on various prospect but the major among them has been the prospect of feature demand of the resource recovered or the product derived from the resource as well as possible delivery of these resources with no prohibitive economic environment or social costs (Andersson et al., 2009)

This section therefore gives a wrap-up of the findings from the field survey carried out in the sampled schools and institutions visited, the case study for characterization and quantification of organic waste as well as an experimental simulation of anaerobic digestion of organic waste. The following were therefore some of the deductions;

Bubbling of the gas was observed after 5 days from the time of the setup of the anaerobic digesters. The cumulative recordings indicated that setup with relatively more concentration of food waste and grass clippings by ratio registered early production of biogas ranging between 40 – 200 mls. They further registered the highest daily biogas production that ranged between 250mls to 600mls, with the longest production period of averagely 19 days. the highest biogas produced was 876mm of cumulative water displacement equivalent to 6,633.76mL of biogas for a relatively period of 19 days. The least biogas registered was 41mls for biogas setups that comprise a relatively low percentage of food waste.

Setup with relatively more concentration of food waste and grass clippings by ratio further registered a relatively high percentage of 26% – 33% and the least percentage of methane concentration of 13% was registered with substrate ratios with low concentration of kitchen waste and grass clippings. This therefore gave a high prospects of good energy recovery from the organic solid waste.

Methane gas recovery from the organic waste can reliably be confirmed as the most viable resource option to offset the effects of environmental degradation activities for both pollution and global warming most profoundly substituting the high wood biofuel demand by schools and institutions (Somanathan and Bluffstone, 2015).

5.2 Recommendations

5.2.1 General

From the results of resource recovery potential, there is need to promote waste separation in academic institutions through the waste management chain right from the point of generation, collection, transportation and disposal, given the considerable potential for not only biogas recovery but also recycling and reuse for paper and plastic waste. The implementation should however be participatory with all teachers, supporting staff and students fully engaged in a compulsory manner to foster addiction thereby causing a behavior change within these institutions and the society at large.

For long term consideration of effective waste management for environmental sustainability most especially for academic institutions that have a high demand for wood biofuels, Anaerobic digestion for selected wastes (high moisture), is recommended as part of the mix of mature waste management technologies due to its notable benefits of; energy recovery (methane), reduced process times and reduced volume of residuals; In general, anaerobic digestion technologies incur lower capital costs than other methods of waste disposal like incineration and landfills. On the other hand, the Digestate (residue) can be used as manure for agriculture production hence reducing on the operation of landfills and dumping sites with biodegradable waste.

5.2.2 To policy

Due to the willingness by institutions to adopt effective and sustainable waste management practices, there is a need to enact bylaws and guidelines that clearly stipulate, guide and educate academic institutions and local authorities on the application and implementation of effective and sustainable solid waste management practices for resource recovery, recycling and reuse.

5.2.3 For further studies

Based on the uncertainty in data analysis for waste generated, there is need to undertake a detailed analysis to ascertain the waste generation trends from the identified waste generation centers for comprehensive planning.

Additionally, there is need to undertake further analysis for the enhancement of methane composition from the biogas generated from the organic waste streams.

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APPENDICES

Appendix A.1; Introductory letter of the student by Kyambogo University

KYAMBOGO UNIVERSITY

FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL AND BUILDING ENGINEERING

P O. BOX 1 Kyambogo – P. o. Box 7181 Kla/ Ug

Website: www.kyu.ac.ug; Email: civil@kyu.ac.Ug

Tel. +256 414 287340; Fax: +256 – 414 289056/ 222643

TO

THE MUNICIPAL EDUCATION OFFICER

MBALE MUNICIPAL COUNCIL

MBALE DISTRICT

RE: REQUEST FOR INFORMATION AND NECESSARY ASSISTANCE

This serves to introduce to you **Mr. Kayizzi Patrick Reg. No. 17/U/14679/GMEW/PE** who is a Final Year student undertaking research in ***"Resources Recovery from Organic Waste"*** for the award of a **Master's Degree in Water and Sanitation Engineering** of **Kyambogo University**.

As a requirement of this Programme, students in their final year are required to undertake research under supervision of the University and also publish their thesis in recognized research journals and websites by the 1st Week of July 2019

The purpose of this letter is to request your office/ institution to accord our student necessary support to enable him gather necessary information to enable him accomplish his research.

Any assistance rendered to him will be highly appreciated

Yours Faithfully

Dr. Jacob Nyende
Head of Department

THE HEAD OF DEPARTMENT
CIVIL AND BUILDING ENGINEERING
KYAMBOGO UNIVERSITY

For MEO
Received
2/05/2019

Appendix A.2; Introductory letter of the student to academic institutions by Mbale Municipality

MBALE MUNICIPAL

LOCAL GOVERNMENT COUNCIL

EDUCATION DEPARTMENT
TELEPHONE:33518
FAX:256-45-35340
E-Mail:mbalemc@yahoo.com

MUNICIPAL OFFICES
PLOT 62-68 REPUBLIC STREET
P.O PRIVATE BAG
MBALE, (UGANDA)

Our Ref: ***CR.2137.***
Your Ref:

Date: 10th May, 2019.

The Headteacher/Principal/Vice Chancellor,

--Primary/Secondary/Tertiary/University.

RE: MR. KAYIZZI PATRICK REG. NO. 17/U/14679/GMEW/PE.

This is to introduce to you **Mr. Kiyizzi Patrick** who is a final year student of Kyambogo University.

He is undertaking research in ***Resources Recovery from Organic Waste"*** for the award of a **Master's Degree in Water and Sanitation Engineering of Kyambogo University**.

Please accord him the necessary support to enable him accomplish his research.

Yours faithfully,

10/05/19

Municipal Education Officer
Mbale Municipal Council

Kamuli Mayeku Boaz
MUNICIPAL EDUCATION OFFICER
MBALE MUNICIPAL COUNCIL.

Appendix A.3.1; Request for permission to conduct research at Islamic University in Uganda

KYAMBOGO UNIVERSITY

FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL AND BUILDING ENGINEERING

P O. BOX 1 Kyambogo – P. o. Box 7181 Kla/ Ug

Website: www.kyu.ac.ug; Email: civil@kyu.ac.Ug

Tel. +256 414 287340; Fax: +256 – 414 289056/ 222643

1st July 2019

TO THE UNIVERSITY ENGINEER
ISLAMIC UNIVERSITY IN UGANDA
MBALE (Uganda)

RE: REQUEST FOR PERMISSION TO UNDERTAKE DATA COLLECTION AT THE UNIVERSITY PREMISES

Reference is made to the above subject, I am **Kayizzi Patrick a Final year Masters Student of Kyambogo University Reg. No. 17/U/14679/GMEW/PE** undertaking research in ***"Resources Recovery from Organic Waste generated from Institutions"*** for the award of a **Master's Degree in Water and Sanitation Engineering**.

As a requirement of this Programme, students undertake research under supervision of the University and also publish their thesis in recognized research journals.

