Innovative Approach to Solid Waste Management in Lead City University, Ibadan: Adaptive Landfill Technology

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Certification

This is to certify that **John Adedayo OLANREWAJU** with matriculation number LCU/PG/001960 carried out this research work titled **"Innovative Approach to Solid Waste Management in Lead City University, Ibadan: Adaptive Landfill Technology'** in the Department of Public Health, Faculty of Basic Medical and Health Sciences, Lead City University, Ibadan, Oyo State, for the award of **Doctor of Philosophy Degree (PhD) in Public Health (Occupational and Environmental Health)** and that this has not been previously submitted.

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Dedication

To the Glory of Almighty God, my wife; Olanrewaju Deborah Olufunke and my lovely children;

Olanrewaju Janet Olamide, Olanrewaju James Olaoluwa and Olanrewaju Juliet Olamidun

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"Even though the above mentioned institutions and persons have assisted in the completion of this research work, I alone stand responsible for the errors, if any found in the work"

Abstract

Solid waste management (SWM) is one of the most challenging issues faced by institutions that suffer from serious pollution problems caused by the generation of large waste quantities as a results of student's explosion. Reliable national data on waste generation and composition that will inform effective planning on waste management in Lead City University, Ibadan is absent. To help obtain this data on an institutional basis, selected source of waste generations in the university were recruited to obtain data on rate of waste generation, quantification, sorting and separation efficiency and per capita of waste. Therefore, the study's title, "Innovative approach to solid waste management in Lead City University, Ibadan: Adaptive Sanitary Landfill Technology," focused on the management of solid waste in the University. A pilot source sorting and separation was conducted at the selected twenty-seven (27) hostels being the sources of waste generation in the Lead City University, Ibadan from November 2022 to April, 2023 for collection of data on composition, generation rate and compliance level of separation of the waste. Also, experimental methods were utilized to measure the amount of Liquefied Gases (LFG) concentrations generated using the handheld Sewerin Multitec 540. Results shown that majority of the lecturers (19.79%) agreed that Open dump system practices in Lead City University, Ibadan have positive environmental impacts while majority of the students (31.25%) agreed that the best way to tackle waste problem is sorting from generation before collection and disposal. Total numbers of students living in Lead City University hostel (LCU) were 3,892 out of 13,647, of which 9,755 stayed off campus. The overall student population of Lead City University at the time of this project work is 13,647. Independence Champion and Wisdom Hall with total number of students of 548 have the highest number of waste generation per week of 677.50kg while Maintenance Hall with total number of students of 27 have the least number of waste generation per week of 68.30kg. Also, out of the five components of waste, food ruminants have highest waste generation of 1,967.70kg in all the twenty-seven (27) halls of residences in the university and Papers have the least waste generation of 961.00kg in all the twenty-seven (27) halls of residence in the university. The research also revealed that certain amount of Liquefied Gases (LFG) concentrations were measured in the morning and afternoon, addition of activated charcoal made the amount of methane (CH4) gases (LFG) increased by removing impurities such as Hydrogen Sulphide (H_2S) and Carbon Dioxide (CO_2) and finally, the amount of liquefied gases (LFG) generated after the addition of animal manures was higher compared to when not added. Correction results shown that the interactions are statistically significant. Conclusively, the research project aims to strengthen the inclusive waste management structural model and serve as a planning tool for establishing a cohesive, financially secure, environmental friendly, and socially inclusive university environment through sustainable waste management by constructing an indigenous adaptive sanitary landfill at LCU, Ibadan.

Keywords: Solid waste management (SWM), Adaptive Sanitary Landfill and University

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Table of Contents

Contents **Page**

Chapter Four: Results and Discussion of Findings

List of Tables

List of Figures

List of Plates

List of Acronyms

Abbreviation	Meaning
MSW	Municipal solid waste
LFG	Landfill gases
VOC	Volatile organic compound
FC	Fixed carbon
FLW	Food loss and waste
LCU	Lead City University, Ibadan

Chapter One

Introduction

1.1 Background to the Study

Waste is a natural by-product of societal trends as life and population increase. After its first use, it happens to be unwelcome or unimportant material that can be gotten rid of or thrown away. Animals excrete, plants shed their leaves. Every day, people produce an infinite amount of wastes that are released in many varieties. Development of any country requires industrialization. It results in increased production, consumption, and demand for a range of items that improve living conditions and habitat with resultant increase in waste output in a variety of ways, many of which have a major negative impact on the environment. Rapid growing populations, economic growth and rise in community living standards have accelerated the generation rate of municipal solid waste (MSW) causing its management to be a major worldwide challenge[1]. People with disabilities are more vulnerable to danger from improper trash treatment. Waste is frequently seen as a threat when suitable disposal and management systems are lacking. It not only degrades the beauty of living places but also contributes to pollution and poses a serious threat to the health and existence of all living things. Any country's ability to develop and maintain its citizens' health depends in large part on how effectively trash is managed[1]. Nowadays, efficient waste management is a national concern. therefore, government, non-governmental stakeholders as well non-governmental organization need to make every citizen aware, especially the young, and a collaborator in fostering a clean society nation[1].

As provided in Agenda 21, basic sanitation would be inaccessible to 2 billion people, and globally, half of the people would be without proper municipal solid waste management (MSWM) services[2]. Financial inefficiency in providing urban services, including solid waste management, has stressed the in-hand resources and deterioration in service quality[3]. Waste received at waste dumps, landfills and incinerators characterize the potential for recycling.

Inorganic waste items are recycled because of growing demand but require a mechanism for their sale at competitive prices. Institutional-level recycling arrangements could take considerable quantities of waste out of the disposal system. The mixed waste storage challenge of material recovery and waste recycling directly impacts the quality and quantity of the product and the success of material recovery. This research paper will deliberate on existing practices of waste recycling, the potential of material recovery, and suggest measures for maximizing resource generation and waste reduction using waste recycling options. Present waste disposal options like open dumping and landfill sites have become a persistent apprehension to solve. Management of mounting quantities of MW spawned by the changing lifestyle is bestowing a challenge. The issue is how to deal with the waste quantities without changing the lifestyle. Spawned by public pressure, limited land dump development options, and changed local authorities' attitudes, it requires new initiatives. Preventing pollution is a key goal of EU waste management plans, waste generation and moderate its malice. The option of safe and secure waste disposal should be exercised when alternates like waste reuse, recycling, and waste recovery cannot be used. Researchers have viewed that the waste management approach needs to reduce waste quantities received at landfills and maximum material recovery to the possible extent[4,5] It has been observed that "waste reduction is the most efficient method for minimizing the generation of waste and defecating many of the waste disposal problems[6]."

In both emerging and advanced cultures, the process of gathering, managing, and treating solid waste before disposal has become essential. But through time, the majority of garbage has grown to be seen as being of inferior value and capable of being recovered and repurposed for valuable things. But the price of building a sanitary landfill facility (SLF) have been a major barrier for its implementation, and these technologies also require considerable technical expertise, which is not often available in developing nations for the successful operation of the SLFs[7].

There was massive increase in the population of students, lecturers and others workers in the Lead City University Ibadan as a result population explosion in Nigeria and also recent strike action embarked upon by Nigerian universities. These lead to more wastes being generated in the university and causes more environmental risks and issues for public health. Thus, waste management systems present a significant challenge to university management. The financial difficulties it throws on public and private universities are more significant. As a result, the volume of waste produced and the difficulty of waste management both increase as towns and cities around the world develop and their populations rise. Perhaps the United Nations' (UN) Millennium Declaration (September 2000) attention to this issue best captures the seriousness of the issue. The declaration's eight Millennium Development Goals (MDGs) include three that having to do with waste management or resource efficiency[6]:

i. Reverse the loss of environmental resources and ensure environmental sustainability by incorporating sustainable development ideas into national policies and programs,

ii. By decreasing the percentage of people whose income is less than $1 per day between 1990 and 2015, eradicate extreme poverty and hunger.

iii. Create a global partnership for development by addressing the unique requirements of landlocked nations, small island developing states, and least developed nations.

In response to the problem of waste in Lead City University Ibadan, recycling station for PET Bottles (Polyethylene terephthalate) was launched on campus in 2012. This serves as a symbol of the dedication to environmental sustainability. Reduce, reuse, and recycle are the three R's of waste management and environmental sustainability. In the university, there is a model of a PET bottle that serves as a recycle bin.

In many ways Lead City University, Ibadan is currently facing waste management problems because of its population that is on increase, over a million. Hospital wastes in Lead City University comprise 20% (hazardous or risky) and the remaining 80% of it is household waste components, often known as non-risk waste. It becomes absolutely necessary for waste characterization by finding out how much paper, glass, food waste, etc. is discarded in the waste stream within Lead City University in order to generate data information in planning how to reduce waste, set up recycling programs, and conserve money and resources. In the Municipal Solid Waste (MSW), this stream of waste has various components like organic waste, plastics, metal cans, paper, cardboard, glass, inert materials etc., Some of the constituents in this waste can be recycled, while some can be reduced and used and some others have to be only disposed. As a result, it should be handled and disposed of in a way that minimizes cross-contamination and potential human exposure. Hospital risk waste at Lead City University is broken down into the following seven broad categories: (i) radioactive waste (ii) sharp objects (Needles & Syringes) (iii) infectious (iv) anatomical/pathological (v) chemical (vi) pharmaceutical and (vii) pressured containers. These waste types are produced by university hospital. Therefore, this research is a case study of waste management in Lead City University using adaptive sanitary landfill of waste management.

1.2 Statement of the Problem

Although urban expansion in Africa, and Nigeria in particular, has provided the people with important benefits including employment and economic prosperity, it has also led to environmental issues. An increase in resource use and significant daily wastes production from numerous urban centers go hand in hand with a rise in quality of life. Governments, local councils, and other organizations are unable to handle the huge volumes of wastes (liquid, solid and gaseous) with associated costs. Domestic waste disposal and burning place a heavy burden on the environment, potentially contaminating groundwater supplies, polluting adjacent surface waters with organic and inorganic trash, and contributing to global warming through the release of carbon dioxide from landfills and incineration facilities. Continuous economic expansion, urbanization, and industrialization have led to a rapid rise in the volume and variety of solid waste, which has made it difficult for national and municipal governments to assure efficient and sustainable waste management. It also predicts a 37.3% increase in global municipal garbage generation between 2007 and 2011, or an increase of about 8% per year. Both organizational readiness to tackle the task of successful disposal and serious worries regarding the range of new materials that enter waste streams demonstrate this. In most urban and rural communities in developing nations, particularly in Nigeria, the problem of solid waste manifests itself in air pollution from open burning of wastes, water pollution from depositing solid waste in streams, and soil contamination. Due to the threats to the environment and the implications for public health that come with waste, the non-sustainable management of municipal solid waste is a significant challenge to Lead City University. The financial burdens of hiring a waste consultant to handle the waste management system throws on university management are more significant. Therefore, when the population and the number of students and staff at the institution rise, more waste is produced, which makes controlling it more difficult.

There are waste piles in every open area of several Nigerian urban regions that are still developing, like Lead City University in Ibadan. Because there is no appropriate or efficient means for students to dispose of their solid waste, there is a significant litter problem. A collection system to remove waste from university hostels or easy collection points is lacking at many universities, and the dense student population of this campus prevents students from burying rubbish on their arena. Even when a collection system exists, it frequently falls short.

The palmer Development Group 1993 identifies some common problems: Too few collections per week, inadequate on-site storage and irregular services.

The amount of collection services offered in the majority of Nigeria's emerging metropolitan areas is not generally known, but it is obvious that many of these locations have inefficient collection services. Concern should be raised about the lack of space for proper waste management and disposal, the lack of technology for waste collection, transportation, and processing for useful purposes, and the council's financial limitations in dealing with the ever increasing volume of waste produced from various sources. Waste management is inefficient and ineffective in Lead City University, Ibadan, poor collection coverage, irregular collection, accumulation of rubbish (junk piles), and burning without management of air and water pollution are the results. There is a need to identify common barriers impeding efficient solid waste management throughout Nigeria's towns and cities, and Lead City University in particular, despite the fact that waste management conditions are somewhat different across the nation.

In order to enhance effective management of waste in Lead City University, Ibadan, the management introduced the recycling station (PET Bottle which stands for polyethylene terephthalate) in 2021 which is a representation of the dedication to environmental sustainability. Reduce, Reuse, and Recycle are the three R's of the 3Rs waste management and environmental sustainability paradigm. It is necessary to find ways to turn waste into wealth, and that was the technology behind the introduction of an adaptive sanitary landfill in Lead City University. The adaptive sanitary landfill was introduced in an effort to support the university management's efforts to combat environmental hazards associated with poor waste management.

1.3 Justifications of the Study

Wastes are an expanding concern that have recently attracted more political attention. The management of Lead City University in Ibadan is presently concentrating on strategies to address the problems presented by institutional solid waste management because waste generation at the university is rapidly rising due to the continuous influx of students to private universities that necessitated rapid growth or high rates of student population, which has resulted in massive waste generation. The persistent problems of these waste management crisis in Lead City University, Ibadan; make it mandatory to evaluate the most affordable, environmental friendly waste management choices for Lead City University.

For healthy ecosystems and human health, waste generation, disposal, collection, transport, and processing are crucial. There is a lot of material on the detrimental consequences of waste management on health. Cancer and congenital abnormalities are the two main health outcomes that have been demonstrated to be statistically related with trash exposure[4]. Due to the presence of solid waste dumping sites near hostels on the campus's periphery, flies, mosquitoes, and rodents which act as disease-carrying vectors and compromise the population's health because their organic defenses are still developing and become a source of infections for the students. The university management has not yet calculated the Lead City disposal site, which is not exceptional. However, because of growing populations, a booming economy, and higher living standards in the academic community, the rate of solid waste produced in the university and its surrounds has dramatically increased. If we don't act quickly to improve sanitation and solid waste management through development of adaptive sanitary landfill waste management system in Lead City University, Ibadan, the growing student population levels and rapid urbanization of the university community may further exacerbate the major urban environmental concerns of municipal waste management, sanitation, and associated detrimental health impacts. Therefore, to sustain solid waste or environmental issues in developing countries, formal education for sustainable development is essential at all levels of education, able to trigger a whole societal transformation. For better environmental sustainability or waste management sustainability education, lecturers with the right knowledge, attitude, skills, and innovation, are required. Accordingly, this study will review how formal environmental education in institutions can help sustain solid waste management (SWM) toward cleaner production (CP) in low/middle-income countries. As far as it is known, no similar systematic review has been made in this field, in the context of developing countries. A result from a search in the ScienceDirect database (2000–2020) reveals that 391 review papers have been produced in this area. However, none of these studies have associated the formal education and SWM practices in developing countries. Thus, it is expected that this review can complement the determination of decision-makers and solid waste management providers that aim to improve management system schemes in Nigeria universities. Furthermore, this review aims to contribute to determining which factors need to be investigated further in future research in SWM, which are created in Nigeria universities.

1.4 Aim and Objectives of the Study

The research was aimed at developing a sustainable and effective institutional waste management system for Lead City University, Ibadan.

Specific Objectives

The specific objectives of the study were to;

i. determine socio-demographic distribution of the respondents.

ii. characterize and quantify wastes from specific sources within Lead City University

iii. carry out a proximate analysis of the organic institutional solid waste in the Lead City University

iv. design and construct an adaptive indigenous landfill for the management of institutional biodegradable organic wastes in Lead City University.

v. evaluate the biogas generation from adaptive indigenous landfill in Lead City University, Ibadan

1.5 Research Questions

The following questions were answered by this research:

1.What are the types and quantities of wastes generated in Lead City University?

2.What is the efficiency of the adaptive indigenous landfill in generating biogas from the wastes?

3.Is the technique environment friendly for solid waste management in the institution?

1.6 Significance of the Study

Wastes are an expanding concern that have recently attracted more political attention. The management of Lead City University in Ibadan is presently concentrating on strategies to address the problems presented by municipal institutional solid waste management because waste generation at the university is rapidly rising, due to continuous influx of students to private colleges, there has been a need for rapid growth or high rates of student population with resultant increase in massive waste generation

It is anticipated that the conclusions will help Lead City University management make deft waste management choices for the good of their communities. The study will highlight the involvement of many stakeholders and the degree to which they may be active in solving the problem, raising awareness that will strengthen initiatives to eliminate it. Without excluding national, small, and medium-sized businesses engaged in waste management, this dissertation is equally pertinent to international organizations with solid financial and technological backgrounds. This knowledge will assist communities in identifying specific sources of income, reducing waste and helping to achieve the Millennium Development Goals (MDG).

1.7 Scope of the Study

Due to this waste management issue at Lead City University, it has become crucial to evaluate the most affordable, environment friendly waste management choices for Lead City University.

1.8 Limitations of the Study

Pausity of fund was a major limitation as there is no funding for the research work. Moreover, encumbrances such as allocation of land for adaptive sanitary landfill, collection and sorting of organic wastes and short timeframe for the research were encountered on the field.

1.9 Operational Definition of Terms

Effective solid waste management: Waste management that intended to reduce the adverse effects of waste on human health, the environment, planetary resources and aesthetics.

Environmental sanitation: This can be described as a ways and manner through which waste can be manage in environment without having adverse effects on the environment.

Open dump site: This is the open space designated for the dispose of waste in a particular community

Adaptive Sanitary Landfill: Adaptive landfills are disposal locations created using engineering concept that guarantee waste control and surface water avoidance through the placement of well-designed and well-constructed surface drainage.

Lead City University, Ibadan: A non-profit private school of higher learning, Lead City University was founded in the urban area of the city of Ibadan (population range: 1,000,000–5,000,000). established in 2005.

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Chapter Two

Literature Review

2.1 Conceptual Review

Waste generation rates are increasing globally. The cities in the world produced 2.01 billion tons of solid trash in 2016, or 0.74 kilos per person each day. The annual trash generation is anticipated to rise by 70% from 2016 levels to 3.40 billion tons in 2050 due to growing urbanization and population growth.

Residents of developing countries, particularly the urban poor, are more negatively impacted by unsustainable garbage management than citizens of developed countries. Over 90% of rubbish is frequently dumped in uncontrolled dumps or burned outdoors in low-income countries. These actions have negative effects on the environment, public safety, and health. A breeding place for disease-carrying organisms, poorly handled garbage produces methane, which fuels climate change, and can even encourage. For the construction of sustainable and habitable communities, waste management is crucial, yet it is still difficult in many developing nations and cities. The cost of efficient garbage management typically accounts for 20% to 50% of municipal budgets. In order to operate this crucial municipal function, integrated systems that are effective, sustainable, and socially responsible are needed[1].

Until recently, most peoples don't pay close attention to the waste their company generates. Many groups are happy to create a system for collecting trash. Waste management is receiving more and more attention, and proactive firms are seeing the advantages of creating a waste reduction program, because of the following advantages;

- Save Money - Recycling more can save disposal expenses and boost your revenue.
- Knowledge is power - By being aware of the quantity and kind of the wastes your company generates, you'll be in a better position to find solutions to save hauling expenses and bargain for waste and recycling services that truly meet your requirements.
- Sharing and reporting information with stakeholders is made simpler by tracking your waste management activities on a single platform and utilizing a set of uniform

  indicators.

- Promote sustainability - Among sustainability's essential elements is the efficient management of waste, water, and energy. Enhancing your company's sustainability can enhance your brand, draw desirable tenants to your facilities, and motivate employees.
- Lower greenhouse gas emissions - Recycling and waste prevention have a big potential to reduce greenhouse effects.

Cambridge English Dictionary defined waste is an unnecessary or wrong use of money, substances, time, energy, abilities etc, but Ecolife dictionary defined waste management as the concept that involves the collection, removal, processing, and disposal of materials considered waste. Waste materials can be solid, gaseous, liquid, or even hazardous and are generally generated through human activity[2].

Municipal solid waste is disposed of at sanitary landfills. A large area of land was purchased by the government, and engineering systems were installed there to help manage surface water, contain municipal waste, and ensure worker safety. Once a sanitary landfill was constructed, it was lined with synthetic plastics to prevent surface water contamination[2].

2.1.1 Types of Waste

Three categories of wastes exist. They serve as the foundation for physical condition, biodegradability, and effects on human health. It is further divided into solid (visible to the human eye), liquid (consisting of domestic and commercial effluents), and gaseous (not visible to the naked eye) substances based on their physical states. Waste was further divided into biodegradable (organic) and non-biodegradable (metals, plastics, paper, and glassware) materials based on biodegradability. It is divided into hazardous (dangerous) and non-hazardous (nondangerous) categories based on its effects on human health[2].

Biodegradable waste

These are the wastes that come from our kitchen and it includes food remains, garden waste, etc. Biodegradable waste is also known as moist waste. This can be composted to obtain manure. Biodegradable wastes decompose themselves over a period of time depending on the material.