The purpose of this communication is to therefore request for permission to undertake data collection from the University. The exercise will involve:-

- Mapping out organic waste generation points, collection method, transportation and current method of disposal,
- Characterizing and quantifying the different organic wastes generated,
- Performing offsite resource recovery experiments for recovery of biogas from the organic waste as a preferred option and later share the results as well as publication of my thesis

Looking forward to your positive response

Yours faithfully

Kayizzi Patrick
(MSC Water & Sanitation student)

Received
1/7/19

Appendix A.3.2; Request for permission to conduct research at Islamic University in Uganda

PATRICK KAYIZZI
KYAMBOGO UNIVERSITY
GRADUATE SCHOOL
FACULTY OF ENGINEERING
P. o. BOX 1 KYAMBOGO
Mob: 0754 911 324; 0774 017 887
Email: enockpatrick16@gmail.com

3rd Oct 2019

TO:

THE UNIVERSITY ENGINEER
ISLAMIC UNIVERSITY IN UGANDA
MBALE (Uganda)

RE: METHODOLOGY FOR DATA COLLECTION AT THE UNIVERSITY PREMISES

Reference is made to the above subject, my earlier request to collect data about waste management and your consent about the same.

Here with is my proposed methodology to undertake the exercise;

i. General data collection about the institution as per the data collection sheet in appendix 1 and it will be an interaction with any of the staff members under estates department

ii. Detailed data collection about waste stream from point of generation to point of disposal as per appendix 11 and basically it will be physical weighing or volumetric determination of the waste. Under this section and with the guidance of one of the Estates field staff, I intend to sample two areas per category viz; (Administrative structures, Lecture room blocks, Accommodation blocks and cafeteria block and any other that may contribute significantly to the over results)

iii. The generated data will then be subjected to computer aided software XLstat for analysis

iv. All Data collected will then be shared with the University Estates department prior to publication

The exercise will be conducted for four weeks and at least 2 days per week.

Hope you find the information satisfactory

Yours faithfully

Patrick Kayizzi
(MSC Water & Sanitation Research Student)

Received 4/10/19

Appendix A.4.1; Permission to Conduct research at Islamic university in Uganda

Organisation of Islamic Cooperation
Islamic University in Uganda

منظمة التعاون الإسلامي
الجا معة الإ سلامية في أو غندا

ESTATES AND WORKS DEPARTMENT

IU/EWD/103/3

15th October, 2019

The University Coordinator
IUIU

Assalam Alaikum

RE: MR. KAYIZZI PATRICK

This is to introduce you to **Mr. Kayizzi Patrick,** a masters student pursuing Water and Sanitation Engineering at Kyambogo University.

He has been granted permission to conduct his research within IUIU under the title **"Resources Recovery from organic waste generated from Institutions".**

The purpose of this letter therefore is to request you to allow him access the halls of residence and cafeterias with the purpose of assessing waste generated.

Thank you.

fr Dauda ML Semujju
UNIVERSITY ENGINEER

Cc. Manager Joblink Services Ltd.

ISLAMIC UNIVERSITY IN UGANDA
21 OCT 2019
RECEIVED
OFFICE OF THE UNIVERSITY CO-ORDINATOR

Appendix A.4.2; Permission to Conduct research at Islamic university in Uganda

Organisation of Islamic Cooperation
Islamic University In Uganda

منظمة التعاون الإسلامي
الجامعة الإسلامية في أوغندا

Coordinator's Office

Our Ref: UC/221/2 **Date:** 4th November, 2019

Mr. Kayizzi Patrick
Kyambogo University
KAMPALA

Dear Sir

RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH WITHIN IUIU

Reference is made to a letter IU/EWD/103/3 dated 15th October, 2019 from the University Engineer regarding the above mentioned subject matter.

This is to convey permission for you to conduct your research within IUIU under the title "***Resources Recovery from Organic waste generated from Institutions",*** with effect from 6th November, 2019 to 5th May, 2020.

By copy of this letter all departmental heads of units and managers of cafeterias are hereby requested to accord you the necessary assistance to enable you access the students' halls of residence and cafeteria.

Looking forward to receive you in IUIU.

Yours sincerely

ISLAMIC UNIVERSITY IN UGANDA
CO-ORDINATOR'S DEPARTMENT
04 NOV 2019
OFFICE OF THE UNIVERSITY COORDINATOR

Sulait D. Kabali
AG. UNIVERSITY COORDINATOR

C.c VR (F&A)
" University Engineer
" Male Warden
" Female Warden
" Manager, Joblink Services Ltd
" Manager, Hawaz Restaurant
" Manager, Nabeel Restaurant
" Manager, Larvim Restaurant
" Manager, Food Science Restaurant

P.O.Box 2555, Mbale - Uganda. Tel: +256 352 512100, Fax: +256 352 280 525, E-mail:info@iuiu.ac.ug, website:www.iuiu.ac.ug

Appendix A.5; Permission to Conduct research at Ministry of Water and Environment Regional Laboratory Mbale

This request to use the laboratory is granted.
16/7/2020.

PATRICK KAYIZZI
KYAMBOGO UNIVERSITY
GRADUATE SCHOOL
FACULTY OF ENGINEERING
P. o. BOX 1 KYAMBOGO
Mob: 0754 911 324; 0774 017 887
Email: enockpatrick16@gmail.com

25th May 2020

Laboratory Manager
Look into this request and advise accordingly.
25-05-2020

TO:

THE REGIONAL MANAGER
MINISTRY OF WATER AND ENVIRONMENT
WATER RESOURCES MANAGEMENT
KYOGA WATER MANAGEMENT ZONE
MBALE

RE: Request for permission to utilize the Regional Laboratory facilities

Reference is made to the above subject, I am **Kayizzi Patrick a Final year Masters Student of Kyambogo University Reg. No. 17/U/14679/GMEW/PE** undertaking research in ***"Resources Recovery from Organic Waste generated from Institutions"*** for the award of a **Master's Degree in Water and Sanitation Engineering**.

The research is intended to establish the possibility of undertaking water resource pollution control through an integrated approach of waste disposal control in form of resource recovery and re-use.

The purpose of this communication is to therefore request for permission to utilize the regional Laboratory facility to setup experiments and to also undertake water quality tests that will facilitate collection of relevant information for the research. Activities to include:-

- Water Quality test for water resources in the project area (Islamic University In Uganda-IUIU)
- Quality tests for leachate from organic waste at the dumping site of IUIU
- Setting up of a methane production and inoculation experiment of organic waste feed stocks
- Undertaking quality tests for the digestate

Looking forward to your positive response

Yours faithfully

Patrick Kayizzi
(MSC Water & Sanitation Research Student)

Appendix B.1; Questionnaire for general data collection from institutions

Code of questionnaire		Date:	
Interviewer's name			
Respondent's name			
Position & Phone contact			

1. General information

1.1 Name of the school/ Institution	1.2 Address	1.3 Type		1.4 Category	
		Primary		Day	
		Secondary		Boarding	
		Tertiary		Both	
		University			

1.5 Location

Village	Parish	Sub county	County	District

1.6 National grid reference coordinates	Eastings	Northings	Elevation

1.7 Land coverage	1.8 Population				1.9 Total population
	Day/ non-residents		Boarding/ residents		

2. Waste Management

2.1 Do you have a waste management policy for your institution

Yes		No.	