Non-biodegradable waste

These are the wastes which include old newspapers, broken glass pieces, plastics, etc. Non-biodegradable waste is known as dry waste. Dry wastes can be recycled and can be reused. Non-biodegradable wastes do not decompose by themselves and hence are major pollutants[2].

2.1.2 Sources of Wastes

Domestic wastes include waste (kitchen waste), trash (paper, polythene, plastic, glass fragments), old toys, old clothes, and old mattresses, among other things. Community wastes include those from educational institutions, businesses, markets, public restrooms, hospitals, construction sites, and other facilities. Commercial wastes include bulky garbage from businesses such as shops, offices, hotels, non-government markets, and stores, as well as abandoned gadgets, plastic bags, buckets, and bottles, packaging materials, paper fibers, and thermocol. Industrial wastes include waste from paper and pulp mills, oil refineries, tanning and distilling operations, thermal power plants, chemical plants, metal smelters, coal, ash, acids, and chemicals, as well as waste from the nuclear industry, unused metal sheets, metal scraps, rubber, leather, toxic effluents, fibers (residues), heavy metals, solvents, resins, sludge, and other substances. Agricultural wastes include manure, livestock manure, crop residues, sugarcane bagasse, old pesticides and fertilizers, farm waste, and livestock dung.

Mining Wastes: Waste products from mining include waste rock, tailings, mine water, chemicals, and others. Nuclear explosions, nuclear testing, the use of radioactive materials in scientific and medical research, products contaminated with radionuclides, such as radioactive diagnostic or therapeutic materials, etc. all produce radioactive waste

Construction Wastes: Construction wastes include debris from demolition, excavation, remodeling, road construction, site cleanup, and the disposal of wood, glass, metal, plastic, and concrete.

Municipal Wastes: Municipal wastes include waste from households, street cleaning, sewage treatment plants, institutions and other organizations, public restrooms, and

Biomedical Wastes: Hospitals, clinics, laboratories, etc.

Health-care Wastes: Medical wastes include syringes, needles, disposal scalpels and blades, expired, unused, and contaminated medications and vaccines, swabs, bandages, gloves, disposable medical devices, urine bags, sanitary napkins, napkins, diapers, human tissues, organs, or fluids, body parts, contaminated animal carcasses, disinfectants, sterilants, heavy metals, broken tyres, and other items.

Electronic Wastes (E-wastes): Discarded electronic equipment, such as computers, TVs, music systems, transistors, tape recorders, mobile phones, computer cabinets, mother boards, CDs, cassettes, and MP3 players, as well as its associated wires, cords, switches, chargers, batteries, and circuits, are referred to as electronic wastes (or "E-wastes")[3].

2.1.3 Waste Management Techniques

Various approaches are employed for waste management depending on the deposition and kind of garbage. From person to person, place to place, period to time, and country to country, they could differ. They are:

2.1.3.1 Recycling

Gathering wastes from various locations, separating them based on the nature of the products, and using the wastes for recycling. In America, robots are utilized to remove waste from the Baltimore River. Recycling techniques are used in Malaysia and Hong Kong to manage building wastes[4]. recycled construction and municipal solid waste and used it to create highly eco-friendly geopolymer composite[5]. Recycling of waste product is very important as this process helps in processing waste or used products into useful or new products. From various research works, it has been established that recycling helps in controlling air, water, and land pollution. It also uses less energy[6]. There are a number of items that can be recycled like paper, plastic, glass, etc. Recycling helps in conserving natural resources and also helps in conserving energy. Recycling helps in protecting the environment as it helps in reducing air, water, and soil pollution.

2.1.3.2 Composting

Organic wastes are segregated from other trash and left in a pit for a long time to be broken down by bacteria. This then decomposes into nutrient-rich compost, which is used as plant manure. These fertilizers increase the fertility of the soil. The organic process of composting improves the soil's fertility. The vermicomposting technique lessens its negative effects on the environment and improves the soil's nutrient content[6]. Vermicomposting is a successful method for sustaining organic farming that is both sustainable and helps to keep the ecosystem in balance[6]. Black Soldier Fly (Larvae) was utilized for high levels of organic waste reduction and quick composting times. The leftovers were then subjected to additional E. Eugeniae treatment, which produced vermicompost of the highest quality[7]. onion trash being vermicomposted with a cow dump produces a valuable agricultural enriched nutrient circle[8].

2.1.3.3 Landfilling

Landfilling is the practice of dumping waste materials in the ground. A proper landfilling method should be used, including coating the base with a protective layer and choosing a location with low groundwater levels, among other things. This process calls for skilled labor. Construction of horizontal wells lowers leachate levels in municipal solid waste landfills in China[9]. The Hg emission from landfills is controlled by a model based on physical, chemical, and biological processes[10]. More gaseous Hg0 was found to be converted to Hg^{2+} during the cooling process when municipal solid waste and sewage sludge were combined for incineration. Less environmental harm to the atmosphere is caused as a result[11].

2.1.3.4 Incineration

Incineration is the process of burning waste materials at a high temperature. The proper filters are employed to prevent air pollution, which is brought on by the burning of garbage. Direct incineration without anaerobic digestion was discovered to be a more preferable sustainable way for treating sludge12. The technology of coal power plants together with waste incineration was regarded as a promising technique for conserving fossil fuels and waste disposal[13]. Plasma, mechanochemistry, hydrothermal, photocatalytic, and biodegradation technologies, which have demonstrated their efficacy in purifying materials, are regarded as the best sources of MSWI fly ash[14].

2.1.3.5 Bioremediation

Bioremediation is the process of employing microorganisms and bacteria to remove impurities, pollutants, and toxins from soil, water, and other environments. The main threat to the human population is posed by the radioactive waste that energy power plants release. Bioremediation is utilized to lessen these wastes. Technologies for bioremediation help restore the soil's natural state and address the issue of heavy metal pollution[15]. For the safe discharge of water from industrial activities, bioremediation is a cost-efficient, eco-friendly method that is promoted[16].

2.1.3.6 Waste-to-Energy

Waste-to-energy is the process of converting waste into energy in the form of heat or electricity. Anaerobic digestion technology is used in China for energy recovery and has been proven to be a successful strategy to reduce the degree of harm caused by GHG emissions connected to FW treatment1[7]. Waste-to-energy (WtE) processes like pyrolysis, gasification, incineration, and biomethanation may safely and sustainably convert MSW, a suitable source of renewable energy, into usable energy (electricity and heat)[18].

2.1.3.7 Remote Sensing & GIS

The practice of gathering data about distant objects or places, usually from planes or satellites, is known as remote sensing. Vector data and remote sensing (RS)[19] were used to determine that 75% of municipal solid trash was dumped at landfill sites in Coimbatore without being treated. A method to measure process level emissions from waste management plants is remote sensing[20]. The overlaying of datasets and locations that satisfy the site appropriateness requirements is necessary for the use of remote sensing and GIS for distinct verification of the sensible objectives of solid waste discharged. The spatial examination tools provided by GIS are combined with the datasets and locations to organize and survey in order to determine potential waste areas[21].

2.2 Theoretical Review

Municipal solid waste is disposed of at sanitary landfills. It is a sizable area of land that the government has acquired where engineering measures have been installed to help manage surface water, control municipal garbage, and regulate safety in the sanitary landfill[22]. A synthetic material is used to line a sanitary landfill after it has been dug up to prevent surface water contamination[23]. Specialized pipes are buried in the earth to collect methane gas and drain off foul odors[24]. To prevent exposure, waste is placed in a big pit that has been appropriately compacted with layers of clay soil and topsoil. At the sanitary landfill, groundwater, surface water, and leachate are also monitored[25]. Water and regular garbage are mixed when put into a sanitary landfill. It breaks down and produces leachate. Methane gas is created and released into the atmosphere[26]. Compressed, routed via an air cooler, routed through a second filtering chamber, warmed, and packed sanitary landfill gas-methane is used to produce electricity[27].

Recycling, Reuse, Reduce, Remanufacture, and the use of sanitary landfills are examples of waste disposal practices that support sustainable manufacturing systems. These practices employ cost-effective strategies to conserve waste and safeguard the environment[29]. Environmental contamination is caused by activities connected to all manufacturing operations that create industrial waste and contaminate the environment[30]. Hazardous gases from industrial waste include hydrocarbons, organosulfur, carbon dioxide, nitrogen, alcohol, and greenhouse gases.[31]. Sanitary landfills produce hazardous trash that cannot be disposed of there as well as heavy metals that damage the land, water, and air[32].

Sanitary landfill operations convert waste gas to methane gas, which is then contained, gathered, cleaned, and used for energy generation[33] to minimize pollution. Daily trash is gathered in sanitary landfills and covered with topsoil to prevent air pollution caused by the stench of the waste being mixed with water. Pipes are buried to minimize underground water pollution since leachates pollutants impact underground water[34]. Environmentalists monitor and regulate sanitary landfills, which guarantees that Goal 7 of the Sustainable Development Goals (SDG), Access to affordable and clean energy, will be achieved by using sanitary landfills as a sustainable manufacturing waste disposal method[35]. There are drawbacks to using sanitary landfills to dispose of manufacturing waste, such as the lack of independent experts to monitor the ground water for beneficial environmental effects. Another drawback is the need to save water and stop water contamination. Most sanitary landfills are constructed and operated to subpar standards. Underutilization of the Gas (sanitary landfill Gas) produced. The significance of creating hygienic landfills is not widely understood.

2.3 Review of Empirical Studies

In developing nations in Africa, especially Nigeria, the issue of waste management is historical and ongoing. Concerns for human health, air, water, and land degradation are only a few of the issues Nigerian municipalities' waste management issues span. For a developing economy like Nigeria to develop a feasible solution, it is imperative to analyze the main issue influencing the effective management of municipal trash.

Municipal solid waste disposal is growing more indiscriminate and is associated with poor standards of living, urbanization, population increase, bad governance, poverty, and low levels of environmental awareness and environmental knowledge management. These wastes primarily have home trash characteristics and are generated domestically[36]. In order to achieve desired change in addressing socioeconomic and environmental concerns, it is necessary to share ideas and expertise due to the persistent issues with municipal garbage management in Nigeria. Municipal trash issues have been addressed in the past using a variety of strategies and actions, with little to no success. Effective municipal waste management necessitates the development and use of knowledge management techniques that ensure environmental sustainability and socioeconomic development. Municipal solid waste management is a crucial component of the city's infrastructure that guarantees the preservation of the environment and public health. Knowledge management is a broad term that refers to systematic efforts made by an organization to manage the knowledge of its personnel through a variety of direct and indirect methods, including the use of particular ICT types, the management of social processes, the structuring of organizations in a particular pattern, or through the use of specific cultures and people management practices[36].

The research work attempts to look at the comparative analysis of the economic and environmental sanitation implications of existing open dump site and a proposed adaptive sanitary landfill in Lead City University, Ibadan.

2.3.1 Processes and Procedures for Waste Management Currently in Use in Nigeria

Municipal waste management refers to the overall procedure for sorting, storing, collecting, transporting, processing, extracting resources from garbage, recycling, and disposing of waste. In

Nigeria, waste is typically thrown along roadside ditches, in open pits that are nearby, and in drainage channels. Municipal rubbish disposal without consideration is becoming a more common practice in Nigeria's majority of urban centers.

In contrast to large cities, municipal solid waste is managed in backyards of homes by burning, composting, feeding animals, and occasionally being dumped at landfills. Storage, collection, transportation, and disposal are the steps in Nigeria's waste management process[36].

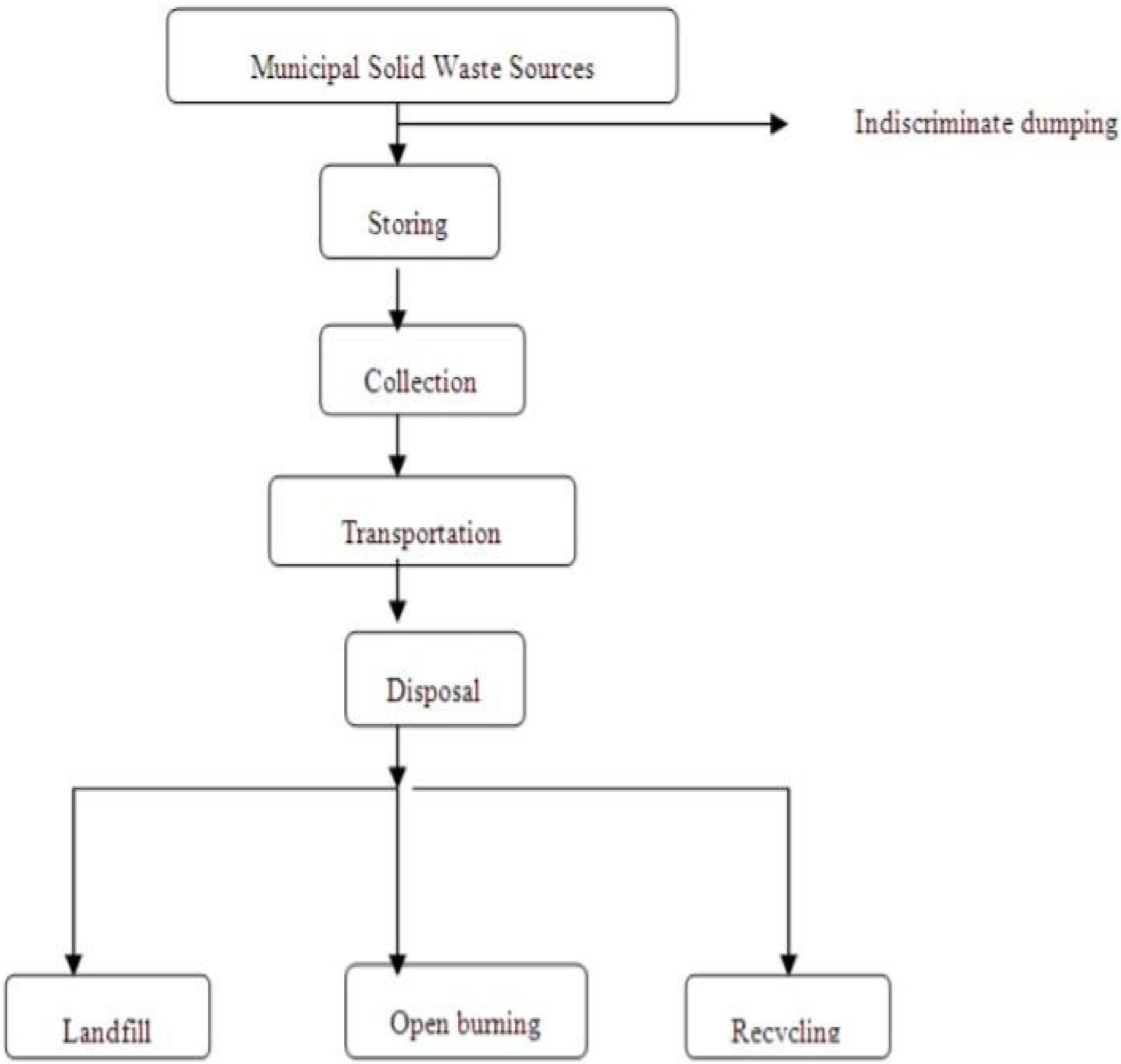

Fig. 1 Existing municipal solid waste management flowchart for Nigeria

Municipal solid waste can be disposed of using a variety of methods, but the most popular ones are landfilling, incineration, composting, anaerobic digestion, and recycling. Although open dumping, land filling, and open burning are now the most often used municipal waste management techniques in Nigeria, incineration is rarely used. In Nigerian hospitals, where medical waste is burnt on a modest scale, incineration is a cost-effective method for disposing of municipal waste[36].

Landfilling is the simplest and least expensive form of garbage disposal. Landfills have a significant negative influence on the environment, however this impact could be reduced by taking sanitary measures and encouraging trash minimization. In 2007, 49% of England's methane emissions were attributable to landfills. The environmentally favorable option of recycling is also not fully utilized. Nigeria doesn't have any official recycling industries. Scavengers recycle trash informally by purchasing people's unwanted valuables, visiting legal and illicit dump sites, and collecting recyclable materials[36].

2.3.2 Generation of Municipal Solid Waste

Nigeria produces 25 million tonnes of municipal solid trash each year, with garbage generation rates ranging from 0.66 kg per capita per day in urban areas to 0.44 kg per capita per day in rural regions, as opposed to 0.7-1.8 kg per capita per day in affluent nations. Municipal solid waste output is steadily rising from households, businesses, and other establishments, among others[36].

Table 1.1. Waste Generation and Composition in some Cities in Nigeria

City	Population	Tonnes/month	Density (kg/m3)	kg/capita/day
Lagos	8,029,200	255,556	294	0.63
Kano	3,228,700	156,676	290	0.56
Kaduna	1,458,900	114,433	320	0.58
Port Harcourt	1,053,900	117,825	300	0.6
Onitsha	509,500	84,137	310	0.53
Ibadan	307,840	135,391	330	
Makurdi	249,500	24,242	340	0.48
Abuja	159,900	14,785	280	0.66
Nsukka	100,700	12,000	370	0.44

Source: Oyebode O: Evaluation of municipal solid waste management for improved public health and environment in Nigeria, Eur. J. Adv. Eng. Tech. 5(8) 525 – 534, 2018.

Household, business, industrial, agricultural, and institutional facilities are just a few of the Nigerian entities that produce municipal garbage. Urban vs rural locations, as well as states, produce trash that is different in both quantity and composition. The amount of garbage produced varies from state to state and also grows yearly as a result of the direct relationship between population, socioeconomic status, and level of urbanization. The socioeconomic status, industrialization, and commercialization are all factors that affect the makeup of the garbage produced by any state. This is associated with socioeconomic development and urbanization[36]

2.3.3 Waste Management Policies and Regulations

To accomplish a number of objectives, the Federal Government of Nigeria passed Decree No. 58 on December 30, 1988, creating the Federal Environmental Protection Agency (FEPA). In Nigeria, waste management is one of the key responsibilities of the municipal, state, and federal governments. Municipal garbage management is also handled at the state level by state environmental protection agencies and state waste management organizations. In Nigeria's main cities and urban areas, garbage is currently managed by each state's environmental protection agency and waste management agency[36].

2.3.4 Municipal Waste Management and Knowledge Management Linkages: Influencing Factors

Municipal waste management in Nigeria is plagued by a wide variety of issues, many of which, according to these issues, are connected to the country's political, technological, psychological, and economic factors. These issues range from inadequate funding, subpar law and policy execution, a lack of professionals and infrastructure, a lack of awareness, subpar recovery and recycling programs, and subpar disposal methods[36].

2.3.5 Knowledge Management Obstacles in Nigerian Municipal Waste Management

1. Cultural Belief: Cultural Belief: Wastes are not seen as wealth but rather as priceless and useless materials. Wastes are not considered valuable resources that can be recovered for material recovery and energy recovery.
2. Communication Channels: In order to spread new information, communication channels like the media and posters are frequently used instead of face-to-face interactions, which include one-on-one practical connection.
3. Collaboration with International Solid Waste Management Organization/ Agencies: The existence of limited collaboration with International Solid Waste Management organizations impedes rapid sustainable development within the Waste sector.
4. Centralized waste collection containers: Nigeria does not have any centralized municipal storage containers. The placement of sorted and recycled materials from various categories is made difficult for the towns as a result.

5. Product and Packaging Producer Involvement: Packaging manufacturers have a limited amount of involvement in waste management. Instead of managing content packages, producers' interests lie more in the creation of these packages.
6. Morale of the workforce: Field personnel who are in charge of rubbish collection and transportation frequently have low morale. The level of stigmatization they experience at work, their meager compensation, and frozen progression all affect how well they function.[36]

2.3.6 Solid Waste Management–Courses and Effects of Poor Management of SWM in Developing Countries

Waste is an undesirable substance produced inevitably by human activity[37]. Every ecosystem used by humans and animals produces it. It can be categorized as solid, liquid, or gas and is thought of as refuse of worthless or useless items, material to be disposed of, or material that has been used for no purpose at all by individuals within a certain location. SW is made up of waste solids such as sludge, trash, and junk. In addition, SW from mining, agriculture, industry, electronics, and municipal waste—which consists of domestic and business operations—is included.

Solid waste Management is a serious environmental issue in emerging nations, is the collection of these various, undesired solid waste products from various home activities in urban areas. A significant cause for concern is the anticipated rise in waste management expenses in developing nations[38]. Scarlat et al.[39] reported that 125 million tons per year of SWM were created in Africa in 2012. By 2025, the amount of waste produced is predicted to reach 244 million tons annually. By 2050, waste creation is expected to double or triple in most emerging countries due to rapid economic growth brought on by industrialization and population expansion[40]. Polluted cities are the result of improper waste management in developing country towns. Leachate, which pollutes surface and groundwater by releasing methane (CH_4) and other gasses, is one of the issues connected to contaminated ecosystems. More than 800 tons of waste carbon dioxide are discharged into the environment each year, according to research by Lee et al. [41]. Inadequate waste management practices lead to clogged sewers, flooding, the spread of illnesses through vector breeding, and an increase in respiratory problems due to floating particles from burning waste[40, 42]

The underlying issues affecting SWM in most developing countries have been recognized in the majority of reviewed studies as being rapid population growth (urbanization), inadequate human resources, lack of facilities like vehicles and infrastructure, improper route planning, weak organizational structure, insufficient budget, weak legislation, lack of enforcement, low public awareness, corruption, conflict, political instability, and lack of political well-being[43], in addition to other activities brought on by a lack of government regulation. The primary challenge to effective SWM management is the failure to collect between one-third and two-thirds of the generated SW[44,45]. Due to the quantity of uncollected waste, there is a serious health risk to people, animals, and plants from the chemicals that contaminate the soil, water, and atmosphere[46].

Gaps in SWM are caused by insufficient enforcement mechanisms and a lack of a complete and efficient regulatory framework controlling the SW sector. A study from Khateeb et al has also demonstrated that several of the developing countries without financial resources are lacking human and organizational capacities[47]. As an example, most developing countries do not have monitoring tools to assess the trash that is generated to enhance planning at the various local, district, regional, and country-level holistically[48.49.50]. To monitor the collection of bins and trucks, newer technological devices have been developed recently, including geographic information systems (GIS), radio-frequency identification (RFID), and international systems for mobile/general radio packet services[51]. Unfortunately, owing of its expensive cost, this technology is almost nonexistent in all underdeveloped nations.

3.3.7 Lecturers' Knowledge of Solid Waste Management

One of the most important instruments for raising awareness among the populace, especially in developing nations, is education. Age-related improvements in waste separation are reported by Singhirunnusorn et al.[52]. Compared to younger generations, older people segregate their waste more. According to other research done in developing nations, most older generations are willing to sort their waste[53,54,55] because they might grow to appreciate the environment and become more conscious of its effects. Therefore, in developing nations, environmental education is crucial to closing the knowledge gap between the young and the old regarding waste management, trash sustainability, and waste segregation. Environmental education can raise people's knowledge of the environment and the problems that come with it, according to UNESCO[56.] It cultivates the specialized knowledge and abilities required to address environmental issues and encourages commitments, attitudes, and drives for making decisions and acting responsibly. According to the US Environmental Protection Agency (EPA)[57], environmental education encompasses more than just environmental knowledge. It rather increases critical thinking, aiding to addressing difficulties, and providing good decision-making skills. Additionally, it raises public awareness and knowledge of environmental issues and empowers people to share information or viewpoints on environmental issues in an effort to make responsible decisions. Concepts and environmental behavior patterns are referred to as environmental knowledge[58]. According to Olsen et al[59], lecturers are the main source of information that students need to acquire in order to use education to preserve human life, practice environmentally responsible behavior, and accomplish sustainable development. Growing environmental knowledge makes people more conscious of environmental issues, which may motivate them to take action to save the environment[60]. However, the lecturer's expertise in SWM is crucial, especially in developing nations, to solving problems pertaining to waste management or environmental difficulties. Consequently, lecturers can give students a solid foundation in knowledge and an in-depth comprehension of newly emerging environmental issues through formal education[61.62]. On the other hand, inaccurate views that teachers convey to their students could lead to disinformation that has significant long-term repercussions. countries[63].

3.3.8 Students' Knowledge and Awareness of Solid Waste Management

Developing a sense of connection to nature begins with an awareness of natural cycles. This will be the start of the environmental awareness campaign. According to Anija-Obi[64], environmental education is a field of study that seeks to promote among citizens, not only awareness and understanding of the environment, but the relationship of man with the environment and mandatory actions of responsibility to allow survival, while improving the life quality standard. In most developing nations, the understanding and awareness of SWM among students is crucial for waste sustainability. Research has indicated that early life experiences have an impact on children's cognitive and emotional development as well as the formation of long-lasting environmental attitudes and behaviors.[65,66,67]. A study by Evans et al.[65] indicates that children understand the ecological and human impacts on the environment from environmental problems awareness. Education affects environmental awareness and attitude, according to research by Tikka et al.[68]. The majority of pupils in poor nations lack the practical information necessary to support proper waste management practices in their classrooms and, at home, to influence their families' knowledge as a result of teachers' ignorance. In most developing nations, environmental education has been part of the curriculum in recent years, although teachers' actual knowledge of the subject is still quite limited. Because of these inadequacies, most developing countries now have weaker standards for managing trash for sustainability. A case study by Panko and Sharma demonstrated that plunging students into practicalities of environmental education, i.e., trash management, promote a profound comprehension of the larger principle of knowledge and attitudes to be acquired[69]. In developing nations, sustainable and efficient waste management is possible if teachers and curriculum levels are carefully developed, and if they have the required training to practically transfer knowledge and raise student awareness. Waste management, which is achieved through environmental education, needs to be realistically oriented in order for developing nations to meet 12 of the 17 Sustainable Development Goals (SDGs) of the 2030 agenda. Governments in developing nations must mandate trash segregation in schools at all levels in order to improve behavioral and attitudinal changes and close the knowledge gap between the elderly and the younger generation on garbage management.

2.3.9 Solutions for Knowledge Management Proposed

In this regard, knowledge management solutions are presented in terms of an approach that is more focused on people than just technology in managing municipal waste[71].

2.4 Theoretical Framework

2.4.1 Basic Requirements for Sanitary Land Fill

Any site's design and operation must fulfill four requirements in order for it to be considered a sanitary landfill.[72], they are;

i. Isolation of the hydrogeological system, whether whole or partial

ii. Formal engineering preparations

iii. Long-term management

iv. Concealing and disposing of waste as planned

2.4.2 Landfill Site Selection

There are various factors to take into account while choosing a landfill location[73].

i. Neighborhood (distances from homes, from rivers and other bodies of water, and from airports)

ii. Local hydrogeological and geological conditions

iii. Local seismic conditions

iv. The presence of groundwater and how it is used now and in the future

v. The possibility of flooding, subsidence, and landslides

vi. Distances traveled and the state of the infrastructure (such as access roads)

vii. Access to the final and interim cover materials

viii. Site topography

2.4.3 Community Areas and Other Locations

Landfill sites shouldn't be situated next to inhabited buildings, streams, or other bodies of water. There should be at least 500 meters of space available. When choosing a landfill location, city growth and future land usage should be considered because urban settlements have a tendency to grow quickly in many tropical nations. Greater distances to the waste site are advised if there is an airport nearby (possible risk to planes from bird hit). Flight distances of more than a few kilometers might be advised depending on the airport's flight patterns. In addition to the need for a minimum buffer zone between residential areas and the landfill site, distances should be kept to a minimum because garbage transport costs rise practically linearly with distance. Sites should be placed away from current and planned residential areas, yet close enough to minimize transit expenses. A "buffer zone" should be created around the landfill to separate it from the surrounding residential area (cultivated area with bush flora). This buffer zone is intended to mitigate noise and odor nuisances caused by the landfill operation, absorb scattered dust produced by landfill equipment and garbage collection trucks, and prevent vector migration into residential areas.

2.4.4 Design of Landfill

Due to both the high organic composition of the waste and the high precipitation rates, leachate emissions from waste that has been landfilled are a major issue. It is therefore necessary to create an appropriate landfill. The separation of trash from the environment at a minimal cost, taking into account both building and operation expenses, is one of the guiding concepts for landfill design. A base lining system can be used to achieve the separation from the surrounding area (at the landfill's base).

The following are requirements for sanitary land fill design:

1. Choosing the lifespan or goal year
2. Choosing an appropriate spot
3. Conducting a financial analysis and choosing a timeline for the landfill's construction.
4. The expected quantity and analysis of trash haulage, as well as taking into account the actual conditions on the authorized service area, are additional factors that must be taken into account.

The planning, surveying, and preparation of the full design process could take several years. As a result, it is advised to include a reserve margin or buffer in the plan so that, if necessary, the life span of the landfill may be extended by an additional 10-year term to accommodate the transition phase. This will help prevent an excessive buildup of garbage. Given the dire state of waste management and landfills, which has also resulted in the inability of existing landfills to entice private investment, the following new landfill design technique is suggested for development in an effort to entice private investment in waste management by promising financial rewards. The proposed design is based on a combined strategy for energy production and trash disposal. Only the new landfills that are being considered for construction can use this method. The current landfills might not be eligible for application. The following presumptions will be used:

1. Waste is separated at the source, and when it gets to the landfill, it shouldn't have much recyclable material in it. Most of the time, direct garbage shipment is taken into consideration because the planned landfills with changed designs might be distributed throughout the mainland, providing more opportunities to reduce transportation costs and improve waste collecting. In this design technique, as opposed to the typical approach, the amount of land needed will be determined for the degree of waste creation, and for a specific landfill life, the number of cells needed is chosen.

2. The upcoming factors will be taken into account

i. Waste in landfill density, kg/m^3

ii. The amount of garbage produced daily (in tons)

iii. Tonnes of garbage produced annually

iv. Compostable and non-organic/reusable solid waste fractions, as well as collection effectiveness

iv. The portion to be landfilled

v. The effectiveness of the landfill

vi. The depth of fill (m)

vii. Volume of cover soil to that of waste, expressed as a ratio.

ix. After-landfill trash volume, daily cover included, in m^3

x. Base length of the land fill

xi. xi. Base width

2.4.4.1 The Base-Lining System

Landfill regulations in wealthy nations frequently call for a composite liner at the landfill foundation. A high density polyethylene (HDPE) sheet and a clay layer with a thickness of 40 to 80 cm typically make up this composite liner. Particularly the latter is pricey and thus frequently out of reach for landfill operations in developing nations. As a result, it is advised to employ a "single" baseliner system made of compacted clay layers. To reduce transportation costs and traffic, the clay material should ideally be accessible close to the dump site. So, choosing a site is important for determining the entire expenses of landfilling. International landfill construction standards can be used as a source of inspiration for the requirements for clay compaction and the necessary hydraulic conductivity. Sometimes only removing the top 20 to 30 cm of the soil and compacting it with large machinery is enough to marginally improve the low permeability of the existing soils. Thus, specific expenses for base lining system construction can be decreased to less than US$1 per m^2. Comparatively, base lining system construction prices in the US are said to be 20 to 30 US dollars per square meter, whereas expenditures in the European Union may even be much higher, reaching 70 US dollars per square meter. At least 2% slope should be present on the liner's surface. Figure 3: Base Single-line System Schematic[73].

2.4.5 Designated Landfill Capacity (DLC)

The DLC is the final landfill design volume for the intended life of the landfill, taking into account both the volume of waste and the covering material that will be compacted and landfilled (JMESS, ISSN: 2458-925X, Vol. 3 Issue 9, September 2017; www.jmess.org JMESSP13420411). The physical dimensions of the landfill and the total area required are determined using the DLC (Revised Draft, 2004). The most crucial factor in the equation used to calculate the size of the landfill site for the suggested goal lifespan is the ADLV. It is often calculated by finding the correlation between the expected average annual volume or amount of waste dumped into the landfill and the volume that has been lowered after compaction. Based on historical data of the actual volume of waste dumped, at least for the last five years, the average yearly volume of waste must be estimated. Alternately, the ADLV can be calculated by comparing historical data from other LAs with comparable urban populations and waste management practices to the vehicle haulage volume (ton) and landfill volume (m^3). The following equation can be used to determine the vehicle haulage volume (VHV) if only information on the carrying capacity of vehicles is available: Carrying Capacity (m3) x Typical Specific Gravity of Waste (ton/m3) equals VHV [ton]. (2.1) The expected weight of solid wastes to be landfilled in a given year is known as the ADLW. Based on historical data and historical trends of the actual weight of garbage collected from the houses, it is possible to calculate the average weight of the waste and the generation rate. Estimates of the predicted solid waste volume should be made up to the goal lifespan in intervals of five years. The following variables will cause a steady yearly increase in the amount of solid waste:

i. Population growth;
ii. Service area coverage expansion;
iii. An increase in the per capita generation rate as a result of rising living standards
iv. An uptick in commercial activity

2.4.6 The Sanitary Landfill System's Purpose

The following are the primary duties of a sanitary landfill system:

i. Storage and treatment
ii. Environmental protection
iii. Land development

The sanitary landfill system must be planned with an eye toward protecting the surrounding area by avoiding unwarranted occurrences such waste overflow and leachate seepage, the spread of vectors and the attraction of wild animals, waste dispersal, and odor emission. The main job of a waste disposal plant is to store and treat garbage so that it can be stabilized and have a smaller volume. However, the nearby communities, who frequently have more pressing concerns regarding the environment and land development, view landfills as unclean and unattractive. As a result, it is essential to develop and create a landfill system that can maintain the balance of the three aforementioned functions.

2.4.7 Sustainable Management of Solid Waste

A significant problem has been presented by the correct and sustainable management (SWM) of solid wastes (SW) produced in various parts of the world[74]. Nevertheless, it is more obvious in emerging countries like Nigeria than in industrialized ones. due of their inability to focus on managing their created solid waste due of the speed at which industrial and economic development is occurring, many emerging countries have failed to do so[75]. The six stages of the solid waste management processes include; generation, collection, storage, processing/recovery, transportation, and disposal can be broadly categorized into six categories[76]. Solid waste is temporarily stored or gathered at various collection points or dumpsters, loaded into waste trucks or compactor vehicles, cleared, and transported to transfer stations, treatment facilities, or other locations. According to the Integrated Solid Waste Management (ISWM) hierarchy, processing and recovery refers to various treatment and recovery procedures that support use, reduction, and recycling (energy recovery) operations. The characterization analysis of the generated SW serves as the foundation for any effective SWM design or practice. Because the formation of garbage has become an integral part of life and necessitates proper attention, a thorough analysis of the many components that comprise the waste stream generated is important[42]. namely, lower institutional costs and a longer lifespan for the sanitary landfill, if any. Additionally, a decrease in the amount of solid trash generated in any city or institution directly reduces the negative effects on the area's environment and social values. Higher education institutions are supposed to lead the environmental protection and preservation movement and/or uphold their moral and ethical obligations. Additionally, universities educate and teach those who are thought to be the society's experts in this field. Most higher institutions with their alleged knowledge of environmental management, including solid waste management, have necessary potential to spread the necessary awareness through campaigns and knowledge transfer, creation of the tools and technology required to develop and promote sustainable behaviors on campus and in the local communit[77] The aforementioned procedures will not only stand as an example for students and the community, but they will also lower the cost of the overall management process. However, most Nigerian universities have failed in this regard because of the general problems that plague most developing countries, including but not limited to: an increase in the production of solid waste, rapid economic growth, political interference, corruption, an increase in population growth, a lack of knowledge of the various factors encountered at various stages of waste management, poor infrastructure, and inadequate expertise. In order to recommend more effective solid waste management strategies for Nigerian universities and the entire Nigerian nation, the work's goal is to discuss waste reduction and recovery techniques, assess and compare their application among higher institutions in various parts of the world, both developing and developed. This paper will serve as a reference for Nigerian university authorities in developing policies and plans for the appropriate recovery of resources from their generated solid wastes.

2.4.8 Techniques for Utilizing and Reducing Waste

Typically, this entails choosing and putting into place the required infrastructure, tools, technologies, and practices to create a sustainable system. In accordance with the Integrated Solid Waste Management (ISWM) principles, every schedule for sustainable waste management needs to include the following tactics: preventing the creation of avoidable wastes, reducing the waste produced through recovery, reusing the recovered wastes, recycling the recyclables, composting organic wastes for energy/electricity production, and ultimately disposal at sanitary landfills. This approach assists waste managers in putting into place a sustainable system by allowing for proper consideration of the environmental, economic, and social variables unique to the specific site. Composting, resource recovery and recycling, as well as treatment and disposal systems, were some of the solid waste management options that Ogwueleka[78] highlighted. He continued by saying that the informal sector is currently engaging in garbage recovery/recycling, reuse, and composting. The recovery/recycling process aids in the recovery, transformation, and repurposing of valuable resources like plastic, polythene, paper, organic wastes, etc., boosting the economy. These procedures greatly minimize the amount of solid waste disposed of at landfills, so increasing the landfill's lifespan, lowering the amount of toxic emissions from those facilities, and saving a respectable sum of money for the authority. Composting organic waste results in composts that can be used to enhance soil for reforestation and the preservation of green spaces on campuses and in the surrounding area. Additionally, under controlled temperature, humidity, and pH conditions, the anaerobic digestion of the organic component, whether alone or in conjunction with a waste water treatment facility, produces a sizable amount of methane gas that can be used to generate electricity for on-campus use[71-82]. Food scraps are often used as animal fodder. Agunwamba[83] claims that efficient and effective application of these concepts in waste management could reduce collection and transportation costs by 18.6% and landfill maintenance expenses by 57.7%. 1.3. A description of the approaches for utilizing and reducing solid waste that have been identified Application of appropriate/suitable management systems or technologies is a key component of solid waste usage and reduction approaches in order to create a sustainable and ideal system free of contamination and pollution. These procedures reduce pollution of the air and water, generate jobs, and conserve resources for later use. To prevent contamination, waste that will be recycled or used again should be collected in separate bins at the source.

2.4.8.1 Reduce

This entails minimizing wastes at the time of production or before to disposal[84]. It also entails taking relevant SW management principles into account and incorporating them, starting with the material design and continuing through all processes to the final step of material consumption. Both the quantity and the damaging impacts of SW generated are greatly decreased. This can also be accomplished by introducing the idea of reusability of the products throughout the production and design stages while using fewer but higher quality material resources in product manufacturing. This will make a significant contribution to implementing the solid waste reduction strategy. Industries have a significant part to play in reducing solid waste. By producing more products in greater quantities while using less raw materials, they can adopt more effective production techniques. Using less materials to create items is another way to put it. Separation at source[76, 77, 85, 87)] is a crucial tactic for reducing waste. This is accomplished by placing distinct bins or containers with clearly identified collection spots, such as homes, businesses, workplaces, commercial spaces, offices, etc., at these locations.[76-77]. Making use of reusable items rather than disposable ones, such as handkerchiefs instead of tissue papers, rechargeable batteries, refillable ink pens, etc., cotton/textile bags for shopping rather than plastic bags, buying products with less packaging or buying products in bulk to reduce the amount of materials used for the packaging, maintaining a healthy environment, and recycling are some of the potential methods of reducing the amount of MSW generated.

2.4.8.2 Reuse

This entails utilizing waste or resources that have been disposed of in their unaltered state. It also entails gathering abandoned usable items from sources that are no longer using them and transferring the so-called wastes to the sources that may still utilize the resources effectively. Glass bottles, PET bottles, textiles, papers/cardboard, leathers, food scraps, metals, and other items that can be put to use in a manner that is comparable to that for which they were originally designed are examples of solid waste that can be reused. These examples amply demonstrate the critical role that reuse plays in MSW management and how it can promote sustainability.

2.11.3 Recycle

To do this, waste materials must be reprocessed or changed before being put to use. Wastes that have been recycled or treated are no longer considered wastes but rather precious resources. Paper wastes, for instance, can be recycled into new paper products that can be used for a variety of tasks, such as printing, tissue paper, cardboard, etc. Metal wastes and glass bottles can be melted down to create other useful metal and glass products, and plastic (PET or HDPE) bottles can be turned into plastic ropes or rubber coatings for electrical wires. Ifeoluwa[88] asserts that composting and all waste-to-energy procedures are considered to be major recycling activities. Consequently, the following paragraphs will discuss composting and other waste-to-energy technologies:

2.4.8.3 Composting

By using a diverse population of microbes, mixed wastes are biologically transformed into humus-like compounds during the breakdown process known as composting. Sometimes, in order for the process to be successful, it needs to be carried out in a very ideal and regulated atmosphere with the right humidity level, aeration, and temperature[89].

It needs a moisture level of between 40 and 60 percent and a carbon to nitrogen ratio of roughly 25 to 155. It's a technique or method used to recover or transform primarily organic wastes for other really beneficial applications[90]. It actually entails the microbial transformation of organic wastes including food scraps, leaves, sludge, fruit scraps, animal manure, etc. into soil humus[90,91]. The composting process must be appropriately regulated by regulating the biological and oxygen requirements as it progresses through the several phases to produce the final compost[92]. The components in this composting process for organic waste are broken down into stable compounds that can be used as soil conditioners or fertilizers[55]. In nature, there are many creatures that decompose.