2.2 Monthly budget for waste management

2.3 Who manages waste disposal					
Students		Designated staff		Municipal council	
2.4 Do you separate waste		Yes		No	
2.5 If yes at what stage		Generation		Disposal	
2.6 Major categories of organic waste generated from the institution					
Paper waste	Food waste	Green waste	Nonhazardous wood	Landscape and pruning waste	
2.7 What is the method of collection and containment					
Polythene		Garbage skips		Non/ground	
2.8 How do you dispose you waste		Onsite		Offsite	
2.9 If offsite, where			2.10 Is it designated by council authorities		
2.11 If onsite disposal is done;					

2.12 Do you have designated places for disposal	Yes		No			
	If yes, how many?		Why?			
2.13 What method of disposal do use	Burning		Resource recovery		Non	
2.14 Please explain						

2.15 Are you satisfied with your current waste disposal system	Yes		No.	
2.16 Please explain				
2.17 What could be the related challenges with the current system				
2.18 Suggestions to improve or solve the challenges				

3. <u>Fuel</u>									
3.1 What do you use as source of fuel for cooking									
Fire wood		Electricity		Cooking gas		Renewable energy		Others	
3.2 How much is spent on cooking fuel									
3.3 Please comment on the expenditure									

Very high		Moderate		Low	

3.4 Any challenges with the current source of fuel for cooking
3.5 Suggestions to improve or solve the challenges

Appendix B.2; Questionnaire for data collection at Islamic university in Uganda

APPENDIX 11		Date:	
Interviewer's name			
Respondent's name			
Position & Phone contact			

2. General information					
2.1 Name of the school/ Institution	2.2 Address	2.3 Type		2.4 Category	
		Primary		Day	
		Secondary		Boarding	
		Tertiary		Both	
		University			

2.5 Location				
Village	Parish	Sub county	County	District

2.6 National grid reference coordinates	Eastings	Northings	Elevation

1	Building Name	Coverage (SM)	Purpose	Number of occupants	Major organic waste generated
Use additional sheet is more buildings					

Organic waste

1	Building Name					
	Business time					
	Time interval	**Paper waste**	**Food waste**	**Green Waste**	**No- hazardous wood**	**Land scape and pruning waste**
Use additional sheet is for additional buildings						

Appendix B.3; List of Academic Institutions in Mbale Municipality

LIST OF GOVERNMENT PRIMARY SCHOOLS

NO.	DISTRICT	SCHOOL NAME	SCHOOL TYPE
1	Mbale Municipal Council	Namatala Primary School	Government
2	Mbale Municipal Council	Fairway Primary School	Government
3	Mbale Municipal Council	Wanambwa Primary School	Government
4	Mbale Municipal Council	Gangama Primary School	Government
5	Mbale Municipal Council	St. Micheal Senkulu Primary School	Government
6	Mbale Municipal Council	Mbale Police Wanyela Primary School	Government
7	Mbale Municipal Council	Busamaga Primary School	Government
8	Mbale Municipal Council	Boma Primary School	Government
9	Mbale Municipal Council	Nkoma Primar School	Government
10	Mbale Municipal Council	Elgon Primary School	Government
11	Mbale Municipal Council	Yoweri Primary School	Government
12	Mbale Municipal Council	Jalilu Islamic Primary School	Government
13	Mbale Municipal Council	Maluku Primary School	Government
14	Mbale Municipal Council	Convenant Primary School	Government
15	Mbale Municipal Council	Bujoloto Primary School	Government
16	Mbale Municipal Council	Joyce Primary School	Government
17	Mbale Municipal Council	Northroad Primary School	Government
18	Mbale Municipal Council	Islamic University Primary School	Government
19	Mbale Municipal Council	Namakwekwe Primary School	Government
20	Mbale Municipal Council	Buyonjo Primary School	Government
21	Mbale Municipal Council	Wambwa primary School	Government
22	Mbale Municipal Council	Doko Primary School	Government
23	Mbale Municipal Council	Mayor Mbale Primary School	Government
24	Mbale Municipal Council	Wambogo Primary School	Government
25	Mbale Municipal Council	Umar and Yumbe Memorial P/s	Government
26	Mbale Municipal Council	Nabuyonga Primary School	Government
27	Mbale Municipal Council	Zesui Primary School	Government
28	Mbale Municipal Council	Nashibiso Primary School	Government

LIST OF PRIVATE PRIMARY SCHOOLS

NO.	SCHOOL NAME	SCHOOL LEVEL	SCHOOL TYPE
1	Mbale Junior School	Primary	Private
2	Iqra Junior School	Primary	Private
3	Khadija Education Center	Primary	Private
4	king Faisal Muslim	Primary	Private
5	St. Bakhita Child Pirmary School	Primary	Private
6	Impact Primary School	Primary	Private
7	Mensa Junior School	Primary	Private
8	Grace PrimarySchool	Primary	Private
9	Skynet Pirmary School	Primary	Private
10	Alpha Primary School	Primary	Private
11	Taata Kids Primary School	Primary	Private
12	Townside Primary School	Primary	Private
13	Lisa Primary School	Primary	Private
14	Demiro Primary School	Primary	Private
15	Happy Hours Academy	Primary	Private
16	Together for Uganda Chrisco	Primary	Private
17	Mbale Tower Primary School	Primary	Private
18	Nkonkonjeru Primary School	Primary	Private
19	Froebel Primary School	Primary	Private
20	Fountain Public Primary School	Primary	Private
21	supreme primary school	Primary	Private
22	Erisa Primary School	Primary	Private
23	Kings Education Centre	Primary	Private
24	Together For Uganda	Primary	Private
25	Trust Primary School	Primary	Private
26	Maama Kids Education Centre	Primary	Private
27	Bright Parents	Primary	Private
28	Mother Care	Primary	Private
29	Lisa Primary School	Primary	Private
30	Mbale Junior Primary School	Primary	Private
31	Child of Hope Primary School	Primary	Private
32	East Land Primary School	Primary	Private
33	Waheed Primary School	Primary	Private
34	Stepping Stones	Primary	Private
35	St. Mark Primary School	Primary	Private
36	Good Foundation Primary School	Primary	Private
37	Crane Primary School	Primary	Private
38	Aden Primary School	Primary	Private
39	Mensa Primary School	Primary	Private
40	Little Angles Primary School	Primary	Private
41	Good Care Primary School	Primary	Private
42	Winners Primary School	Primary	Private
43	Parental Care Primary School	Primary	Private