Actinomycetes, fungi, and bacteria are among them. These microorganisms can be found everywhere, including in dust, fruits, vegetables, and the soil. Composting can be divided into two categories: aerobic and anaerobic, according to Pathak et al. Composting that occurs aerobically requires oxygen. Along with water and heat, this process also results in the production of various gaseous substances like CO_2 and NH_3 further to heat and water[55]. "Pathak et al." However, to effectively treat any type of organic waste, the proper combination of components must be used in conjunction with the carefully monitored conditions mentioned in the previous paragraph. Any deviation from these conditions that is large enough to stop decomposition in its tracks. Woods and papers are excellent sources of carbon, but sewage sludge and food waste are important sources of nitrogen[90]. To maintain a proper and consistent supply of oxygen throughout the process[58], forced or passive sources of ventilation must be applied to the waste being treated. Contrarily, anaerobic composting refers to the decomposition of garbage in the absence of oxygen. Carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), and other gaseous products are released in trace amounts together with organic acids[90] during this process. This method has traditionally been used to compost mostly animal manure and sewage sludge from people. However, MSW and green waste composting have recently become popular[93].

2.4.8.4 Solid Waste Energy Recovery

Anaerobic digestion, combustion/incineration, gasification, and pyrolysis are some of the different technologies used to recover energy from solid waste in order to transform SW materials into other significant and extremely useful forms. These forms include fuel, usable heat, and electricity. The term "waste-to-energy (WtE) technologies" is frequently used to describe these procedures. As was said in the preceding section, anaerobic digestion involves the breakdown of waste in the absence of oxygen. On the other hand, the conversion and treatment of SW[94] entails the direct use of thermal energy through combustion, gasification, and pyrolysis. It has been stated that some of the listed processes, such as gasification and pyrolysis, can also be used to transform microalgae into energy and compounds in addition to SW[95]. Gasification is the thermal and chemical conversion of carbonaceous materials into gaseous products at high temperatures (700 C) while they are present with a gasification agent[94]. Using gasification agents, it can alternatively be defined as the thermochemical conversion of carbon-based solid or liquid materials, such as feedstock and other organic materials, into gaseous byproducts known as combustible gas[96]. Three main components make up a gasification system: an energy recovery system, a gasifier, and a gas cleanup system[96]. The gasification agent is a gaseous substance that facilitates the quick conversion of feedstock/organic wastes into gaseous elements through various heterogeneous processes. This technique entails changing the chemical makeup of the material at a high temperature of at least $700^{0}C$[94,96]. Carbon dioxide (CO_2), carbon monoxide (CO), gaseous hydrogen molecules (H_2), methane gas (CH_4), water (H_2O), and higher hydrocarbons in trace amounts make up the gaseous products, commonly known as combustible gas Additionally, the gasification agent contains several types of pollutants, such as ash, tiny char particles, and tars[97], as well as inert gases. According to Kumar[98], the gasification process can reduce waste volume by 95% or more even without the use of waste pretreatment, depending on the reactor technology and the waste type. Due to the integrated flue gas cleanup system, which is less demanding in gasification conversion processes[98], it was noted that the technology provides a better future alternative than SW incineration. Furthermore, the gasification process emits less carbon dioxide (CO_2) than the incineration method does. In terms of the amount of MSW that is decreased during each phase, the gasification method reduces more garbage. Combustion, often known as incineration, is the process of burning solid and liquid wastes in a controlled atmosphere, or incineration facility[98]. Industrial waste, sewage sludge, municipal solid waste (MSW), hazardous waste, and clinical waste are only a few of the waste types that can be incinerated[99]. This method can also be referred to as a regulated process that burns waste directly in the presence of oxygen at high temperatures between 700 and 1000 °C. Gases, inert ash, and energy in the form of heat are released throughout the process[98, 99]. The nature and density of the trash have an impact on the net energy released[99]. The volume of combustible wastes is reduced by 80 to 95% during the incineration process, which is a very appealing aspect. It breaks down organic waste into substances like methane (CH_4), carbon dioxide (CO_2), and inert ash[99]. The thermal energy produced by this process can be captured and used for public electricity production[98], district heating applications, and other uses. However, they can still be helpful in the building sector. The inorganic components included in the garbage being burnt are mostly to blame for the occurrence of this inert ash. Controlling air pollution is one of SW implementation's biggest drawbacks[100]. This method of waste treatment is best suited, especially when the option of landfilling is not an option or when it is necessary to dispose of garbage distance from the sources of the waste. In addition to the cost of hiring experienced labor to operate it, installing the necessary equipment for an incinerator facility is quite expensive. These elements make garbage management through incineration quite pricey[98]. Nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4) are among the gases emitted during the incineration and open burning of garbage. These pollutants pollute the environment and, in higher concentrations, the ozone layer[99,100]. Wastes are thermally degraded during the pyrolysis process without the presence of oxygen. The procedure produces recyclable materials including oil/wax, char, and gaseous materials often referred to as combustible gases[101,102,103]. With this kind of waste treatment, MSW can be converted into fuel and safe-to-dispose-of materials like metals and char. Additionally, the procedure can be adjusted to produce either solid char, gas, or liquid/oil products. A technology called a pyrolysis reactor, which serves as an efficient waste-to-energy converter68, is also a part of the process. By changing a few operating factors, such as temperature or heating rate, pyrolysis can produce a mixture of solid, liquid, and gaseous products. Because of this flexibility element, the approach is currently receiving a lot of interest on a global scale[102,103]. Additionally, it offers a significant opportunity to convert low-energy density materials into high-energy density biofuels, assisting in the recovery of more valuable chemicals[101]. Pyrolysis systems come in a variety of configurations, including fast, catalytic fast, intermediate, slow, and vacuum[101]. This method also has the unique benefit of being able to transform many types of raw materials, such as municipal and industrial waste. Such waste fractions of MSW as yard trash, feedstock/food waste, paper, plastics, and cloth/textiles, for example, can be transformed by it[101.]

2.4.8.5 Function of Protecting the Environment

The function of environmental protection is crucial for reducing and averting negative impacts on human health as well as for safeguarding the local natural ecosystem. These negative consequences are brought on by issues with leachate discharge to the landfill, emission of volatile greenhouse gases, bad odor, vectors, and other types of pollutants like noise and disruptions.

2.4.8.6 Leachate (Reducing pollution of ground and surface waters)

Environmental laws and regulations such as the "Environmental Quality Act 1974," "Environmental Quality (Sewage and Industrial Effluents)," and other standards and by-laws enacted by the Local Authorities all have an impact on the quality of the leachate emitted by sanitary landfill systems. As a result, the leachate discharge from sanitary landfill systems must be handled in accordance with the standards outlined in the applicable regulations. If the leachate from the sanitary landfill site was discharged without treatment, it might be toxic and contaminate the water sources. The leachate quantity must be handled by an adequate and efficient leachate treatment system, which must also have enough of a buffer to handle any transitory spikes in the quantity that may be brought on by excessive rainfall.

2.4.8.7 Vectors

Landfill sites frequently serve as breeding grounds and food sources for vectors and animals like flies, rats, birds, and stray canines. Daily cover dirt should be piled on top of the waste that has been landfilled in order to reduce and prevent such occurrences. To stop flies and other insects from breeding there, insecticides can be sprayed all over the area. To keep grazing and wild animals out of the area, a perimeter fence should be put in place. This will also keep people from scavenging in the trash.

2.4.8.8 Gaseous Products

Methane, ammonia, and hydrogen sulfide are the principal gaseous products released from the sanitary landfill site. Whether the waste layer is decomposing aerobically or anaerobically determines the composition of the gases. It is important to pay attention to the anaerobic landfill, which can release a substantial amount of methane and is primarily composed of organic waste. Such volatile vapors can explode if an excessive buildup occurs. Long after the dump has been closed, these dangerous situations can still exist. The majority of these gasses are dangerous to people and the environment, but the landfill typically produces only little amounts that are not concentrated enough to have an immediate impact. To facilitate the gasses' dispersal, a gas venting system may be required to be installed to the atmosphere.

2.4.8.9 Offensive Odours

There are often two disagreeable odours that emanate from landfill sites: the odour of new, rotting waste material and the odour created by the decomposition process. When the dump site is close to populated areas, it may be necessary to regulate how much of the stench is released into the environment. After the day's activities are complete, it is advised to place a suitable cover material on the waste layer. Offering gas collection and treatment facilities is a further, improved approach.

2.2.8.10 Noise Annoyances and Pollution

An annoyance and source of discomfort for the local people is excessive noise and disturbances that may be brought on by dust or vibrations emitted from the landfill. These are typically brought on by activities involving the trucks used to transport garbage, equipment utilized on the site, or leachate treatment facilities. In order to reduce the effects of noise pollution and annoyance, it could be essential to modify the operation of the landfill that is close to populated areas by assessing the waste transportation system and the choice and use of machinery and equipment

2.4.9 Waste Management in Universities

Universities and other educational institutions produce a lot of rubbish every day. Over 610,000 tonnes of garbage are thought to be generated annually by the Nigerian educational system. In order to educate young people, a variety of materials are needed, including used paper in the classroom, food packaging, and cafeteria garbage. In addition to teaching students how to be environmentally responsible citizens who understand their role in safeguarding the environment, universities have a duty to reduce and recycle garbage. All of these objectives must be accomplished with a solid waste management strategy for schools.

2.4.9.1 University Waste Disposal

Every institution has a legal obligation to make sure that an effective waste management system is in place, with the goal of reducing, reusing, and recycling the trash generated. This entails segregating as much as you can for recycling while using the proper bins for storage and disposal. Universities are being held up as examples of how to handle waste in an environmentally beneficial way. Many universities struggle to create an effective university waste management system because of the variety of garbage produced by universities. The kind of garbage determines the best method of disposal. Try to prevent even non-recyclable trash from traveling to landfills because university requires operate under a zero landfill policy.

For instance, when it comes to food waste at universities, it is advisable to promote landfill alternatives like composting. An additional choice is anaerobic digestion, a procedure that uses food waste from schools to produce biogas for the production of renewable energy. It is possible to incinerate general waste to produce refuse-derived fuel as an alternative to fossil fuels.

2.4.9.2 Universities' Bins

There are numerous university bins available to use to store your trash safely and securely before collection because university waste comes in a variety of formats. These include recycling bins for the institution to make sure recyclable garbage such as paper, cardboard, plastic, and other items is segregated so it can be recycled easily.

2.4.9.3 Universities and Recycling

Recycling is crucial in academic institutions because it lowers the amount of garbage transported to landfills and the associated landfill tax. There are other benefits to recycling in universities, including energy savings, pollution reduction, the production of new materials, and a favorable impact on children's futures. Your university may increase recycling rates and earn the rightful reputation for being environmentally friendly by implementing an effective waste management system. This involves placing recyclable products in the proper university recycling bins to prevent landfill waste[104].

There are many different recycling techniques, but the following are examples that are frequently used in universities:

- Paper and card make up at least 25% of the garbage that universities produce. These are recycled separately and used to create new cardboard and paper products.
- Depending on their size, plastics can be crushed, depolymerized, or put through thermal compression to form new plastics.

- ❖ Glass is separated by color, cleaned, crushed, and heated to generate new glass goods. Depending on the type, plastic can be shredded, depolymerized, or put through thermal compression to create new polymers.

2.4.10 Waste Management in University

Waste management strategies that include sorting, reducing, reusing, recycling, and composting are effective. The garbage generated by universities needs to be disposed of in a way that has the fewest harmful consequences on the environment. Only universities with no other options are permitted to establish waste pits and incinerate waste there.

Composting organic waste • Burning garbage • Landfills, offal holes, or waste pits at schools • Waste separation • Reducing waste • Recycling waste • Composting waste

2.4.11 The Advantages of Waste Management in Higher Education

Universities have a sizable obligation that might be challenging to manage: waste management. Nigerian colleges generate more than 610,000 tonnes of garbage annually, including a variety of waste categories such food, packaging, paper, and stationery equipment. An efficient waste strategy can enhance a facility on a number of levels by correctly managing waste, recycling, and removing trash from university grounds.

2.4.11.1 An Improved School

The university will be significantly cleaner because there will be less rubbish piling up there and a better procedure for disposing of it. This is advantageous for the staff and students' health as well as for the university's reputation among visitors and potential parents because it maintains them well above the legal limits.

2.4.11.2 Less Risks

Students and employees may be put at risk by poorly managed waste facilities and bins since spilled or abandoned trash could cause someone to trip or fall. The institution won't be exposed to these possible threats if it has routinely managed and maintained waste disposal facilities.

2.4.11.3 Increased Recycling and Increased Sustainability

Waste management companies may assist universities in correctly segregating their waste, recycling it after collection, and streamlining their overall system to reduce waste output. As a result, their university is more environmentally friendly and produces less garbage that needs to be disposed of in landfills.

2.4.11.4 Encourages Students to Dispose of Waste Responsibly

As we previously indicated, institutions are crucial in teaching students how to effectively manage garbage. A more sustainable generation will be created as a result of the university's excellent waste management policy, which will teach students how to recycle, keep areas clean, and limit their trash production.

2.4.12: Measurement of Landfill Gas

Researchers and the solid waste industries and facilities are investing time and money in developing methods to measure landfill methane emissions in order to quantify the greenhouse gas emissions that landfills contribute to as well as to find ways to use landfill gasses in energy renovations[105].

2.4.12.1: What Components Make Up Landfill Gas?

Landfill gas is a complex mixture of hundreds of different gases. In terms of volume, landfill gas typically contains 40% to 60% carbon dioxide and 45% to 60% methane. Other minor components of landfill gas include nitrogen, oxygen, ammonia, sulfides, hydrogen, carbon monoxide, and non-methane organic compounds (NMOCs) like trichloroethylene, benzene, and vinyl chloride. The typical landfill gases, their percentage by volume, and their properties are listed in Table 2.1.

Table 2.1: Components of Typical Landfill Gas

Component	Percent by Volume	Characteristics
Methane	45–60	Methane is a gas that occurs naturally. It has no colour or smell. Landfill is the single biggest source of man-made methane emissions in the United States.
Carbon dioxide	40–60	The atmosphere naturally contains very little carbon dioxide (0.03%). It has no color, no smell, and a mild acidity.
Nitrogen	2–5	Approximately 79% of the atmosphere is made up of nitrogen. It has no flavor, no aroma, and no colour.
Oxygen	0.1–1	Approximately 21% of the atmosphere is made up of oxygen. It has no flavor, no aroma, and no color.
Ammonia	0.1–1	Ammonia is a colorless gas with a strong smell.
NMOCs (non-methane organic compounds)	0.01–0.6	NMOCs are organic substances, or substances containing carbon. (Even though methyl is an organic chemical, it is not an NMOC.) NMOCs can arise naturally or artificially through chemical processes. NMOCs most typically found in landfills include acrylonitrile, benzene, 1,1-dichloroethane, 1,2-cis dichloroethylene, dichloromethane, carbonyl sulfide, ethyl-benzene, hexane, methyl ethyl ketone,

		tetrachloroethylene, toluene, trichloroethylene, vinyl chloride, and xylenes.
Sulfides	0–1	The rotten-egg odour that permeates the landfill gas combination is caused by sulfides, which include hydrogen sulfide, dimethyl sulfide, and mercaptans. Even at very small amounts, sulfur dioxide can produce offensive odours.
Hydrogen	0–0.2	A colorless, odorless gas is hydrogen.
Carbon monoxide	0–0.2	A gas with no smell or color, carbon monoxide.

Sources: EPA (1995); Tchobanoglous, Theisen, and Vigil (1993).

2.4.12.2: What Process Produces Landfill Gas?

Landfill gas is created by three processes: bacterial breakdown, volatilization, and chemical reactions.

- ❖ Bacterial breakdown. The majority of landfill gas is created by bacterial decomposition, which happens when bacteria naturally found in organic waste and the soil used to cover the landfill break down garbage. Food, garden garbage, street sweepings, textiles, and wood and paper goods are all examples of organic waste. Organic waste is broken down by bacteria in four stages, each of which results in a different alteration in the gas's composition.
- ❖ Volatilisation. Certain wastes, especially organic substances, can produce landfill gases when they transform from a liquid or a solid into a vapor. Volatilization is the term for this action. The volatilization of specific compounds disposed of in the landfill may produce NMOCs in landfill gas.

- Chemical processes. Certain waste-related chemicals can react to produce landfill gas, which includes NMOCs. For instance, if ammonia and chlorine bleach mix together inside the landfill, a dangerous gas is created.

The Bacterial Decomposition of Landfill Waste in Four Phases

In four stages, bacteria break down garbage in landfills. With each of the four phases of decomposition, the composition of the gas produced changes. Since waste is frequently accepted at landfills for 20 to 30 years, there may be numerous stages of decomposition happening simultaneously in the waste there. Therefore, more recently buried waste in one region may be in a different stage of decomposition than older waste in that same area.

Decomposition caused by bacteria goes through four phases.

Phase I

Organic waste is broken down into its lengthy molecular chains of complex carbohydrates, proteins, and lipids during the first stage of decomposition by aerobic bacteria, which can only exist in the presence of oxygen. Carbon dioxide is this process' main output. As the landfill progresses through the four phases, the nitrogen level decreases from the phase's beginning. Phase I continues until all of the oxygen is used up. Depending on how much oxygen is present when the waste is dumped in the landfill, phase I decomposition might last for days or months. The amount of oxygen in the trash will change depending on various conditions, such as how loose or compressed it was when it was buried.

Phase II

Phase II decomposition begins once the landfill's oxygen supply has been depleted. Bacteria transform substances produced by aerobic bacteria into acetic, lactic, and formic acids as well as alcohols like methanol and ethanol through an anaerobic (without oxygen) process. The landfill turns significantly acidic. As the acids and moisture in the garbage combine, they breakdown some nutrients and make nitrogen and phosphorus available to the landfill's numerous bacterial species. Carbon dioxide and hydrogen are the gases produced as byproducts of these processes. Microbial processes will revert to Phase I if the dump is disturbed or if oxygen is inadvertently introduced into the waste.

Phase III

Phase III breakdown starts when specific anaerobic bacteria eat the organic acids created in Phase II and produce an organic acid called acetate. As a result of this process, the landfill becomes a more neutral environment where methane-producing bacteria can flourish. Bacteria that produce both methane and acid coexist harmoniously and benefit from one another. Acidproducing bacteria produce substances that the methanogenic bacteria ingest. Too much carbon dioxide and acetate would be poisonous to the bacteria that produce acid, yet methanogenic bacteria absorb these substances.

Phase IV

When the composition and production rates of landfill gas stay mostly unchanged, phase IV decomposition starts. Phase IV landfill gas typically includes 2% to 9% sulfides and between 45% and 60% methane by volume, 40% to 60% carbon dioxide, and other gases. After the waste is placed in the landfill, gas will continue to be released for at least 50 years (Crawford and Smith 1985). Gas is produced at a consistent rate in Phase IV, typically for around 20 years. For instance, if there are larger levels of organics in the waste, as could be the case at a landfill that receives more domestic animal waste than is typical, the gas generation could last longer.

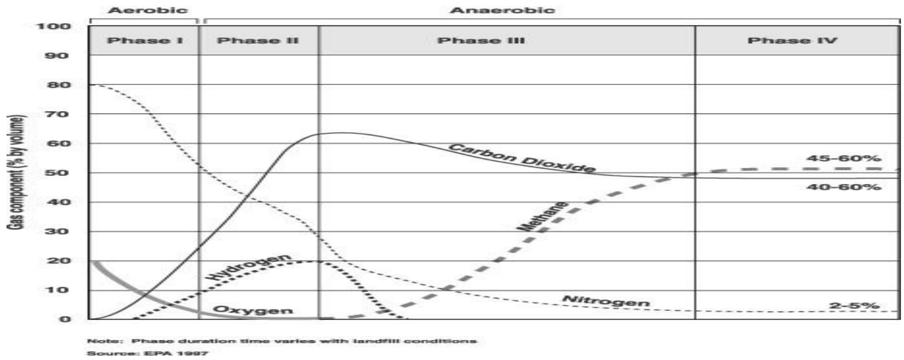

Fig2.1: **Typical landfill gas production stages**

Sources: EPA (1995); Tchobanoglous, Theisen, and Vigil (1993).

2.4.12.3: What Factors Influence the Production of Landfill Gas?

The amount and pace of landfill gas produced at a given location depends on the waste's properties (such as composition and age) and a number of environmental variables (such as oxygen levels in the dump, moisture content, and temperature).

- The makeup of waste. More landfill gas, such as carbon dioxide, methane, nitrogen, and hydrogen sulfide, are created by the bacteria during decomposition of organic waste the more of it there is in a landfill. The likelihood that NMOCs and other gases will be created by volatilization or chemical reactions increases with the amount of chemicals dumped in the landfill.
- The age of the refuse. In general, more recently buried garbage (i.e., waste buried less than 10 years) produces more landfill gas through bacterial decomposition, volatilization, and chemical reactions than does older waste (buried more than 10 years). Five to seven years after the garbage is buried, peak gas production often happens.