LIST OF SECONDARY SCHOOLS

NO.	DISTRCTS	SCHOOL NAME	SCHOOL LEVEL	SCHOOL TYPE
1	Mbale Municipal Council	St. Paul's College Mbale	O-A Level	Private
2	Mbale Municipal Council	Wanale View S.S	O-A Level	Private
3	Mbale Municipal Council	Bugisu H.S	O Level	Private
4	Mbale Municipal Council	Nkoma H.S	O-A Level	Private
5	Mbale Municipal Council	st. Marys S.S	O-A Level	Private
6	Mbale Municipal Council	Mbale H.S	O-A Level	Government
7	Mbale Municipal Council	Nkoma S.S	O-A Level	Government
8	Mbale Municipal Council	Mbale S.S	O-A Level	Government
9	Mbale Municipal Council	Town Side H.S	O-A Level	Private
10	Mbale Municipal Council	Mooni H.S	O-A Level	Private
11	Mbale Municipal Council	Mbale Comprehensive H.S	O-A Level	Private
12	Mbale Municipal Council	Oxford H.S	O-A Level	Private
13	Mbale Municipal Council	University Link H.S	O-A Level	Private
14	Mbale Municipal Council	Maluku S.S	O-A Level	Private
15	Mbale Municipal Council	Manafwa H.S	O-A Level	Private

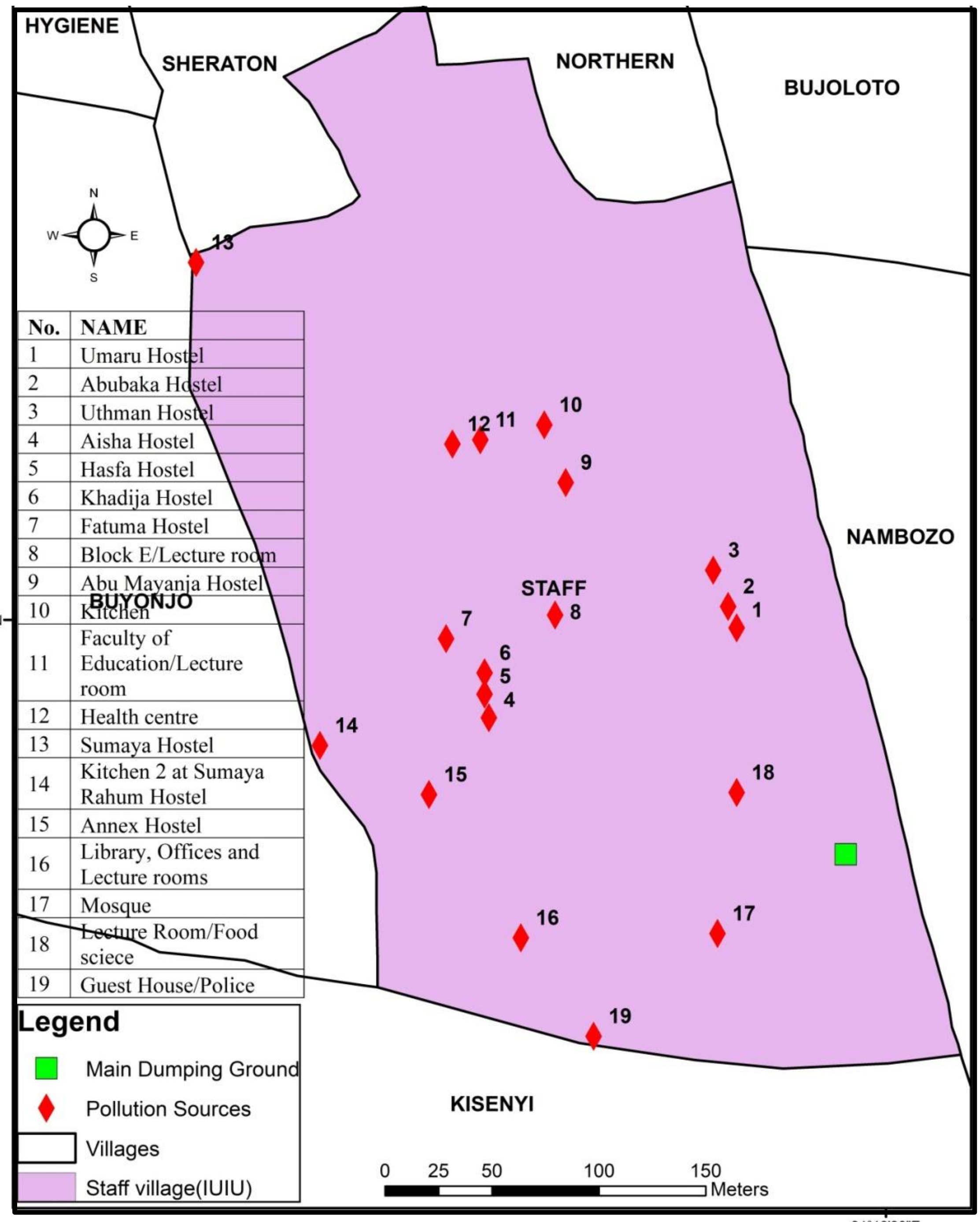
MBALE MUNICIPAL LOCAL GOVERNMENT COUNCIL INSTITUTIONS

NO	NAME OF SCHOOL
1	MBALE MUNICIPALITY COMM. POLYTECHNIC
2	MBALE SCHOOL OF CLINICAL OFFICERS
3	MBALE SCHOOL OF HYGIENE
4	MBALE SCHOOL OF NURSING AND MIDWIFERY

LIST OF UNIVERSITIES

1. Uganda Christian University (UCU)
2. Uganda Martyrs University
3. Islamic University in Uganda (IUIU)
4. Livingstone University
5. Bugema University
6. Koozi University

Appendix B.4; Detailed GIS map for waste generation points at Islamic University in Uganda



Appendix B.5; University Facilities and Population distribution

Facility Name		Description	
Abumayanja Kitchen		On average feeds 500	
Sumaya Kitchen		On average feeds 500	
Food Science Cafeteria		On average feeds 200	
Police Station		10 House quarters	
Guest House		Has 20 rooms	
Sports facility		1 football pitch	
Mosque		Has a sitting capacity 800	
Administration block		Has 20 Offices	
Bank		2 tellers and an ATM	
University Health Centre		100 Out-Patient	
		20 In-Patient	
Category	**Description**	**Type**	**Population**
	Staff	Non-residents	136
		Residents	234
	Students	Non-residents	2,317
		Residents	
Male Hostels	Abumayanja	Non-residents	0
		Residents	526
	Abubakar	Non-residents	0
		Residents	49
	Aisha	Non-residents	0
		Residents	38
	Fahima	Non-residents	0
		Residents	22
	Hafusa	Non-residents	0
		Residents	35
	Khadija	Non-residents	0
		Residents	52
	Umar	Non-residents	0
		Residents	36
	Uthman	Non-residents	0
		Residents	64
Female Hostels	Sumaya	Non-residents	0
		Residents	786
	Rahman	Non-residents	0

Facility Name		Description	
		Residents	258
	Annex	Non-residents	0
		Residents	151
TOTAL	Non-residents		2,453
	Residents		2,251

Appendix B.6; Records of Organic waste collection

WEEK 1, Day 1 (12 Nov 2019)							
Time Interval (hrs)	Volume per physical composition (m³)						
	Plastic bottles	Papers	Food Waste	Fruit waste	Leaves, Grass cuttings and prooning	Food pealings and vegetables	Total
0800 - 1000		0.1361	0.4475	-	0.3599	0.1040	1.0474
1000 - 1200		0.2102	0.1200	0.0257	0.8016	0.0918	1.2494
1200 - 1400		0.1360	-	0.0832	0.3420	0.4170	0.9782
1400 - 1600		0.1253	0.2575	0.0110	0.0430	0.0112	0.4480
1600 - 1800		0.0673	0.6350	0.0150	-	-	0.7173
Total		0.675	1.460	0.135	1.546	0.624	4.440
		Weight					
0800 - 1000		18.159	82.737	-	55.911	57.975	214.782
1000 - 1200		25.380	24.222	3.143	124.548	45.507	222.800
1200 - 1400		16.702	-	10.165	53.137	177.934	257.938
1400 - 1600		14.679	44.945	1.314	6.681	5.622	73.241
1600 - 1800		7.868	113.632	1.714	-	-	123.214
Total		82.788	265.536	16.336	240.277	287.038	**891.974**

WEEK 1, Day 2 (13 Nov 2019)							
Time Interval (hrs)	Volume per physical composition (m³)						
	Plastic bottles	Papers	Food Waste	Fruit waste	Leaves, Grass cuttings and prooning	Food pealings and vegetables	Total
0800 - 1000		0.0418	0.3250	-	0.1658	-	0.5325
1000 - 1200		0.1320	0.0855	0.0430	0.8119	-	1.0724
1200 - 1400		0.0423	-	-	0.0860	0.2120	0.3403
1400 - 1600		0.6484	-	-	-	0.3120	0.9604
1600 - 1800		0.5568	0.3400	0.0350	-	0.4430	1.3748
Total		1.421	0.751	0.078	1.064	0.967	4.280
		Weight					
0800 - 1000		5.943	49.660	-	28.045	-	83.648
1000 - 1200		31.292	14.515	5.259	113.153	-	164.219
1200 - 1400		16.883	-	-	13.362	106.424	136.669
1400 - 1600		77.813	-	-	-	176.045	253.858
1600 - 1800		66.816	51.912	4.186	-	227.501	350.415
Total		198.747	116.087	9.445	154.560	509.970	**988.809**

Week 2, Day 1 (29th Nov 2019)							
Time Interval (hrs)	Volume per physical composition (m³)						
	Plastic bottles	Papers	Food Waste	Fruit waste	Leaves, Grass cuttings and prooning	Food pealings and vegetables	Total
0800 - 1000		0.5400	0.6250	-	0.0138	0.1590	1.3378
1000 - 1200		0.1738	0.2000	0.0675	0.9075	0.7150	2.0638
1200 - 1400		0.1240	-	0.1580	0.2660	0.2260	0.7740
1400 - 1600		0.1450	-	-	0.5320	-	0.6770
1600 -1800		0.1775	0.5000	-	0.1060	0.0485	0.8320
Total		1.160	1.325	0.226	1.825	1.149	5.685
		Weight					
0800 - 1000		78.538	95.500	-	2.114	78.924	255.075
1000 - 1200		23.353	31.538	8.255	126.884	323.001	513.032
1200 - 1400		16.583	-	19.753	45.920	99.834	182.091
1400 - 1600		16.640	-	-	101.107	-	117.747
1600 -1800		21.298	75.432	-	16.469	24.347	137.546
Total		156.412	202.470	28.008	292.495	526.107	**1,205.492**

Week2, Day 2 (30th Nov 2019)							
Time Interval (hrs)	Volume per physical composition (m³)						
	Plastic bottles	Papers	Food Waste	Fruit waste	Leaves, Grass cuttings and prooning	Food pealings and vegetables	Total
0800 - 1000		0.2221	0.7513	-	0.3366	0.0687	1.3787
1000 - 1200		0.3018	0.1169	0.2120	0.4840	1.2327	2.3473
1200 - 1400		0.2300	-	0.1945	0.2043	0.0773	0.7061
1400 - 1600		0.4350	-	0.1050	0.7044	0.0500	1.2944
1600 -1800		0.3284	0.7425	0.0500	0.3774	0.0212	1.5195
Total		1.517	1.611	0.561	2.107	1.450	7.246
		Weight					
0800 - 1000		29.640	114.791	-	58.312	30.930	233.672
1000 - 1200		44.258	17.626	25.928	84.900	543.921	716.633
1200 - 1400		31.307	-	26.713	37.872	43.069	138.961
1400 - 1600		46.823	-	11.869	98.384	30.396	187.473
1600 -1800		39.408	99.726	6.985	58.630	10.642	215.392
Total		191.435	232.143	71.495	338.099	658.958	**1,492.130**

WEEK 3 -Day 1 (4 Feb 2020)							
Time Interval (hrs)	Volume per physical composition (m³)						
	Plastic bottles	Papers	Food Waste	Fruit waste	Leaves, Grass cuttings and prooning	Food pealings and vegetables	Total
0800 - 1000		0.1800	0.4700	0.0375	0.2550	0.1375	1.0800
1000 - 1200		0.3200	-	0.0550	0.6050	0.3925	1.3725
1200 - 1400		-	-	-	-	-	-
1400 - 1600		0.2900	-	0.0125	-	0.0250	0.3275
1600 -1800		0.2900	0.3075	0.0125	-	0.0250	0.6350
Total		1.080	0.778	0.118	0.860	0.580	3.415
		Weight					
0800 - 1000		21.600	71.816	4.586	39.619	82.830	220.452
1000 - 1200		38.400	-	6.390	67.867	197.035	309.692
1200 - 1400		-	-	-	-	-	-
1400 - 1600		34.800	-	1.682	-	12.550	49.032
1600 -1800		34.800	36.931	1.697	-	14.094	87.522
Total		129.600	108.747	14.355	107.487	306.509	**666.697**

WEEK 3 - Day 2 (6 Feb 2020)							
Time Interval (hrs)	Volume per physical composition (m³)						
	Plastic bottles	Papers	Food Waste	Fruit waste	Leaves, Grass cuttings and prooning	Food pealings and vegetables	Total
0800 - 1000		0.1750	0.3550	0.0850	0.2000	0.1250	0.9400
1000 - 1200		0.4375	0.0800	0.1250	0.6375	0.4125	1.6925
1200 - 1400		-	-	-	-	-	-
1400 - 1600		0.2900	0.2600	0.0125	-	0.0250	0.5875
1600 -1800		0.2900	0.2000	0.0125	-	0.0250	0.5275
Total		1.193	0.895	0.235	0.838	0.588	3.748
		Weight					
0800 - 1000		21.000	65.093	8.878	31.074	62.750	188.795
1000 - 1200		52.500	12.224	15.288	85.746	209.374	375.131
1200 - 1400		-	-	-	-	-	-
1400 - 1600		25.056	35.557	1.437	-	13.956	76.005
1600 -1800		23.490	29.215	1.712	-	12.224	66.641
Total		122.046	142.089	27.314	116.820	298.303	**706.572**