- The landfill's oxygen level. Only when oxygen is no longer present in the waste will methane begin to be created.

- The moisture level. Moisture (unsaturated conditions) in a landfill promotes bacterial decomposition, which boosts gas generation. Furthermore, gas-producing chemical processes may be encouraged by moisture.

Temperature. The temperature of the landfill rises, which stimulates more bacterial activity and more gas production. The rates of volatilization and chemical reactions may also accelerate under higher temperatures. More specific information about how these factors impact the rate and volume of landfill gas production is provided in the box on the following page.

2.4.12.4: How is Landfill Gas Transported?

Gases are typically expelled from the landfill after they are formed beneath the surface. Gases have a tendency to fill up empty space and then expand, allowing them to "migrate" through the landfill's soil and refuse layer's constrained pore spaces. Gases from landfills that are lighter than air, like methane, have a natural propensity to rise, usually through the surface of the dump. Densely compacted garbage or landfill cover material (such as daily soil cover and capping) can prevent the upward migration of landfill gas. When upward motion is restricted, the gas usually migrates horizontally to other sites inside the dump or to locations outside the landfill so that it can resume its upward course. In essence, gases move in the direction of least resistance. Because some gases, like carbon dioxide, are denser than air, they will gather in underground spaces like utility corridors. Diffusion (concentration), pressure, and permeability are the three key variables that affect the migration of landfill gases.

The concentration of diffusion. Whether a space is a room or the earth's atmosphere, a gas has a natural tendency to reach a uniform concentration over time. In a landfill, gases flow from high gas-concentration areas to low-gas-concentration places. Landfill gases permeate out of the landfill to the surrounding areas with lower gas concentrations because gas concentrations are often higher in the landfill than in the surrounding areas.

- The pressure. Areas of high pressure, where gas flow is constrained by compacted waste or soil coverings, and areas of low pressure, where gas movement is unconstrained, are produced by gases collecting in a landfill. Gases move from high-pressure to low pressure regions as a result of the pressure variations throughout the landfill. Convection is the term used to describe the movement of gases from high-pressure locations to low pressure areas. Subsurface pressures in landfills are frequently higher than atmospheric pressure or indoor air pressure as more gases are produced, increasing the pressure inside the dump. Gases tend to flow to outdoor or indoor air when there is a higher pressure inside the landfill.
- Permeability. Wherever the paths of least resistance are found, gases will also travel in that direction. The degree to which gases and liquids can pass through interconnected spaces or pores in waste and soils is known as permeability. Moisture-laden clay is typically substantially less permeable (fewer connected pore spaces) than dry, sandy soils
(more connected pore spaces). Gases typically travel through high-permeability regions (such as sand or gravel) as opposed to low-permeability regions (such as clay or silt). Low-permeability soils, including clay, are frequently used as landfill covers. As a result, gases in a covered landfill may travel horizontally rather than vertically more frequently.

Table 2.2: Factors Affecting the Production of Landfill Gas

Factors Affecting the Production of Landfill Gas

Composition of waste. More landfill gas is created by bacterial decomposition the more organic waste that is present in a landfill. Some forms of organic waste have nutrients like sodium, potassium, calcium, and magnesium that support the growth of bacteria. Landfill gas generation rises when these nutrients are present. Alternately, certain wastes include substances that damage bacteria and reduce gas production. For instance, when waste has excessive salt concentrations, methane-producing bacteria may be suppressed.

The landfill's oxygen. The production of methane by bacteria doesn't start until the oxygen is depleted. The longer aerobic bacteria can continue to breakdown garbage in Phase I, the more oxygen there is in the landfill. More oxygen is available if garbage is loosely buried or often disturbed, which allows oxygen-dependent bacteria to live longer and create water and carbon dioxide for longer periods of time. However, methane production will start sooner if the trash is substantially compacted because in Phase III, methane-producing anaerobic bacteria will take the place of the aerobic bacteria. Any oxygen left in the landfill will slow methane generation because anaerobic bacteria don't begin to make methane until the aerobic bacteria have consumed all of the oxygen. Barometric highs have a tendency to add air oxygen to the surface soils in the shallower parts of a landfill, which could change the bacterial activity. In this case, trash in Phase IV, for instance, could briefly return to Phase I until all the oxygen is consumed once more.

Content of moisture. Because moisture promotes bacterial development and spreads germs and nutrients throughout a landfill, the presence of a specific amount of water in a landfill enhances gas output. Maximum gas production is promoted (for example, in a capped landfill) by a moisture content of 40% or greater, based on the wet weight of garbage. Due to the increased density of the garbage in the landfill and the slowed rate of water infiltration, waste compaction reduces gas production. If there has been a lot of rain or if permeable landfill covers have been used, then the rate of gas production is higher.

Temperature. Bacterial activity rises in warm environments, which in turn accelerates landfill gas production. Lower temperatures prevent bacteria from growing. Bacterial activity typically decreases sharply below 50 degrees Fahrenheit (F). In shallow landfills, the impact of weather variations on gas output is much larger. This is because, in contrast to deep landfills where the garbage is covered by a thick layer of soil, the bacteria are less protected against temperature variations. A covered landfill typically keeps its temperature steady, boosting gas production.

Although temperatures as high as 158° F have been recorded, bacterial activity emits heat that stabilizes a landfill's temperature between 77° F to 113° F. Increases in temperature also encourage chemical reactions and volatilization. Emissions of NMOCs typically double with every 18°C of temperature.

Age of Refuse. Debris buried more recently will release more gas than debris buried earlier. Usually within one to three years, landfills start to release noticeable amounts of gas. Usually 5 to 7 years after garbage is placed, gas production reaches its peak. However, a landfill may continue to leak minor amounts of gas for 50 or more years. Nearly all gas is created within 20 years of the material being dumped. However, a low-methane yield scenario predicts that slowly degrading garbage will start producing methane after 5 years and keep doing so for the following 40 years. Depending on when the waste was initially deposited in each region, different parts of the landfill may be going through various stages of the decomposition process at the same time. Depending on when the waste was initially dumped in each region, different parts of the landfill may be going through different stages of the decomposition process at the same time. The duration of gas production is significantly influenced by the amount of organic material in the waste.

Sources: DOE 1995, EPA 1993, Crawford and Smith 1985

2.4.13: Health and Safety Concerns with Landfill Gas

Landfill gas in particular raises a number of health and safety concerns, including the risk of explosion and suffocation, as well as problems with odors coming from the landfill and low-level chemical emissions. Environmental experts can respond to community health challenges with the aid of several tools. Additionally, as landfill gas emissions can contain mixes of hundreds of different gases, there are both known and unknown health impacts related to these emissions on both the short and long term. There won't be any negative consequences on health when individuals aren't exposed to landfill gases. Exposures only take place if the landfill is creating dangerous quantities of gases and if those gases are escaping and reaching people. It might be challenging to address community worries about the potential negative effects of landfill gas emissions on health.

2.4.13.1: How are Individuals Exposed to Landfill Gas?

Gases from the dump or nearby communities may be inhaled by people. The migration of landfill gases might occur above or below ground. Gases may pass through the landfill's surface and into the surrounding air. Once in the atmosphere, the landfill gases can be blown by the wind to the neighborhood. Gases migrating above ground are indicated by odors produced by routine landfill operations. Additionally, subterranean soil may allow gases to infiltrate buildings or utility corridors on or near the landfill. A possible exposure pathway and the transport of waste gases are shown in Fig. 2.2. The quantities of gases that escape from a landfill and to which people are exposed depend on a variety of variables. methods for capturing and regulating landfill gas.

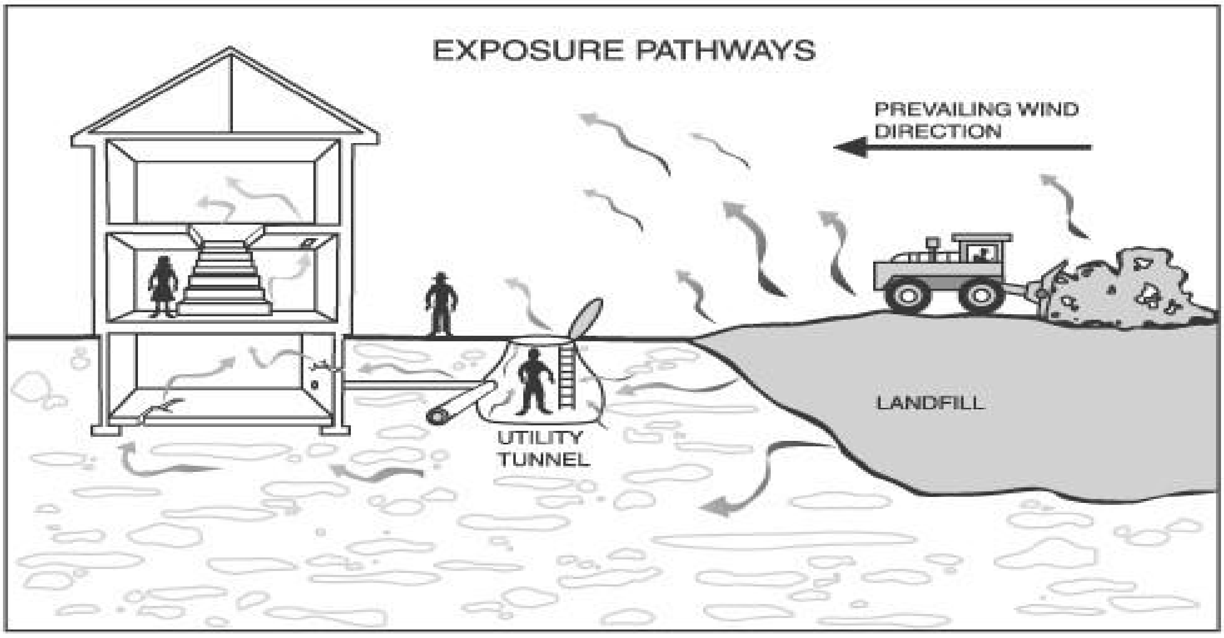

Figure 2.2: Possible Routes for Gas from Landfill Exposure

Sources: EPA (1995); Tchobanoglous, Theisen, and Vigil (1993).

2.4.13.2: Threats from Explosion

When landfill gas and air interact in a specific ratio, an explosive mixture could result. Below this heading, the following information will be provided:

• The prerequisites for landfill gas to present an explosion threat.

• The kinds of gases that could possibly be explosive dangers.

• How to determine whether a dump poses an explosion hazard.

2.4.13.3: When Does Landfill Gas Present a Risk of Explosion?

Landfill gas must meet the following requirements in order to present an explosion risk:

- Production of gas. Gas from a landfill must be produced, and this gas must include explosive amounts of certain substances.
- Migration of gas. Gas from the landfill must be able to migrate. Landfill gas may migrate through natural subsurface geology or underground conduits. When working effectively, gas collection and treatment systems limit the quantity of gas that can escape from the landfill.
- Gas collecting in a small area. The gas needs to build up to a concentration where it might blow up in a small area. A manhole, a subsurface space, a home's utility room, or a basement are all examples of restricted spaces. The lower and upper explosive limits (LEL and UEL) of a gas, as stated at right, are used to determine the concentration at which it has the potential to ignite.

LEL and UEL, or lower and upper explosive limits

The explosive limit is the gas concentration at which an explosion is possible. The lower explosive limit (LEL) and upper explosive limit (UEL) of a gas define its likelihood of exploding. The percentage of a gas in the air by volume is measured by the LEL and UEL. A gas is not explosive at concentrations above its UEL and below its LEL. However, if a gas is present in the air between the LEL and UEL and an ignition source is available, there may be an explosion threat.

Table 2.3 Gas explosions at landfills

Gas explosions at landfills
Despite the fact that landfill gas explosions are extremely rare, a number of incidents that may have been brought on by such an explosion have been recorded.
1999 While playing on a playground in Atlanta, a young girl, age 8, sustained burns to her arms and legs. According to reports, the region used to be a prohibited dump for many years. (2000) Atlanta Journal-Constitution
1994 A methane explosion severely burnt a woman while she was playing soccer at a park constructed over a former landfill in Charlotte, North Carolina. (1994, Charlotte Observer)
1987 In Pittsburgh, Pennsylvania, a house explosion may have been brought on by off-site gas migration.(EPA 1991)
1984 Near an Akron, Ohio, landfill, landfill gas traveled and obliterated one home.A temporary evacuation was ordered for ten homes. (EPA 1991)
1983 In Cincinnati, Ohio, a house next to a landfill was destroyed by an explosion. Reports of minor injuries were made. (EPA 1991)
1975 In a storm drain line that passed through a landfill in Sheridan, Colorado, there was an accumulation of landfill gas. All the kids who were playing in the pipe were seriously hurt when a candle was lit, causing an explosion. (USACE 1984)
1969 The basement of an armory in Winston-Salem, North Carolina, experienced methane gas migration from a nearby landfill. The gas exploded as a result of a lighted cigarette, killing three individuals and badly hurting five more. (USACE 1984)

Sources: EPA (1995); Tchobanoglous, Theisen, and Vigil (1993).

The box above describes just a handful of numerous recorded instances where all the requirements for explosions were satisfied and explosions actually took place.

2.4.13.4: Which Gases Are Potentially Explosive?

- **Methane.** Gas from landfills contains methane, which is the component most likely to cause explosions. In the range of its LEL (5% by volume) and UEL (15%), methane is explosive. Methane is unlikely to erupt within the confines of the dump because its normal landfill concentrations are 50% (far higher than its UEL). However, as methane migrates and is diluted, the mixture of methane gas may reach explosive levels.

  Furthermore, while oxygen is essential for causing an explosion, the biological activities that generate methane call for an anaerobic, or oxygen-depleted environment. Although there is enough oxygen to support an explosion at the landfill's surface, methane gas typically diffuses into the surrounding air at concentrations below 5%.
- Additional landfill gasses. Other components of landfill gas, such as ammonia, hydrogen sulfide, and NMOCs, are flammable. However, they rarely pose explosive threats as separate gases because it is improbable that they will be present at concentrations exceeding their LELs. For instance, benzene (an NMOC that may be present in landfill gas) is explosive between its LEL of 1.2% and its UEL of 7.8%. However, it's quite improbable that benzene levels in waste gas will ever be this high. If benzene were found in landfill gas at a concentration of 2 ppb (or 0.0000002% of the air by volume), then benzene would need to accumulate in a closed space at a concentration 6 million times higher than that found in the landfill gas to present an explosion threat.

Table 2.4: Explosion Risks from Typical Landfill Gas Components

Explosion Risks from Typical Landfill Gas Components	
Component	**Possibility of Creating an Explosion Hazard**
Methane	In air at a volume between its LEL of 5% and its UEL of 15%, methane is very explosive. Methane does not explode at quantities between 5% and 15%. Methane can be created in enough quantities in some landfills to build up to explosive levels within the landfill or in structures nearby.
Carbon dioxide	Neither is carbon dioxide explosive nor flammable.
Nitrogen dioxide	Nitrogen dioxide is neither explosive nor flammable.
Oxygen	Although it is not flammable, oxygen is required to support explosions.
Ammonia	Ammonia burns readily. Its UEL is 28%, while its LEL is 15%. Ammonia isn't expected to build up to a level where it may cause an explosion, though.
NMOCs	Chemicals have different potential explosive risks. The LEL and UEL of benzene, for instance, are 1.2% and 7.8%, respectively. However, it is doubtful that benzene and other NMOCs will accumulate in amounts high enough to present explosion risks.
Sulphuric acid	Sulphuric acid is flammable. It has a UEL of 44% and an LEL of 4%.
Hydrogen Sulfide	Hydrogen sulfide won't likely build up in most landfills at a level that would be dangerous for explosions.

Sources: EPA (1995); Tchobanoglous, Theisen, and Vigil (1993).

The possible explosive risks caused by the significant components of landfill gas are listed in Table 2.3. The landfill gas component most likely to present an explosion hazard is methane. There aren't likely to be any additional combustible waste gas ingredients at concentrations high enough to cause an explosion. When methane and flammable NMOCs are mixed in a small area, the total explosive threat is increased.

2.4.13.5: How can I Determine Whether a Dump in my Neighborhood Presents an Explosion Risk?

If a landfill might be a risk for an explosion, the following checklist can help. Several steps can be taken to protect the neighborhood if your evaluation indicates that there is a chance of an explosion.

Table 2.5 Hazard Checklist for Landfill Gas Explosions

Hazard Checklist for Landfill Gas Explosions

☐ **Does the landfill produce gas, and how much, if so?**

Monitoring data are required to provide a response to this question because the major elements of landfill gas, methane and carbon dioxide, are both odourless and colourless.

☐ **Is there a method in place to capture landfill gas?**

Systems for collecting landfill gas reduce the amount of gas that escapes from the dump and enters the neighborhood.

☐ **Flows of gas from the landfill?**

To provide an answer, it could be essential to use data from off-site monitoring.

☐ **Exist any areas where gas could gather if it were to migrate from the dump and reach structures?**

Gases that are allowed to escape from a landfill may move to nearby buildings or the landfill itself. However, it is less likely that gases may migrate to a structure in quantities high enough to represent an explosion concern the further away it is from the landfill. Gases tend to gather most frequently in basements, crawl spaces, or buried utility entrance ports. Homes with basements are more likely to accumulate gases, particularly if they include pipes or cracks that could allow gas to enter.

- **Is gas accumulating at levels high enough to present a risk of explosion?**

  To find the answer, we need monitoring data. To avoid introducing an ignition source into the region, caution should be utilized when choosing sampling equipment.

- **Is there a source of ignition?**

Many different things, such a heater in the basement or a pilot light on a gas stove, can ignite gases. Cigarettes, candles, matches, and sparks are examples of additional sources. It is safer to presume that there is always the possibility of an ignition source because there are so many of them.

Sources: EPA (1995); Tchobanoglous, Theisen, and Vigil (1993).

2.4.13.6: Risks of Asphyxiation

Landfill gas only poses a threat to asphyxiation when it accumulates in an enclosed area (such as a basement or utility corridor) at quantities high enough to replace the surrounding air and produce an oxygen-deficient environment. An oxygen-deficient environment is one that contains less than 19.5% oxygen by volume, according to the Occupational Safety and Health Administration (OSHA). About 21% of the volume of ambient air is made up of oxygen. Table 2.4 provides information on the health impacts of low oxygen levels.

Table 2.6: Oxygen-deficient Environments' Effects on Health

Oxygen-deficient Environments' Effects on Health

Oxygen Concentration	Health Effects
21%	Typical ambient air oxygen content
17%	A decline in night vision (not apparent until a normal oxygen concentration is restored), an increase in breathing volume, and an accelerated pulse
14% to 16%	Increased respiratory rate, quick heartbeat, very poor muscle coordination, rapid exhaustion, and intermittent breathing
6% to 10%	Unconsciousness, incapacitation, vomiting, and nausea
Less than 6%	Convulsive behavior, spasmodic breathing, and death within minutes

OSHA, unpublished data

Any of the gases that make up landfill gas can, separately or in combination, pose a risk of asphyxiation if their presence results in an atmosphere with insufficient oxygen. Carbon dioxide, which makes up 40% to 60% of landfill gas, may present a particular asphyxiation hazard. Because it is denser than air, carbon dioxide that has leaked from a landfill and accumulated in a small area, like a basement or an underground utility corridor, may linger there for hours or days after the area has been exposed to the air (like after a manhole cover has been removed or a basement door has been opened). Since carbon dioxide has no color or smell, it is difficult to detect. 10% or higher carbon dioxide concentrations can cause unconsciousness or death. A headache, perspiration, rapid breathing, elevated heart rate, shortness of breath, dizziness, mental depression, visual abnormalities, or tremor may be experienced at lower dosages. The intensity of these symptoms is influenced by the volume and length of exposure. Even in healthy, typical people, the response to carbon dioxide inhalation varies substantially.

Environmental health specialists should look into the possibility of buried utility lines and storm drains on or near the landfill when evaluating the potential public health risks of migratory landfill gas. These structures not only serve as a conduit for escaping gases, but they also provide a specific risk of asphyxiation for utility workers who disregard OSHA-mandated safety precautions while entering confined spaces. Basements and insulated (or sealed) crawl spaces in nearby homes and business structures should also be evaluated.

2.4.14: Landfill Gas Emissions and Health: Odours and Low-Level Chemical Exposures

Residents frequently complain about the smell of the landfill. In addition to the scents, additional emissions from the landfill may also cause people to worry about their health. • Symptoms that may be brought on by odors from landfill gas are covered in this section.