WEEK 4, Day 1 (17 Feb 2020)							
Time Interval	Volume per physical composition						
(hrs)	(m^3)						
	Plastic bottles	Papers	Food Waste	Fruit waste	Leaves, Grass cuttings and prooning	Food pealings and vegetables	Total
0800 - 1000		0.1600	0.3400	0.0100	0.3320	0.0210	0.8630
1000 - 1200		0.0200	0.0700	0.0200	0.2150	0.2710	0.5960
1200 - 1400		0.1000	-	0.0132	0.1000	0.0760	0.2892
1400 - 1600		0.0180	0.2600	-	0.3340	0.0110	0.6230
1600 -1800		0.1100	0.2950	0.0210	0.2430	0.0170	0.6860
Total		0.408	0.965	0.064	1.224	0.396	3.057
		Weight					
0800 - 1000		23.251	64.005	1.096	51.583	8.919	148.853
1000 - 1200		2.610	10.696	2.665	44.094	132.641	192.707
1200 - 1400		12.000	-	2.063	18.085	42.391	74.539
1400 - 1600		2.095	44.178	-	58.240	6.687	111.200
1600 -1800		12.184	35.790	2.568	38.978	8.380	97.901
Total		52.140	154.669	8.393	210.980	199.018	**625.200**

Week 4, Day 2 (19 Feb 2020)							
Time Interval (hrs)	Volume per physical composition (m³)						
	Plastic bottles	Papers	Food Waste	Fruit waste	Leaves, Grass cuttings and prooning	Food pealings and vegetables	Total
0800 - 1000		0.1462	0.3550	0.0171	0.1923	0.1821	0.8925
1000 - 1200		0.3552	0.0700	0.0311	0.9551	0.5632	1.9746
1200 - 1400		0.0300	-	0.0106	0.3976	0.4392	0.8774
1400 - 1600		0.3335	0.2600	0.0238	0.0970	0.0336	0.7479
1600 - 1800		0.1901	0.2975	0.0476	0.4350	0.0189	0.9890
Total		1.055	0.983	0.130	2.077	1.237	5.481
		Weight					
0800 - 1000		19.889	71.873	1.828	36.146	100.528	230.265
1000 - 1200		47.355	12.343	3.723	162.899	298.579	524.900
1200 - 1400		3.719	-	1.296	62.362	17.197	84.574
1400 - 1600		40.020	39.728	3.203	15.071	18.541	116.563
1600 - 1800		27.807	44.476	6.526	74.405	9.484	162.699
Total		138.791	168.421	16.577	350.883	444.330	**1,119.001**

	Food waste collection													
	Time Interval (hrs)	Source												Total
		Male hostel								Female	Restaurants			
		Abu - mayanja	Abubakar	Aisha	Fahima	Hafusa	Khadija	Umar	Uthman	Rahman Annex	Abu - mayanja	Sumaya	Food Science	
		526	49	38	22	35	52	36	64	151	500	500	200	
week 1 - day 1	0800 - 1000	0.07	0.005	0.01	0.005	0.005	0.0075	0.0125	0.0125	0.0575				0.4475
	1000 - 1200										0.05	0.05	0.02	0.12
	1200 - 1400													0
	1400 - 1600										0.1375	0.1	0.02	0.2575
	1600 - 1800	0.1	0.02	0.015	0	0.0125	0.025	0.025	0.025	0.0875				0.635
	Total	0.17	0.025	0.025	0.005	0.0175	0.0325	0.0375	0.0375	0.145	0.1875	0.15	0.04	1.46

	Food waste collection													
	Time Interval (hrs)	**Source**												**Total**
		Male hostel								**Female**	**Restaurants**			
		Abu - mayanja	**Abubakar**	**Aisha**	**Fahima**	**Hafusa**	**Khadija**	**Umar**	**Uthman**	**Rahman Annex**	**Abu - mayanja**	**Sumaya**	**Food Science**	
		526	49	38	22	35	52	36	64	151	500	500	200	
week 1 - day 2	0800 - 1000	0.05	0.0125	0.0125	0	0	0.00625	0	0.00625	0.0375				0.325
	1000 - 1200										0.02	0.0375	0.028	0.0855
	1200 - 1400													0
	1400 - 1600													0
	1600 - 1800	0.0375	0.00625	0.005	0.005	0.005	0.005	0.005	0.00625	0.015	0.1	0.05	0.01	0.34
	Total	0.0875	0.01875	0.0175	0.005	0.005	0.01125	0.005	0.0125	0.0525	0.12	0.0875	0.038	0.7505

	Food waste collection													
	Time Interval (hrs)	Source												Total
		Male hostel								Female	Restaurants			
		Abu - mayanja	Abubakar	Aisha	Fahima	Hafusa	Khadija	Umar	Uthman	Sumaya	Abu - mayanja	Sumaya	Food Science	
		526	49	38	22	35	52	36	64	786	500	500	200	
week 2 - day 1	0800 - 1000	0.085	0.01	0.0075	0.0075	0.0075	0.0075	0.01	0.02	0.3				0.625
	1000 - 1200										0.0875	0.0625	0.05	0.2
	1200 - 1400													0
	1400 - 1600													0
	1600 - 1800	0.07	0.02	0.02	0.01	0.01	0.02	0.01	0.02	0.05	0.1	0.05	0.05	0.5
	Total	0.155	0.03	0.0275	0.0175	0.0175	0.0275	0.02	0.04	0.35	0.1875	0.1125	0.1	1.325

	Food waste collection													
	Time Interval (hrs)	**Source**												**Total**
		Male hostel								**Female**	**Restaurants**			
		Abu - mayanja	**Abubakar**	**Aisha**	**Fahima**	**Hafusa**	**Khadija**	**Umar**	**Uthman**	**Sumaya**	**Abu - mayanja**	**Sumaya**	**Food Science**	
		526	49	38	22	35	52	36	64	786	500	500	200	
week 2 - day 2	0800 - 1000	0.06375	0.0075	0.0075	0.0075	0.0075	0.0075	0.01	0.02	0.45				0.75125
	1000 - 1200										0.065625	0.03125	0.02	0.116875
	1200 - 1400													0
	1400 - 1600													0
	1600 - 1800	0.035	0.015	0.01	0.01	0.01	0.01	0.01	0.02	0.1125	0.2	0.15	0.05	0.7425
	Total	0.09875	0.0225	0.0175	0.0175	0.0175	0.0175	0.02	0.04	0.5625	0.265625	0.18125	0.07	1.610625

	Food waste collection													
	Time Interval (hrs)	Source												Total
		Male hostel							Female hostel		Restaurants			
		Abu - mayanja	Abubakar	Aisha	Fahima	Hafusa	Khadija	Umar	Rahman	Rahman Annex	Abu - mayanja	Sumaya	Food Science	
		526	49	38	22	35	52	36	258	151	500	500	200	
week 3 - day 1	0800 - 1000	0.05	0.01	0.01	0.01	0.01	0.01	0.02	0.05	0.05	0.02	0.01	0	0.47
	1000 - 1200													0
	1200 - 1400													0
	1400 - 1600													0
	1600 - 1800	0.02	0.00625	0.005	0.005	0.005	0.005	0.005	0.02	0.01	0.1	0.05	0.02	0.3075
	Total	0.07	0.01625	0.015	0.015	0.015	0.015	0.025	0.07	0.06	0.12	0.06	0.02	0.7775

	Food waste collection													
	Time Interval (hrs)	**Source**												**Total**
		Male hostel							**Female hostel**		**Restaurants**			
		Abu - mayanja	**Abubakar**	**Aisha**	**Fahima**	**Hafusa**	**Khadija**	**Umar**	**Rahman**	**Rahman Annex**	**Abu - mayanja**	**Sumaya**	**Food Science**	
		526	49	38	22	35	52	36	258	151	500	500	200	
week 3 - day 2	0800 - 1000	0.05	0.02	0.01	0.01	0.01	0.02	0.02	0.05	0.02				0.355
	1000 - 1200										0.02	0.05	0.01	0.08
	1200 - 1400													0
	1400 - 1600										0.15	0.1	0.01	0.26
	1600 - 1800	0.05	0.01	0	0	0	0.01	0	0.05	0.02				0.2
	Total	0.1	0.03	0.01	0.01	0.01	0.03	0.02	0.1	0.04	0.17	0.15	0.02	0.895

	Food waste collection													
	Time Interval (hrs)	Source												Total
		Male hostel								Female	Restaurants			
		Abu - mayanja	Abubakar	Aisha	Fahima	Hafusa	Khadija	Umar	Uthman	Rahman Annex	Abu - mayanja	Sumaya	Food Science	
		526	49	38	22	35	52	36	64	151	500	500	200	
week 4 - day 1	0800 - 1000	0.05	0.01	0.01	0.01	0.01	0.02	0.015	0.02	0.02				0.34
	1000 - 1200										0.01	0.05	0.01	0.07
	1200 - 1400													0
	1400 - 1600										0.15	0.1	0.01	0.26
	1600 - 1800	0.05	0.005	0	0	0	0	0	0.015	0.05				0.295
	Total	0.1	0.015	0.01	0.01	0.01	0.02	0.015	0.035	0.07	0.16	0.15	0.02	0.965

	Food waste collection													
	Time Interval (hrs)	Source												Total
		Male hostel								Female	Restaurants			
		Abu - mayanja	Abubakar	Aisha	Fahima	Hafusa	Khadija	Umar	Uthman	Rahman Annex	Abu - mayanja	Sumaya	Food Science	
		526	49	38	22	35	52	36	64	151	500	500	200	
week 4 - day 2	0800 - 1000	0.05	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02				0.355
	1000 - 1200										0.01	0.05	0.01	0.07
	1200 - 1400													0
	1400 - 1600										0.15	0.1	0.01	0.26
	1600 - 1800	0.0625	0	0	0	0	0	0	0.01	0.05				0.2975
	Total	0.1125	0.02	0.01	0.01	0.01	0.02	0.02	0.03	0.07	0.16	0.15	0.02	0.9825

Volume of organic Waste Generation per selected Days

	Tue	Wed	Fri	Sat	Tue	Thu	Wed	Mon
Date	**12-Nov**	**13-Nov**	**29-Nov**	**30-Nov**	**4-Feb**	**6-Feb**	**17-Feb**	**19-Feb**
Date	**Wk1-D1**	**Wk1-D2**	**Wk2-D1**	**Wk2-D2**	**Wk3 - D1**	**Wk3-D2**	**Wk4-D1**	**Wk4-D2**
Volume (M^3)	4.440	4.280	5.685	7.246	3.415	3.748	3.057	5.481
Weight (Kgs)	892	989	1,205	1,492	667	707	625	1,119

Weight of organic Waste Generation per day

Date	**12-Nov**	**13-Nov**	**29-Nov**	**30-Nov**	**4-Feb**	**6-Feb**	**17-Feb**	**19-Feb**
	Wk1-D1	**Wk1-D2**	**Wk2-D1**	**Wk2-D2**	**Wk3 - D1**	**Wk3-D2**	**Wk4-D1**	**Wk4-D2**
Weight (Kgs)	892	989	1,205	1,492	667	707	625	1,119

Volume of organic Waste Generation per Day

Date	**12-Nov**	**13-Nov**	**29-Nov**	**30-Nov**	**4-Feb**	**6-Feb**	**17-Feb**	**19-Feb**
	Wk1-D1	**Wk1-D2**	**Wk2-D1**	**Wk2-D2**	**Wk3 - D1**	**Wk3-D2**	**Wk4-D1**	**Wk4-D2**
Volume (M^3)	4.440	4.280	5.685	7.246	3.415	3.748	3.057	5.481

Trend of daily waste collection in kgs

Date	**12-Nov**	**13-Nov**	**29-Nov**	**30-Nov**	**4-Feb**	**6-Feb**	**17-Feb**	**19-Feb**
	Wk1-D1	**Wk1-D2**	**Wk2-D1**	**Wk2-D2**	**Wk3 - D1**	**Wk3-D2**	**Wk4-D1**	**Wk4-D2**
0800 - 1000	214.782	83.648	255.075	233.672	220.452	188.795	148.853	230.265
1000 - 1200	222.800	164.219	513.032	716.633	309.692	375.131	192.707	524.900
1200 - 1400	257.938	136.669	182.091	138.961	-	-	74.539	84.574
1400 - 1600	73.241	253.858	117.747	187.473	49.032	76.005	111.200	116.563
1600 -1800	123.214	350.415	137.546	215.392	87.522	66.641	97.901	162.699
Total	891.974	988.809	1,205.492	1,492.130	666.697	706.572	625.200	1,119.001

Trend of daily waste collection in m^3

Date	**12-Nov**	**13-Nov**	**29-Nov**	**30-Nov**	**4-Feb**	**6-Feb**	**17-Feb**	**19-Feb**
	Wk1-D1	**Wk1-D2**	**Wk2-D1**	**Wk2-D2**	**Wk3 - D1**	**Wk3-D2**	**Wk4-D1**	**Wk4-D2**
0800 - 1000	1.047	0.533	1.338	1.379	1.080	0.940	0.863	0.893
1000 - 1200	1.249	1.072	2.064	2.347	1.373	1.693	0.596	1.975
1200 - 1400	0.978	0.340	0.774	0.706	-	-	0.289	0.877
1400 - 1600	0.448	0.960	0.677	1.294	0.328	0.588	0.623	0.748
1600 -1800	0.717	1.375	0.832	1.519	0.635	0.528	0.686	0.989
Total	4.440	4.280	5.685	7.246	3.415	3.748	3.057	5.481