• How environmental health specialists can determine whether landfill gas emissions may be causing a health danger.

• What scientists currently know about the potential health implications of exposures to landfill gas emissions.

2.4.14.1: Are Symptoms Susceptible to Odours' Effects?

he smells that landfills release frequently cause people in communities close to them to worry. These scents, according to some, are a cause of unfavorable health impacts or symptoms, like headaches and nausea. It is unknown whether a reaction is brought on by the component itself or its smells at the low quantities commonly associated with landfill gas. When the odor is no longer detectable, these effects typically disappear. The biochemistry of smelling things out is explained in the box below.

Both open and closed landfills can emit landfill gas, which is created by bacterial or chemical processes. These smells may disseminate to the neighborhood. Sulfides, ammonia, and several NMOCs are potential contributors of landfill odors, if present at high enough concentrations. Additionally, the disposal of some wastes, such as manures and fermented grains, may result in the production of landfill odours.

Table 2.7 How Are Smells Recognized by People?

How Are Smells Recognized by People?
Between 3,000 to 10,000 distinct smells can be detected by humans. Although it is a popular misconception that people smell with their noses, the nose is simply one component of the olfactory system that enables humans to recognize different odors. Air and pungent substances like hydrogen sulfide are drawn in by the nose's vacuum-like function. Warm air and smelly substances are first retained in mucus around the olfactory membrane after being warmed up in the nasal cavity. Deep within the nasal cavity between the eyes, the olfactory membrane occupies a space less than 1 square inch. Chemoreceptors on the olfactory membrane, which are tiny hairs called cilia, interact with odour causing molecules. Through the olfactory bulb, the receptors communicate with the brain about the smelly molecules. Following that, the odour is interpreted and recognized by the brain

Source: Pacific Science Center 1999; Jacobs 1999.

Similar to the other senses of sight, hearing, taste, and touch, each person has a unique sense of smell. In the same neighborhood or residence, one person may be able to detect a scent similar to that of hydrogen sulfide at incredibly low amounts while another cannot. There isn't a real odor threshold value above which odors are unpleasant and below which aromas are barely perceptible because of this variation. Any given odor threshold values in the literature, such as those in table 2.5, are simply approximations of concentrations that a typical person might be able to detect (AIHA 1989). As a result, while referencing or discussing established threshold values with community members, health practitioners should use caution.

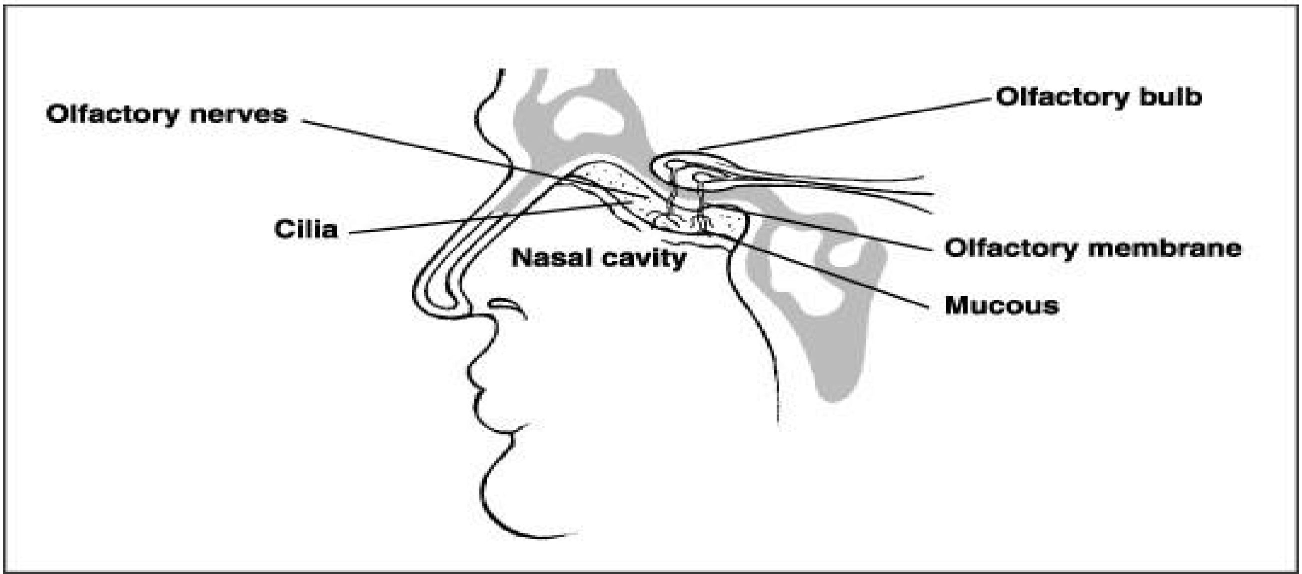

Fig 2.3 Anatomy of Smell

Source: Pacific Science Center 1999; Jacobs 1999.

- Sulphides. The three most prevalent sulfides that cause landfill odors are mercaptans, dimethyl sulfide, and hydrogen sulfide. Even in relatively small quantities, these gases emit an extremely potent rotten-egg smell. The highest rates and quantities of hydrogen sulfide, the most toxic of all three sulfides, are released by landfills.

- Humans can detect hydrogen sulfide aromas at parts per billion (ppb) concentrations as low as 0.5. Humans are particularly sensitive to these odors. People may find the smell repulsive at concentrations of 50 ppb. According to ATSDR (1999a), ambient air concentrations range between 0.11 and 0.33 ppb on average. The Connecticut Department of Health has discovered that the hydrogen sulfide content in the air around a landfill is often close to 15 ppb (CTDPH 1997; ATSDR).

• **Ammonium.** The decomposition of organic material in the landfill results in the production of ammonia, another pungent waste gas. An essential chemical for maintaining plant and animal life, ammonia is found frequently in the environment. Because of the natural breakdown of manure and dead plants and animals, people are exposed to low levels of ammonia in the environment every day. Most people are aware with the distinctive scent of ammonia because it is frequently used as a household cleanser. Ammonia smells make people far less sensitive than sulfide smells do. Ammonia has an odor threshold of 28,000 to 50,000 ppb. According to reports, landfill gas contains 0.1% to 1% ammonia by volume or between 1,000,000 and 10,000,000 ppb of ammonia (Zero Waste America, n.d.). At or near the landfill site, ambient air concentrations are anticipated to be significantly lower.

NMOCs. Hydrocarbons and vinyl chloride are two NMOCs that can emit scents. However, NMOCs typically emit at extremely low (trace) levels and are not anticipated to cause a significant odor issue.

Table 2.8 : Components of Common Landfill Gas and Their Odour Thresholds

Components of Common Landfill Gas and Their Odour Thresholds

Component	Odour Description	Odour Threshold (parts per billion)
Hydrogen Sulfide	A pungent rotten egg odor	0.5 to 1

Ammonia	Noxious, stifling, or acidic odor	1,000 to 5,000
Benzene	Odour similar to paint thinner	840
Dichloroethylene	The aroma is sweet, ether-like, and barely pungent.	85
Dichloromethane	Sweet, similar to chloroform odor	205,000 to 307,000
Ethylbenzene	Aromatic smell, such as benzene	90 to 600
Toluene	Benzene-like aromatic odor	10,000 to 15,000
Trichloroethylene	Chloroform-like sweet smell	21,400
Tetrachloroethylene	Sweet, chloroform- or ether-like odor	50,000
Vinyl Chloride	Weakly sweet smell	10,000 to 20,000

Sources: DOE 1995, EPA 1993, Crawford and Smith 1985.

The smells that come from a landfill may be repulsive or unpleasant to many individuals. Some individuals may develop nausea or headaches in response to the smell. Despite the fact that such reactions are undesirable, medical intervention is typically not necessary. When the odour disappears, symptoms like headaches and nausea frequently subside. The implications on daily life, however, may have a longer-lasting impact. Families in Connecticut who live next to a landfill characterized frequent odor episodes as being quite disruptive. A torrent of nauseous air that lasted for at least two hours startled one household in the early morning hours. The family's level of stress increased significantly as a result of the lack of sleep and aggravation caused by the frequent odor incidents. The increased interruption and stress of daily activities can significantly lower quality of life, even though landfill odors may not have been linked to long term negative health impacts or illness for the majority of individuals. In the following account, odor issues in Danbury, Connecticut, are handled by environmental and health experts.

Table 2.9 The Danbury Landfill: A Story of One Community

The Danbury Landfill: A Story of One Community
One municipality that overcame a landfill odor issue was Danbury, Connecticut. In Danbury, a 100-year-old landfill caught fire in the spring of 1996. The water used to put out the fire encouraged bacterial growth and boosted the formation of sulfur dioxide and hydrogen sulfide, which are sulfur compounds that cause odours. Public worries and inquiries were raised by the rise in scents. Although the amount of hydrogen sulfide in the air was much below levels that could have an impact on human health, some locals reported experiencing nausea and headaches due to the odor. Environmental organizations and local and state health officials collaborated to address the odor issue. To allay neighborhood worries and deal with the odor issue, they did the following:

- As a short-term fix, lime was added to the landfill to minimize sulfide releases and aromas. As a long-term fix, landfill managers installed a landfill liner made of fabric, a gas collection system, and a flaring system.
- Local health authorities published and disseminated a newsletter to inform locals about landfill odors and the measures being taken to lessen them.
- Hydrogen sulfide concentrations were monitored using monitoring equipment in areas where exposure could happen, such as nearby residential properties and shopping malls. Concerned parties developed the following four-tiered response strategy based on measurements of hydrogen sulfide concentrations in the area:
- Landfill operators would take prompt measures to minimize emissions at concentrations more than 100 ppb for 15 minutes.
- Medical staff would be alerted if concentrations exceeded 100 ppb for 2 hours in case sensitive people (such young children, the elderly, or asthmatics) were affected.
- Sensitive people should stay indoors or leave the area if the concentration is above 500 ppb for two hours.
- All residents should evacuate the area if the concentration is over 5,000 ppb for 30 minutes.

When odour control measures were being installed, the first action level occasionally went off. There was never a trigger for the additional action levels. Complaints from the neighborhood significantly dropped after scents were under control.

Sources: DOE 1995, EPA 1993, Crawford and Smith 1985.

It is not widely known or understood how landfill gas odors affect vulnerable individuals, such as those who already have respiratory diseases. When asthmatics who live close to a landfill reported scents, their self-reported wheeze increased, according to a Staten Island research.

However, tests of ambient air revealed levels of hydrogen sulfide and other emissions that were significantly lower than those levels known to be linked to harmful health consequences.

2.4.15: Landfill Gas Monitoring

Professionals in environmental health aren't typically requested to create and carry out sample and monitoring plans at landfills, but you can be asked to examine and offer your input on such plans. When available, you may also need to study and interpret sampling and monitoring data in order to assess potential risks to public health. This chapter covers fundamental knowledge on the many types of landfill gas sampling techniques that you are most likely to encounter (such as monitoring program design, sampling and monitoring equipment, and data interpretation) in order to make such duties easier.

It is crucial to keep in mind that monitoring data collected at landfills may not accurately reflect the amounts of contamination to which individuals may be exposed. However, these statistics typically provide some insight into the general air quality, migration of landfill gas, or potential health risks. The following five categories best describe how landfill gas monitoring is generally done:

- Monitoring of emissions
- Ambient air
- Near-surface gas
- Soil gas
- Indoor air, and emissions

An overview of the main characteristics of each method of monitoring is provided in Table 2.6.

These various monitoring operations' data collection results have quite varied public health ramifications. This chapter discusses each of the five types of monitoring activities after providing an overview of landfill gas sampling techniques. Additionally, issues about data on landfill emissions can be resolved with the aid of mathematical modeling. This chapter provides a concise description of the elements to take into account while analyzing the outcomes of air modeling.

An Overview of Methods for Sampling Landfill Gas

There are too many different landfill gas sampling techniques to include in this booklet. However, the sampling site and the sampling techniques are two crucial considerations when choosing an effective landfill gas sampling procedure. The overall sampling program's use of the data and the questions it will be used to address in selecting the sampling site and sampling techniques. The box below gives a few examples of where gas detectors might be placed.

Table 2.10 Monitoring Stations for Landfill Gas

Monitoring Stations for Landfill Gas
Subsurface, surface, and enclosed space settings are the three types of places where landfill gas monitors are commonly installed at or close to landfills. The three separate monitoring sites can be utilized individually or in conjunction with one another in a sample program to address various landfill gas concerns. Keep in mind that these devices typically do not measure landfill gas levels where people are exposed. Systems below the soil-air interface called subsurface systems are used to measure the concentrations of pollutants in soil gas. From a few inches to many feet below the surface, sample depths are possible.
Surface Systems: Surface Systems take measurements of gas concentrations just a few inches above the soil-air contact.
Systems for Enclosed Spaces:- Systems for enclosed spaces monitor gases in indoor air or in confined places above or next to landfills, such as structures, underground vaults, utilities, or any other sites where the potential for gas buildup is a problem.

Sources: DOE 1995, EPA 1993, Crawford and Smith 1985.

Table 2.11 The Important Characteristics of the Various Landfill Gas Monitoring Methods

Monitoring Type	Overview of Monitoring	Most Common Parameters Reported	Public Health Connection
Subsurfac Gas	The levels of pollutants in soil vapour space are measured by soil gas monitoring systems. Utilizing wells or probes, measurements of soil gas concentrations are made at boundary.	Federal Government mandate that the majority of landfills disclose methane	The data are often helpful to measuring the hazards of explosion and for determining qualitative measurement of pollutants.
Close-by Gases	Examine the gas concentrations at the location.	Although VOC and H2S are not always reported. Methane is the most often detected gas.	Methane concentrations in the open air don't present risk for inhalation or explosion.
Emission	The rate at which chemicals are discharged from a specific source	Methane and NMOC	The amounts of emission chemicals that people actually breathe does not constitute a threat
Air in the atmospher e	Pollution level in outdoor ambient air, or the air that people breathe are measured through ambient air. mandates that the for assessing the hazards	A wide variety of contaminants can be monitored in ambient air	Data from ambient air monitoring characterize pollution levels in the air that people breathe, making them the best indicator of air exposure concentrations near landfill.

Sources: DOE 1995, EPA 1993, Crawford and Smith 1985.

A landfill gas sampling approach can use a variety of landfill gas collection techniques in addition to the sampling site. The following are some examples of these techniques and their effects:

- Mobile versus fixed sampling tools. Portable monitors, which are often small, portable instruments that are simple to carry about a landfill, can be used to undertake certain gas monitoring. This kind of tool is excellent for determining the source of methane leaks or for performing a preliminary screening of landfill gas migration patterns. On the other hand, stationary monitors are often installed in fixed locations and remain there for the duration of the desired monitoring. Though not usually, stationary monitors can produce data of a higher caliber than portable monitors.

- Grab sample versus ongoing observation. The majority of landfill gas monitoring techniques (such as soil gas, emissions, ambient air, and interior air) fall under this classification. Grab sampling is by definition a one-time measurement of gas concentrations that offers a "snap-shot" of the composition of landfill gas at a certain location and time. Unless it is carried out at regular intervals in accordance with a comprehensive plan, this form of sample is typically not relevant for evaluating changes in landfill gas composition over the long term. Continuous monitoring equipment, in contrast, continuously samples and assesses gas concentrations. While some can only monitor average concentrations, some can record variations in concentration over short time periods. However, all continuous monitors offer information about long-term changes in gas composition.

- The comparison between laboratory and field sample analysis. Gas samples are often either collected and delivered to a laboratory for examination or examined right in the field, depending on the data requirements. However, this method can test the amounts of many distinct contaminants and gives results that are extremely exact and precise. Laboratory analysis may take days or weeks to complete and can be expensive. Real-time monitoring, on the other hand, reports concentrations as soon as they are recorded; in some situations, these sensors can track variations in concentration from minute to minute. However, the majority of real-time monitors only measure the concentration of a single pollutant and are therefore less accurate than laboratory analysis.

The characteristics of a specific landfill gas monitoring program differ from landfill to landfill, therefore the ideal sample approach for one landfill might not be suitable for another. The characteristics chosen for gas sampling at the majority of landfills are determined by regulatory requirements (e.g., the soil gas monitoring requirements of the EPA constitute a significant factor in the sampling done at the majority of MSW landfills).

2.4.15: Soil Gas Detection

This section addresses soil gas monitoring and how it relates to landfills, explains why soil gas is frequently monitored at landfills, and provides information environmental health professionals should take into account when analyzing soil gas monitoring data.

2.4.15.1: How Does Soil Gas Monitoring Work?

Gases containing a variety of chemicals are produced when waste decomposes in landfills. These gases travel through soils and may eventually be released to the surface. During its time in the soils, landfill gas is frequently referred to as "soil gas." Therefore, measuring the amounts of gases in the ground is known as soil gas monitoring.

2.4.15.2: Why Are Landfill Soil Gas Levels Monitored?

The amount of pollutants in soil gas at or near landfills should be monitored for a variety of reasons. Although soil gas monitoring may be done for various purposes, the three main reasons why it is done are reviewed below. This chapter goes on to discuss sample techniques and how the monitoring data relate to public health.

- **To Comply with Legal Obligations**. MSW landfills are required to conduct methane soil gas monitoring in accordance with EPA rules under RCRA (Subtitle D). Some MSW dumps might not be subject to these RCRA standards, depending on the year of construction. Regulated by the EPA, states and Indian tribes have latitude in how they apply these rules. As a result, landfills that are used in some states or tribal territories might be subject to different rules than landfills that are used in other locations. The information gathered in accordance with these regulations has two crucial functions: it informs environmental regulators about the effectiveness of landfill gas collection systems and it describes the potential explosion risk that accumulation and migration of landfill gas may present. Methane levels near landfill perimeters must be monitored. For more information on the LEL of landfill gas, see Chapter Three. If methane concentrations at the monitoring stations at the property boundary exceed the LEL, which is the lowest percent by volume of an explosive gas in the air that will allow an explosion, RCRA requires the landfill to report the exceed to the appropriate state authority and develop and implement a plan to correct the problem. The landfill's effectiveness in solving the issue will be evaluated by the state solid waste authority. Not only during landfill operation, but also after closure, methane monitoring must be done.

- **To Describe Potential Fire or Explosive Threats Off-site**. To address worries about landfill gas migration and associated explosion threats, several landfills conduct soil gas monitoring for methane at off-site locations.
- **To Estimate Chemical Movement away from the Site**. Some landfills have been classified as hazardous waste sites by federal or state environmental legislation, or locals are worried about trace amounts of chemicals (mainly NMOCs) that could contaminate nearby homes with soil gas. Methane monitoring data cannot directly address the migration of pollutants from these sites. Therefore, sampling operations may be organized by environmental agencies or the locals themselves as part of site inquiry efforts to detect the various pollutants in soil gases as well as their soil gas concentrations. The most in-depth information about landfill gas contamination levels is provided by such chemical-specific soil gas monitoring.

2.4.15.3: The Method Used to Gather Soil Gas Samples.

Samples of soil gas are taken from permanent soil gas monitoring wells, landfill gas collection wells, and temporary monitoring probes (commonly referred to as punch probes or punch bars). Depending on monitoring issues or regulatory requirements, the locations and sampling techniques for soil gas samples differ from dump to landfill.

2.4.15.4: What Can You Infer from Soil Gas Monitoring Data?

The findings of soil gas monitoring may reveal a wealth of knowledge regarding waste gases and their flow through the landfill. Methane and other gases, such NMOCs, in the landfill and surrounding its perimeter can be identified using soil gas monitoring. The location of the sample, its frequency, and the caliber of the data are crucial considerations when interpreting the results.

Data from soil gas monitoring wells or probes can be used to pinpoint off-site subterranean channels and on- or off-site structures that could be at danger from escaping methane and other gases. Using this data, decision-makers can decide whether and how soil gas collection and treatment are required to safeguard the safety and health of the general public. The chemicals and their concentrations that residents living next to a landfill may breathe in are not, however, really measured by soil gas monitoring data. Underneath the landfill surface, soil gas samples are taken, and the gas concentrations will alter as the gases flow vertically into the atmosphere or horizontally through the subsoil. Environmental laws may also limit monitoring requirements to methane. The subsoil may include other gases, like NMOCs. Environmental health professionals should be cautious when analyzing soil gas data to take into account the sampling locations in relation to potentially exposed people and sample analyses in respect to the gases, particularly NMOCs, that may be present the following list of inquiries should be taken into account while examining soil gas data to make sure that they are accurate representations of subsurface conditions. Regarding the sampling findings, knowing the pressure and water level at the time of the sample can be helpful. In order to control the passage of waste gas, pressure is a crucial aspect. Gases flow between zones of high and low pressure, as was previously discussed. Because of this, if the atmospheric pressure is greater than the pressure in the landfill, ambient air will enter the soil gas well or probe. Under these circumstances, any samples obtained wouldn't be an accurate representation of the landfill gas. Water can impede gas passage, so the level of the water is crucial. A soil gas well or probe releases gases when it is submerged in water.

Table 2.12 Questions to Ask When Analyzing Landfill Soil Gas Monitoring Data

Questions to Ask When Analyzing Landfill Soil Gas Monitoring Data

Select Gases for Monitoring

• Which gases are regularly analyzed?

• Do these contain the chemicals that the public, regulators, and public health professionals have identified as being of concern?

•Do routine updates on methane levels also include oxygen and carbon dioxide?

• Are the most dangerous and/or anticipated to be present in the highest concentrations among the chemicals chosen for monitoring?

• Do the substances chosen for monitoring have any data gaps?

Monitoring Pressure

• Do routine reports contain the ambient (barometric) and well/probe pressures?

• Do any of the soil gas wells or probes have specific pressure gauges?

Sampling Procedures

• Did the EPA authorize the sampling techniques used? Why, if not?

• Are the sample techniques equivalent to or comparable to those suggested by the Solid Waste Association of North America and/or by state regulation programs like the one run by the Missouri Department of Natural Resources?

• Are the chosen procedures advised for gauging the substances chosen for monitoring?

• Are water levels in the soil gas well or probe evaluated following the collection of gas samples?

Sampling Instruments

• Was the sampling equipment made to work in the conditions it was put to use?

- Were the restrictions placed by the manufacturer on the conditions in which the equipment would provide accurate readings adhered to?

Check the depth of screened intervals and the construction of wells.

- How deep are the wells' and probes' bottom boreholes below the surface of the land?
- At what depth below the surface of the land does the well/probe screen start and stop (top and bottom of screen interval)?
- How deep a well or probe is, and how long is the screen interval in relation to the top and bottom of buried waste and the top of the groundwater surface (water table), respectively?
- Does regular or recurring monitoring show if the well or probe is dry or partially filled with water?
- Is there a geology report included with the report on the well construction?
- Have probable subsurface paths been predicted or investigated using geologic analysis?

Locations Under Watch

- Is there a program for monitoring the perimeter that allows for enough space between stationary soil gas monitoring wells?
- Do structures on the property have monitoring wells close by?
- Do the limits of the dump and any nearby properties that include occupied buildings have monitoring wells?

Is the landfill equipped with passive vents that are regularly checked?

- Have handheld instruments been used to undertake a surface sweep study to identify "hot spots" at the landfill's surface that would be the ideal area for long-term monitoring wells or probes?

Other Sources

Are there any further potential sources of contaminated soil gases, such as subterranean storage tanks, petroleum spills, or leaky natural gas pipes?

Monitoring Routines

- How frequently (daily, weekly, monthly, or quarterly) are the monitoring wells/probes sampled?
- Are samples taken at least once every month from wells near occupied buildings on the landfill?
- How often do gas collection and venting systems undergo sampling?
- If there have been reports of large levels of NMOCs in the past, has monitoring been done regularly enough to identify historical patterns of high and low concentration locations across the landfill or at property boundaries?

Is there a provision in the monitoring schedule for sample under the worst-case weather conditions, such as when the landfill's surface is frozen or flooded?

- not provide a consistent methane reading?
- Is there regulatory oversight of sampling team performance?

Quality Parameters for Data

How many sample attempts were successful, on average?

- How reliable were the sampling findings that were reported?
- How accurate were the sampling findings that were reported?

Do samples' oxygen concentrations reach ambient levels, which can be a sign of a leaky well casing or malfunctioning sampling tools?

How many of the monitoring wells/probes are either flooded or do not

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Sources: DOE 1995, EPA 1993, Crawford and Smith 1985.

2.4:16 Landfill Gas Control Measures

We will examine popular landfill gas management technologies under this area. These technologies include ways to gather gases, manage and treat gases, and use gases for social good (such as to produce power or heat buildings). Several factors, such as governmental requirements, odor issues, or uncontrolled gas discharges that could be dangerous or unhealthy, could necessitate the use of gas management techniques at a landfill. It is not required of you as an environmental health specialist to be able to create and carry out a landfill gas control plan. However, you should have a fundamental awareness of the available control solutions to aid in preventing or limiting exposures to landfill gas.

2.4.16.1: Why Would Safety Precautions be taken at a Landfill?

Regulations necessitate the installation of gas control systems by landfills. Landfill management and upkeep are governed by laws and regulations created by the federal government. These regulations have been developed to reduce health and environmental impacts from landfill gas emissions through the reduction of ozone precursors (volatile organic compounds and nitrogen oxides), methane, NMOCs, and odorous compounds. State-specific landfill laws are permitted and must be just as rigorous as federal regulations if not stricter. Some of the relevant laws are reviewed in the boxes on the following page.

As previously mentioned, odor complaints or other safety and health issues may also cause landfill gas collection. A prominent cause of complaints about landfill odors is sulfur dioxide emissions. Uncontrolled discharges of landfill gases may be a risk to safety and health (such as explosion threats) at older landfills or smaller landfills that are exempt from federal and state laws. Even if they are not required by federal or state rules, the landfill may still adopt landfill gas management techniques in such circumstances. To recover landfill gas for energy production, several landfills have also installed voluntary gas collecting, control, or treatment systems.

Table 2.13 Regulation of Landfill Gas Migration by the Federal Government Under

Title D of the Resource Conservation and Recovery Act (RCRA)

Controls on the migration of methane in landfill gas have been necessary since October 1979 as a result of federal regulations issued under Subtitle D of RCRA, which governs the siting, design, construction, operation, monitoring, and closure of MSW landfills. Other elements of landfill gas are not covered by these rules. For MSW landfills operating on or after October 9, 1993, the EPA set criteria for landfill design and performance in 1991. The guidelines impose performance benchmarks for methane migration management and call for methane monitoring. In addition to during operation, landfills are required to comply with monitoring criteria for 30 years following closure. A procedure to routinely check for methane emissions and stop off-site migration must be established by landfills subject to RCRA Subtitle D in order to manage gas emissions. The management of landfills must prevent methane gas concentrations from exceeding:

The structures of the facilities include 1.25 percent by volume of the EL for methane.

• The facility boundary's methane LEL (5% by volume)

The fact that methane is explosive at airborne concentrations between 5% and 15% is reflected in the permitted limits on methane emissions. Corrective action, such as the installation of a landfill gas collection system, must be conducted if methane emissions are higher than the authorized limits. EPA's Office of Solid Waste website at 40 CFR Part 258 offers access to the Subtitle D RCRA regulations for MSW dumps.

Regulations (NSPS/EG) of the Clean Air Act (CAA) set forth federal requirements.

The EPA mandates that affected landfills collect and manage landfill gas under NSPS/EG of the CAA. The NSPS/EG set reduction goals for landfill gas emissions because of odor, potential health consequences, and safety concerns. In order to assess if control is necessary, the regulations substitute NMOCs, which contribute to the creation of local smog. Landfills are required to collect landfill gas and either flare it or use it for energy if they meet specific design capacity and emissions limits. The following two requirements must be met by a landfill in order for it to collect and regulate landfill gas emissions.

•Capacity: a design capacity of 2.5 Mg and 2.5 million cubic meters, or larger.

•Emissions: NMOC emissions must be at least 50 Mg per year.

. For both new and old landfills, the fundamental requirements remain the same. Landfills that started construction before May 30, 1991 and began receiving waste after November 8, 1987 are considered existing landfills. Through the EG, these are controlled. Landfills that started their construction, rehabilitation, or alteration on or after May 30, 1991 are referred to as new landfills. These are governed by the NSPS. On the Internet at http://www.access.gpo.gov/nara/cfr/waisidx_00/40cfr60_00.html, you can find 40 CFR Part 60, Subparts Cc and WWW, which contains the CAA regulations (NSPS/EG) for MSW landfills. You can find state plans and a federal plan to apply the EG for current landfills in 40 CFR Part 62.Additionally, you can access the whole list of Federal Register notices and summaries at http://www.epa.gov/ttn/atw/landfill/landflpg.html.

Sources: DOE 1995, EPA 1993, Crawford and Smith 1985.

2.4.16.2: What Constitutes a Landfill Gas Control Plan?

A landfill gas control plan's objective is to shield people from the emissions of landfill gas. To accomplish this, either landfill gas must be collected and treated there, or landfill gas must not be allowed to enter local structures like homes and buildings. At the landfill or in the neighborhood, technologies used to manage landfill gas can be utilized singly or in combination. Keep in mind that the NSPS/EG mandates a design plan for a landfill's gas collection and control system if it satisfies the requirements listed on the next page. The requirements for the collection and control systems are outlined in the NSPS rule, along with the types of information that must be provided.

2.4.16.3: How is the Gas from Landfills Gathered?

A passive or active collection system can be used to capture landfill gas. In a typical collection system, whether passive or active, a number of gas collection wells are dispersed around the landfill. The volume, density, depth, and area of the waste, as well as the landfill's unique properties, determine the number and spacing of the wells. As gas is produced in the landfill, the previously mentioned collection wells provide the best routes for gas migration. The majority of collecting systems have some level of redundancy built in to ensure continuous operation and safeguard against system failure. Extra gas collection wells may be included in a system's redundancy in the event that a single well fails. The next section discusses the system-specific components for passive and active gas collection systems.

- **Systems for passive gas collection.** For the purpose of venting landfill gas into the atmosphere or a control system, passive gas collecting systems (fig. 2.3) rely on alreadyexisting changes in landfill pressure and gas concentrations. It is possible to deploy passive collecting devices both during and after a landfill's active operation. In passive systems, landfill gas is collected using collection wells, also known as extraction wells. The collection wells are normally made of perforated or slotted plastic and are positioned vertically across the landfill at depths between 50% and 90% of the thickness of the rubbish. If there is groundwater present in the waste, wells stop at the groundwater table.

After a landfill, or a section of a landfill, has been closed, vertical wells are often built. The use of a passive collection system. Horizontal wells may be suitable for deep landfills, active landfills, or landfills that need to recover gas quickly (such as landfills with issues with subsurface gas migration). The collection wells may occasionally vent straight to the atmosphere. Frequently, the gas is transported from the collection wells to treatment or control systems (such as flares). How effectively the gas is trapped within the landfill has an impact on how effective a passive collection system is. The design of the landfill collection system allows for control and modification of gas containment. On the top, sides, and bottom of the landfill, liners can be used to contain gas. Clay or geosynthetic membranes, for example, are impermeable liners that can be utilized to generate preferred gas migration paths and capture landfill gas. By forcing the gas to leak through collecting wells rather than the cover, an impermeable barrier placed on top of a landfill, for instance, will reduce uncontrolled venting to the atmosphere. The effectiveness of a passive collection system is also influenced by the environment, which may or may not be under the system's control. Passive systems fail to remove landfill gas successfully when the pressure inside the dump is insufficient to force the gas to the venting device or control device. As was previously mentioned, when there is a high barometric pressure, it can occasionally happen that passive vents that are not sending gas to control devices allow outside air to enter the landfill. These factors make passive collection systems unsuitable for application in regions where there is a high risk of gas migration, particularly when methane can build up to explosive amounts in structures and enclosed spaces.

- Even if the landfill is exempt from legal regulations, it is rather typical for them to flare gas due to odor issues, for instance. Only in landfills where the cells have been walled in accordance with Subtitle D of the RCRA to prevent gas migration are passive gas collection devices permitted to comply with the NSPS/EG.

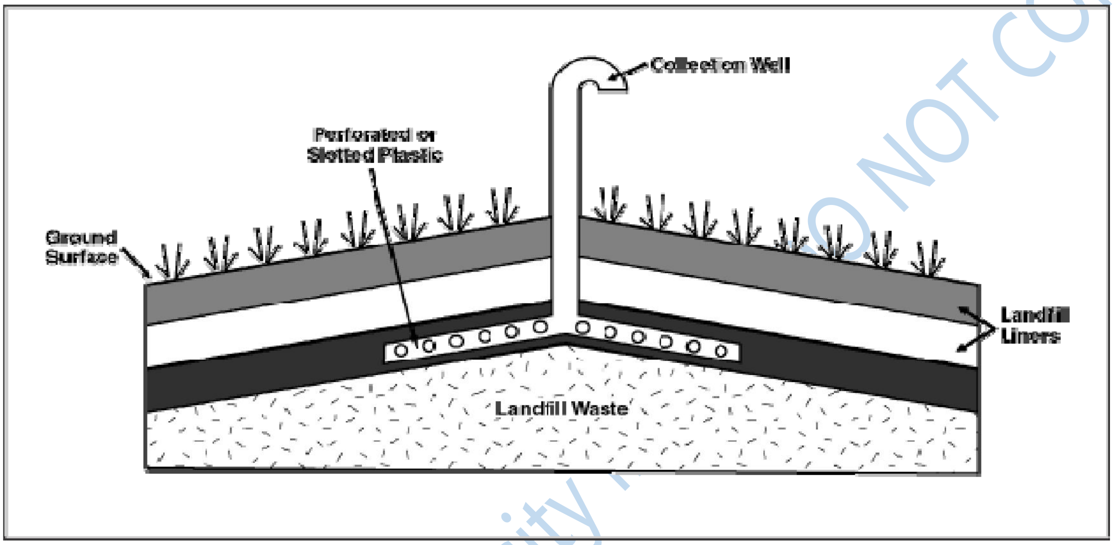

Figure 2.4: Collection of Passive Gas

Sources: EPA (1995); Tchobanoglous, Theisen, and Vigil (1993).

- **Collection of Active Gas.** The most efficient way to collect landfill gas is using welldesigned active collecting systems (fig. 2.4) according to the EPA (1991). In addition to horizontal and vertical gas collection wells, active gas collection systems also include passive collection systems. However, in contrast to the gas collection wells in a passive system, wells in an active system should contain valves to control gas flow and operate as a sample port. The system operator can determine the pressure, composition, and production of gas via sampling. Pumps or vacuums to remove gas from the landfill are part of active gas collection systems, and piping connects the collecting wells to the vacuum. By lowering the pressure inside the gas collection wells, vacuums or pumps draw gas from the landfill. The landfill gas migrates along a favoured channel because of the low pressure in the wells. Depending on how much gas is being produced, a system that actively pulls gas from a landfill may require a specific number, size, and kind of vacuums. A landfill operator can evaluate changes in gas production and distribution and adapt the pumping system and collection well valves to run an active gas collection system as efficiently as possible with the use of information regarding landfill gas generation, composition, and pressure. Future gas management requirements, such as those brought on by landfill expansion, should be included in the system design. A system for active gas collection that works well is described in the box on the following page.

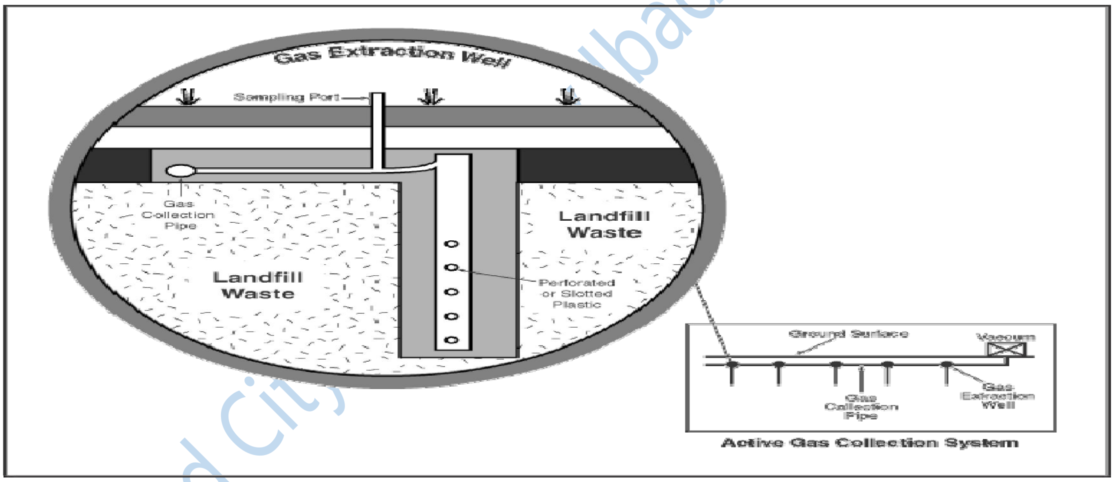

Figure 2.5 System for Active Gas Collection

Sources: EPA (1995); Tchobanoglous, Theisen, and Vigil (1993).

Table 2.14 Creation of an efficient active gas system

Creation of an efficient active gas system
Creation of an efficient active gas system Creation of an efficient active gas system The following design components are included in an efficient active gas collection system (EPA 1991): • • Gas-moving machinery, such as vacuums and pipelines, able to handle the highest rate of landfill gas generation; • Gas collection wells positioned to collect gas from all landfill regions. The kind, depth, and compaction of the waste, as well as the vacuums' pressure gradients and the gas's moisture content, all influence how many extraction wells there should be and how far apart they should be from one another. • the capacity to keep an eye on and modify extraction well flow. Each collecting well has a valve, pressure gauge, condenser, and sampling port, enabling the landfill operator to track and modify pressure as well as gauge gas generation and composition.

Sources: DOE 1995, EPA 1993, Crawford and Smith 1985.

2.4.16.4: What Techniques are available to treat Landfill Gas once it has been collected? In certain passive gas collection systems, landfill gas is simply vented to the atmosphere without any prior processing. If only a little amount of gas is produced and there are no nearby homes or places of employment, this might be appropriate. However, the collected landfill gas is typically managed and treated to lessen any potential risks to safety and health. Technologies for combustion and non-combustion, as well as odor control, are frequently used to treat landfill gas.

Burning. The most popular method for regulating and treating landfill gas is combustion. The chemicals in landfill gas are thermally destroyed by combustion technologies as flares, incinerators, boilers, gas turbines, and internal combustion engines. In most cases, organic molecules are destroyed to a level of above 98%. Methane is changed into carbon dioxide, which has a significant negative influence on greenhouse gas emissions. When at least 20% of the volume of the landfill gas is made up of methane, combustion or flaring is most effective. At this methane concentration, landfill gas will easily combine with surrounding air to generate a flammable mixture, necessitating only an igniting source for operation. Flares must be operated with additional fuel, such as natural gas, at landfills with less than 20% methane by volume, significantly raising operation expenses. while burning

- The most basic type of flare technology, open flame flares (such as candle or pipe flares), consists of a pipe through which gas is fed, a pilot light to ignite the gas, and a way to control the gas flow. An advantage of this technique is how straightforward an open flame flare is to construct and use. Combustion inefficiency, aesthetic issues, and monitoring challenges are drawbacks. Open flame flares are occasionally partially covered to block the flame from view and boost monitoring precision.

- Compared to open flame flares, enclosed flame flares are more complicated and expensive. However, since enclosed flares do away with some of the drawbacks of open flame flares, they represent the majority of flares created today. Multiple burners are contained within fire-resistant walls that extend above the flame in enclosed flame flares. Contrary to open flame flares, combustion in an enclosed flame flare can be controlled, improving reliability and efficiency.

- In addition to effectively destroying the organic chemicals in landfill gas, other enclosed combustion technologies, including as boilers, process heaters, gas turbines, and internal combustion engines, can also be used to produce useful energy or power, as will be discussed later in this chapter.

The possibility that harmful compounds could be produced during the combustion of landfill gas has sparked some public concern. Combustion can produce corrosive gases like SO2 and NOX.

It has also been questioned how dioxins are produced. The EPA looked into the dioxin formation issue and came to the conclusion that the data already collected from a number of landfills did not provide indications of a significant dioxin production during landfill gas combustion. Landfill gas annihilation in a properly built and operated control device, such as a flare or energy recovery unit, is preferred to uncontrolled landfill gas release due to the possible urgent health threat from other components of waste gas. As it becomes available, scientists continue to analyze fresh data on by-product emissions from landfill gas control equipment.

Non-burning. In order to replace combustion, which results in the production of substances including nitrogen oxides, sulfur oxides, carbon monoxide, and particulate matter that contribute to smog, non-combustion technologies were created in the 1990s. The two categories of non-combustion technologies are gas-to-product conversion technologies and energy recovery methods. The pretreatment of the landfill gas is necessary to get rid of pollutants including water, NMOCs, and carbon dioxide, regardless of the non-combustion technique employed. The contaminants of concern for a particular landfill can be addressed using a variety of pretreatment techniques. Following pretreatment, methods for non-combustion technology are used to treat the cleaned-up landfill gas.