	Daily Organic waste composition in m³							
Date	**12-Nov**	**13-Nov**	**29-Nov**	**30-Nov**	**4-Feb**	**6-Feb**	**17-Feb**	**19-Feb**
	Wk1-D1	**Wk1-D2**	**Wk2-D1**	**Wk2-D2**	**Wk3 - D1**	**Wk3-D2**	**Wk4-D1**	**Wk4-D2**
Papers	0.675	1.421	1.160	1.517	1.080	1.193	0.408	1.055
Food Waste	1.460	0.751	1.325	1.611	0.778	0.895	0.965	0.983
Fruit waste	0.135	0.078	0.226	0.561	0.118	0.235	0.064	0.130
Leaves, Grass cuttings and prooning	1.546	1.064	1.825	2.107	0.860	0.838	1.224	2.077
Food pealings and vegetables	0.624	0.967	1.149	1.450	0.580	0.588	0.396	1.237

	Daily Organic waste composition in Kgs							
Date	**12-Nov**	**13-Nov**	**29-Nov**	**30-Nov**	**4-Feb**	**6-Feb**	**17-Feb**	**19-Feb**
	Wk1-D1	**Wk1-D2**	**Wk2-D1**	**Wk2-D2**	**Wk3 - D1**	**Wk3-D2**	**Wk4-D1**	**Wk4-D2**
Papers	82.788	198.747	156.412	191.435	129.600	122.046	52.140	138.791
Food Waste	265.536	116.087	202.470	232.143	108.747	142.089	154.669	168.421
Fruit waste	16.336	9.445	28.008	71.495	14.355	27.314	8.393	16.577
Leaves, Grass cuttings and prooning	240.277	154.560	292.495	338.099	107.487	116.820	210.980	350.883
Food pealings and vegetables	287.038	509.970	526.107	658.958	306.509	298.303	199.018	444.330

Appendix B.7; Daily biogas production in mm

		Time (Days)																		
Biogas /mm	Setups	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	1	0	0	15	15	17	22	25	19	14	8	3	1	0	0	0	0	0	0	0
	2	0	0	0	0	10	5	10	13	11	7	2	0	0	0	0	0	0	0	0
	3	21	27	35	65	68	68	70	75	63	50	33	29	23	17	12	5	0	0	0
	4	0	0	0	0	5	15	12	6	3	0	0	0	0	0	0	0	0	0	0
	5	32	45	51	53	61	65	68	71	77	75	69	62	40	31	27	20	17	9	3
	6	11	37	21	45	53	58	63	23	17	12	7	3	0	0	0	0	0	0	0
	7	5	10	24	35	37	43	47	56	52	46	39	22	15	7	3	0	0	0	0
	8	0	0	0	0	0	15	23	29	10	3	0	0	0	0	0	0	0	0	0

Appendix B.8; Daily biogas production in mL

		Time (Days)																			Total
Biogas (mL)	Setups	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
	1	-	-	65.2	100.0	143.5	168.2	181.7	131.0	106.6	63.7	24.0	8.0	-	-	-	-	-	-	-	992.0
	2	-	-	-	-	43.5	21.7	56.5	108.7	94.6	62.0	13.0	-	-	-	-	-	-	-	-	400.0
	3	91.3	225.4	266.1	481.2	573.5	476.9	476.9	476.9	438.5	354.4	257.1	246.0	192.0	141.2	97.8	38.5	-	-	-	4,833.7
	4	-	-	-	-	21.7	65.2	95.7	47.8	26.1	-	-	-	-	-	-	-	-	-	-	256.5
	5	182.6	358.8	358.6	447.8	490.1	453.8	490.2	593.5	541.4	558.6	579.2	430.8	283.5	229.7	228.7	166.4	140.9	74.2	25.0	6,633.8
	6	47.8	268.8	167.9	315.4	432.0	479.5	438.5	165.0	118.0	86.0	51.9	22.2	-	-	-	-	-	-	-	2,593.0
	7	21.7	43.5	73.9	381.6	257.9	339.6	394.3	414.2	350.0	336.2	289.8	187.6	124.4	59.8	26.1	-	-	-	-	3,300.6
	8	-	-	-	-	-	65.2	165.2	238.8	72.1	20.7	-	-	-	-	-	-	-	-	-	562.1

Appendix B.9; Daily Cumulative biogas in mm

		Time (Days)																		
Cumulative Biogas readings (mm)	Setups	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	1	0	0	15	30	47	69	94	113	127	135	138	139	139	139	139				
	2	0	0	0	0	10	15	25	38	49	56	58	58	58	58	58	58	58	58	58
	3	21	48	83	148	216	284	354	429	492	542	575	604	627	644	656	661	661	661	661
	4	0	0	0	0	5	20	32	38	41	41	41	41	41	41	41	41	41	41	41
	5	32	77	128	181	242	307	375	446	523	598	667	729	769	800	827	847	864	873	876
	6	11	48	69	114	167	225	288	311	328	340	347	350	350	350	350	350	350	350	350
	7	5	15	39	74	111	154	201	257	309	355	394	416	431	438	441	441	441	441	441
	8	0	0	0	0	0	15	38	67	77	80	80	80	80	80	80	80	80	80	80

Appendix B.10; Daily Cumulative biogas in mL

		Time (Days)																		
Cumulative Biogas (mL)	Setups	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	1	0.0	0.0	65.2	165.2	308.7	476.9	658.6	789.7	896.3	960.0	984.0	992.0	992.0						
	2	0.0	0.0	0.0	0.0	43.5	65.2	121.7	230.4	325.0	387.0	400.0	400.0							
	3	91.3	316.7	582.8	1064.0	1637.5	2114.4	2591.3	3068.3	3506.7	3861.1	4118.3	4364.3	4556.3	4697.4	4795.2	4833.7	4833.7		
	4	0.0	0.0	0.0	0.0	21.7	87.0	182.6	230.4	256.5	256.5									
	5	182.6	541.4	900.0	1,347.8	1,837.9	2,291.8	2,781.9	3,375.4	3,916.8	4,475.4	5,054.6	5,485.4	5,768.9	5,998.6	6,227.3	6,393.7	6,534.6	6,608.8	6,633.8
	6	47.8	316.7	484.6	800.0	1232.0	1711.5	2150.0	2315.0	2433.0	2518.9	2570.8	2593.0	2593.0						
	7	21.7	65.2	139.1	520.7	778.6	1118.2	1512.5	1926.7	2276.7	2612.9	2902.7	3090.3	3214.7	3274.5	3300.6				
	8	-					65.2	230.4	469.2	541.4	562.1	562.1								