- Technologies for energy recovery utilise landfill gas to generate energy directly. The only commercially accessible non-combustion energy recovery device at the moment is the phosphoric acid fuel cell (PAFC). Molten carbonate, solid oxide, and solid polymer fuel cells are some of the other fuel cell types that are still being developed. The PAFC system consists of a power conditioning system, fuel cell stacks, a fuel cell processing system, and landfill gas collection and pretreatment. Within this system, numerous chemical processes generate waste gases, electricity, and water. A flare is used to burn up the waste gases.

- Technologies for turning landfill gas into commercial goods including compressed natural gas, liquefied natural gas, methanol, refined carbon dioxide, and methane are referred to as "gas-to-product conversion." Although the procedures used to make each of these products differ, they all involve the collection of landfill gas, pretreatment, chemical reactions, and/or purifying methods. Flares are used in several of the operations to eliminate gaseous wastes.

- Technology to control odours. Technologies for odor control stop odor-producing gases from escaping the landfill. By installing a landfill cover, odors from recently dumped waste or gases created by bacterial decomposition will be stopped. Daily soil covering of a landfill can help to mask the smell of freshly dumped rubbish. At landfill closure, more substantial covers are put in place to stop moisture from penetrating the waste and promoting bacterial development and breakdown. Additionally, vegetation growth on the landfill's lid lessens odors. Another method for getting rid of landfill gas odors is flaring, which thermally destroys the gases responsible for the stench. Another solution used to lessen smells is venting landfill gas through a filter. A bacterial slime filter is used to collect and release landfill gas. As long as there is oxygen, microorganisms will break down landfill materials.

Table 2.15 Calabasas Landfill odour control

Calabasas Landfill odour control
From its founding in 1961 until December 1995, when the County of Los Angeles approved a law restricting its use, the Calabasas Landfill, which serves 1.4 million residents in the Los Angeles region, received over 17 million tons of waste. A system for actively collecting landfill gas was gradually put in place starting in the middle of the 1980s. The system consists of a network of trenches and vertical wells spread out over the trash fill. The system of wells and trenches is subjected to a vacuum in order to attract the gas into the collection system. The gathered gas is transported to a flare station where it is burned off in flares. The gas collection system is one of the main strategies for odor management at the landfill, along with the rejection of smelly loads and the application of daily cover. These actions led to the facility only receiving one odor complaint throughout 1995 (NPS 1997).

Sources: DOE 1995, EPA 1993, Crawford and Smith 1985.

2.4.16.5: If Landfill Gas seeps into surrounding structures, what options are there for controlling it?

Under certain circumstances, the subsurface migration of landfill gas into the neighborhood could pose risks to public safety and health, including the possibility of explosion or suffocation. Landfill gas can enter a house or building through a variety of different openings once it gets there.

Controlling the gas at the source (the landfill) is the ideal method for preventing landfill gas from entering houses. There are, however, a number of straightforward structure- or community-based controls that can be used to cut back on gas entry points and restrict indoor gas movement.

Control measures might be incorporated into the building design if a landfill gas issue is foreseen before to construction. If not, the finished structure might need to be modified. The two primary methods for stopping gases from entering a structure are as follows. In structures where accumulation of explosive volumes of landfill gases is likely, continuous methane monitors with the proper alarms should be strategically positioned, regardless of the techniques used to prevent or decrease landfill gas ingress. To maintain optimal operation, a regular safety check and maintenance program should be implemented for the engineering controls and methane monitors. The limits of various strategies for controlling landfill gas are described in the box below.

- **Gas Pressure Regulators.** Gas will enter a building or structure if the gas pressure within is lower than the gas pressure in the soils around the building or structure. Gas migration within can thus be avoided by managing gas pressure. Passive or active venting to lower gas concentrations under the house, perimeter venting, and crawl-space venting are a few methods for controlling gas pressure.

However, some of these methods can need for pumps that need upkeep and electricity.

- Leakage Area Management. Reduce or eliminate entryways as a further method of preventing gas from entering a facility. Gas can seep into a structure or building through air ducts, drainage pipes, fireplace air vents, and fractures and gaps. Entry paths can be decreased in a basement by sealing cracks and gaps and improving plumbing. However, it's possible that these solutions only fully address indoor gas migration. Installing a low permeability liner around the building's basement or underground area is another option for control.

Table 2.16 What are the options for controlling landfill gas?

What are the options for controlling landfill gas?

Technologies for collecting landfill gas

Active exhalation

- The effectiveness depends on how close the system is placed to the gas source.
- Inadequate operation and monitoring may result in aerobic conditions that might cause pipework to distort and underground fires.
- Needs maintenance and monitoring.

Passive airflow

- Not entirely effective for petroleum-based fumes; most effective when used in shallow pits.

Technologies for Community Control

Pressure Controls for Gas

- There are few performance data for crawl space venting, and maintenance is required.
- Only modest amounts of subterranean gas can be vented passively.

• Active venting can need upkeep.

- **Leakage Area Control**
- Use of sealing, caulking, and liners has had limited success in stopping gas migration. • Plumbing adjustments may only partially solve the issue. Installing a low-permeability liner around the basement or other underground area of the building is another option for control.
- Are there any useful use for gathered landfill gas?

Sources: DOE 1995, EPA 1993, Crawford and Smith 1985.

2.4.16.6: Are there any useful use for gathered Landfill Gas?

The majority of man-made methane emissions in the United States come from landfill gas, which accounts for roughly 40% of all annual emissions (EPA 1996). Consequently, using recovered landfill methane gas as a source of energy is becoming more common at landfills all throughout the country. The risk of explosions is considerably reduced when landfill gas is collected for energy usage. It also benefits the community financially, conserves other energy resources, and may lessen the risk of global climate change.

About 325 landfill gas energy recovery projects in the US currently stop the annual emissions of over 150 billion cubic feet of methane (or over 300 billion cubic feet of landfill gas). Around 220 of these plants produce power, amounting to an annual output of over 900 megawatts. More than 150 new projects are being planned, and 68 more projects are already under construction in 2001. According to earlier research by the EPA and the Electric Power Research Institute, up to 750 of the country's landfills might profitably capture and utilize their methane emissions (DOE n.d.a.).

2.4.16.7: What kind of Landfills are suitable for Gas Recovery, and how is electricity produced from landfill gas?

The viability of setting up a landfill gas recovery system depends on a number of variables, including the rates of waste gas production, the accessibility of users, and potential environmental effects. Energy recovery projects can be supported by a variety of landfill types with differing gas output rates and compositions. However, there are a few principles to take into account when determining if producing electricity from landfill gas is feasible. Some of these rules are listed in the box on the page after this one.

Energy recovery may be performed using combustion- or non-combustion-based technologies, as appropriate. Internal combustion engines, gas turbines, boilers, and process heaters are examples of combustion-based devices that recover energy. For instance, landfill gas may be piped to a neighboring factory, business, institution of higher learning, or public building where it will be burned in a boiler to produce steam for a manufacturing operation or heat for the structure. It might be burned in a process heater for industry to provide heat for a chemical reaction. Gas from landfills can be burned in turbines and internal combustion engines to produce power. The electricity may be sold to the power grid or used to satisfy the energy requirements at the dump or another local facility.

Depending on the users who are located close to the dump, site-specific technical and economic factors, and occasionally environmental consequences, the type of combustion equipment to utilize (such as a boiler, gas turbine, or internal combustion engine) is decided. For smaller landfills, for instance, internal combustion engines are frequently less expensive than gas turbines. However, these engines might produce more NOx, which helps to create ozone. The use of an internal combustion engine may be complicated by NOx emissions if the dump is located in an ozone non-attainment area.

Table 2.17 Which Elements Are Crucial for Landfill Gas Recovery?

Which Elements Are Crucial for Landfill Gas Recovery?

The following elements are suggested as guidelines for economically viable landfill gas recovery projects by landfill gas recovery systems. However, as new technology become available, projects at smaller landfills have been successful thanks to them. Smaller landfills, for instance, can produce enough gas to power a micro turbine to produce a tiny amount of electricity or heat an on-site greenhouse. The economic viability of landfill gas recovery projects can also be improved by a variety of federal and state incentives, including grants, loans, tax credits, and renewable energy purchasing mandates.

•There are more than a million tons of rubbish currently stored at a landfill.

•The waste is more than 35 feet deep and sturdy enough to allow the installation of a well.

•The landfill's footprint is larger than 35 acres.

•The landfill is made up of trash, which can produce a lot of landfill gas with a methane content of at least 35%. According to an industry standard, landfills with gas generation rates of 1 million cubic feet per day are economically viable for gas recovery (EPA 1996).

•Active landfill operation will continue for a number of more years if a dump is still operational.

•A short period of time (no more than a few years) has passed after a landfill was closed.

Gas can thrive in this environment.

Sources: DOE 1995, EPA 1993, Crawford and Smith 1985.

Although not as popular, non-combustion energy recovery devices are also available. A possible new technology for generating electricity from landfill gas without combustion is fuel cells. This technique has been tested, and in the future it might be more cost-effectively comparable to alternative solutions. The purification of landfill gas to remove components other than methane and create a high British thermal unit (Btu) gas that may be marketed as pipeline quality natural gas is one approach that does not entail burning landfill gas at or near the landfill. The high Btu gas will eventually be burned, but it won't cause any pollution close to the landfill. Compressed landfill gas can also be used as a car fuel.

A gas collection system, a system for processing, treating, and converting the gas, and a way to deliver the gas or finished product to the customer are the three fundamental parts of both combustion and non-combustion energy recovery systems (Fig. 2.5). By using active vents, gas is gathered from the landfill. Once there, it is taken for processing at a central location. The amount of processing necessary varies based on the gas composition and the intended use, but usually entails a sequence of chemical processes or filters to remove contaminants. There is little preparation needed for the direct use of landfill gas in boilers. A significant amount of carbon dioxide removal is required before landfill gas can be injected into a natural gas pipeline. To eliminate any particles and water that may be suspended in the gas stream, the gas is at the very least filtered[107].

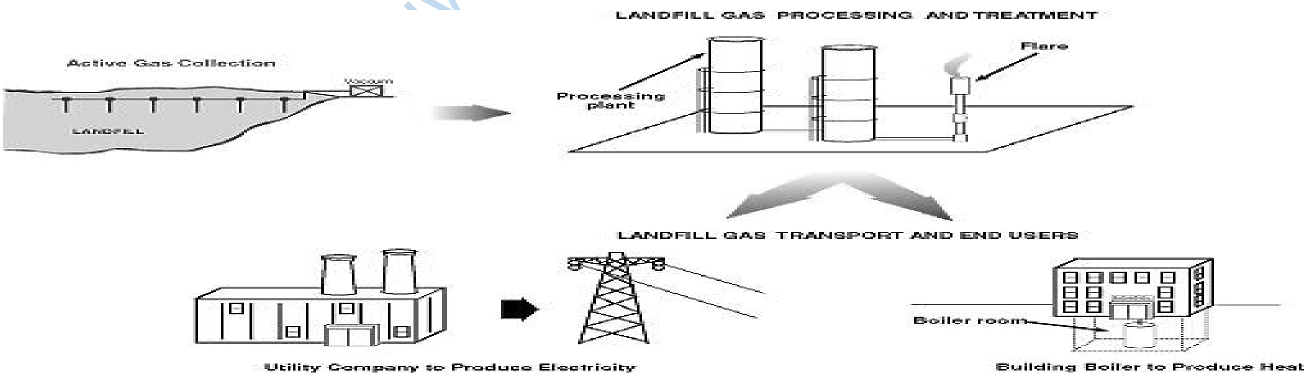

Figure 2.6: Landfill Gas Recovery System

Sources: EPA (1995); Tchobanoglous, Theisen, and Vigil (1993).

2.4.17: Influence of Animal Manures of Biogas Production in Landfill

Animal manure and other composted organic materials (cow dung) increase nutrient content and bioavailability, which encourages microbial activity and the production of complex organic polymers and chemical metabolites that act as bridges and bonding agents for cementing flocculated clay particles into aggregates. The solid, semisolid, and liquid waste products produced by animals raised for the purpose of producing meat, milk, eggs, and other agricultural products for human use and consumption are known as animal manures. They are combinations of waste feed, soil, wash fluids, and any chemical or physical amendments used during manure management and storage, as well as bedding materials (such as straw, sawdust, rice hulls), and other items related to animal production. Since the dawn of civilization, manures have been utilized as beneficial soil additions, and until the 1940s, they were the main type of soil amendment employed in agriculture. Manures are still recognized as key agricultural resources today since they are significant suppliers of plant nutrients and are known to enhance the physical and biological characteristics of soil through the incorporation of organic matter. The shift away from small farms with sufficient land bases to recycle manure nutrients through crop production and the increase in geographically concentrated confined animal feeding operations (CAFOs) have raised questions about the effects of contemporary animal production and manure utilization practices on the environment and human health[106].

2.5 Summary of Gaps in Literature Reviewed

Many different gases can be found in landfill gas. 90 to 98% of landfill gas is made up of methane and carbon dioxide. Nitrogen, oxygen, ammonia, sulfides, hydrogen, and other gases make up the remaining 2 to 10%. Bacteria that break down organic garbage release landfill gases. The quantity of these gases varies according to the type of waste in the landfill, its age, oxygen content, moisture content, and temperature. For instance, if the temperature or moisture content rises, gas production will as well. A landfill can continue to emit these gases for more than 50 years, even though their production typically peaks in five to seven years[104]. The majority of municipal solid waste (MSW) is made up of recyclable materials like paper and cardboard. MSW is produced by a number of buildings, including offices and cafeterias, inside educational institutions, particularly universities. Solid waste can have negative effects on the environment if there is no adequate management strategy in place[105]. Cultural beliefs are a significant impediment to effective waste management in Nigeria. In conclusion, human-centered strategies should be prioritized in municipal solid waste management in addition to technology-centered ones[108].

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Chapter Three

Methodology

3.1 Description of the Study Area

Lead City University (LCU) is situated in Ibadan, Oyo State, Nigeria which has a student population of 41,743 as at the time of carried out the research work. The location of the university is 7.4433° N and 3.9003° E. Lead City University is a non-profit private higher education institution located in the urban city of over 2,550 acres of land. The university was approved for immediate take-off by the board of National University Commission (NUC) in December 2003 and was ratified by the Federal Executive Council on 16 February 2005. The university has graduated more than 5,000 graduates and 2,600 postgraduates. LCU also provides several academic and non-academic facilities and services to students including standard library, housing, sports facilities, micro finance services and as well as administrative services.

3.1.1 Research Study/Design

Cross-sectional and investigation methods were used in the research study. A pilot sorting and separation was conducted at the selected sources of waste generation in the Lead City University, Ibadan from November 2022 to April, 2023 (6 months) for collection of data on composition, generation rate and compliance level of separation at source of the waste. Surveys for solid waste management (SWM) program by the university operators, on-site waste measurements (quantification) and characterizations were conducted.

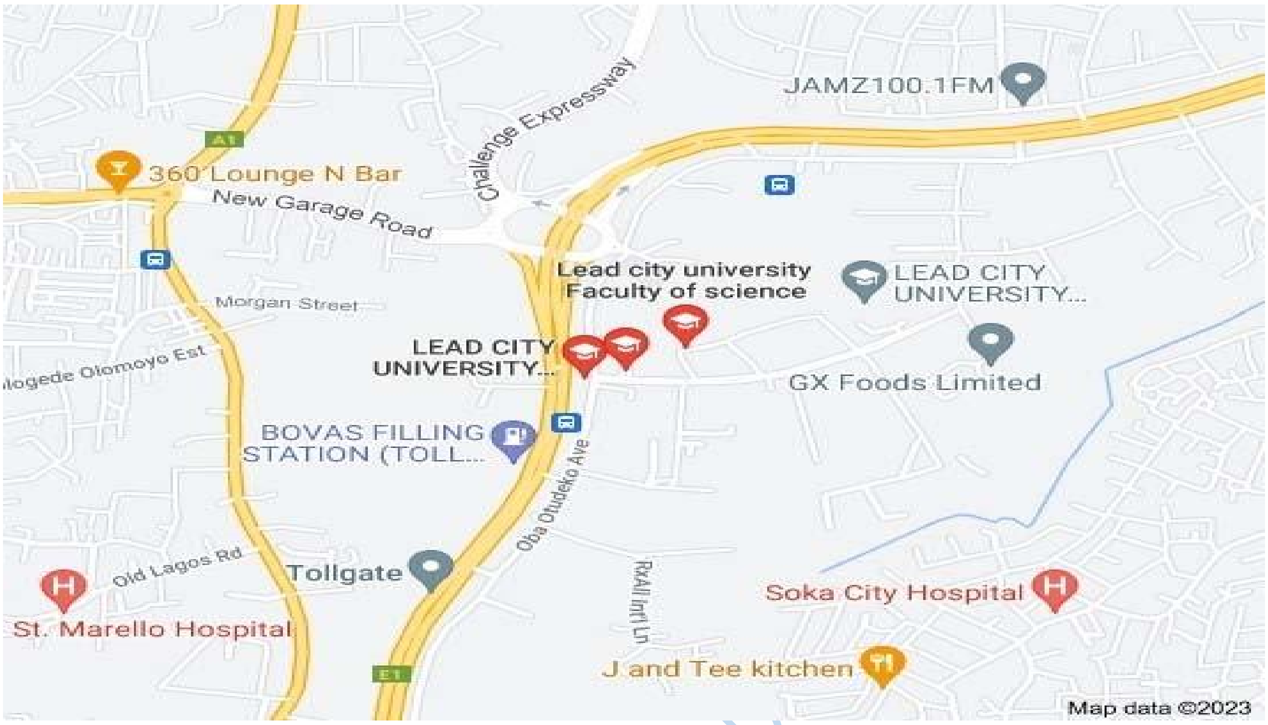

Fig 3.1: Location of Lead City University, Ibadan

Source: Google map

3.1.2 Study Population

The study population was obtained by stratified random selection as follows;

a) students in various hostels (both males and females)

b) all recognized sources of waste generation

c) anticipated amount of waste generated per week at Lead City University

The above steps were taken in order to have the idea of design capacity of adaptive sanitary landfill to be constructed. The sample population exclusively consisted of people who could offer first-hand knowledge of the subject at hand.

Table 3.1: Population of students in male hostels

S/N	Name of the hostels	Total number of the students
1	Exodus Hall	495
2	PG Hall	206
3	Hibiscus Hall	62
4	Block U	228
5	Block I	135
6	Maintenance Hall	27
7	Independence Champion and Wisdom	548
Total		**1,701**

Field survey conducted in 2023

Table 3.2: Population of students in female hostels

S/N	Name of the hostels	Total number of the students
1	Proverb 1	48
2	Proverb 2	48
3	Revelation 1	64
4	Revelation 2	64
5	Apple Hall	232
6	Olive Hall	459
7	Block L	114
8	Block C	114
9	Achiever Hall	104
10	Victory Hall	79
11	Peace 1	64
12	Peace 2	64
13	Camp-David 1	98
14	Camp-David 2	98
15	Camp-David 3	98
16	Camp-David 4	98
17	Camp-David 5	100
18	Camp-David 6	100
19	Jackson Hall	97
20	Hibiscus Hall 2	48
Total		**2,191**

Field survey conducted in 2023

The total number of students living in both male and female hostel is three thousand eight hundred and ninety two (3,892) and three hundred and eighty-four (384) students were randomly selected using the Leslie Kish formula.

3.2 Materials

Objective one

(1) Structured questionnaires

Objective two

(1) Weighing balance of capacity up to 120kg

(2) Mackintosh polythene bags for collecting and weighing waste materials

(3) Shovels and forks for collecting and storing wastes in bags

(4) Gloves, boots and face-masks for personal protection

Objective three

(1) ASTM E1756-01 standard for determining the moisture content

(2) Desiccator for drying

(3) Furnace of varying temperatures

(4) ASTM standard E-872 for determining volatile organic compounds

(5) ASTM D1102 2013 and ASTM D1102 24 procedures for measuring ash

Objective four and five

(1) Jigger to dig 15feet in length, 6 feet in width and 3 feet in height of the top soil

(2) 12 pieces of standard 50kg nylon rice bags sown to make a non-perforated nylon sack

(3) Manual compressor to compress the biodegradable wastes

(4) Pipes to drain off waste water released after compression

(5) 50kg keg used as methane chamber to collect biogas (i.e methane, CO_2, H_2S and H_2O)

(6) Lighter to ignite fire for the test of methane

(7) Activate charcoal to filter out CO_2, H_2S and H_2O (impurities)

(8) Animal manures to aid digestion of the biodegradable wastes

(9) 2mm storm pipe to redirect and manage runoff water from rain and storms.

(9) Handheld Sewerin Multitec 540 to measure methane, CO_2, H_2S and H_2O.

3.3 Methodology

3.3.1 Sample Size Determination

Using the Leslie Kish formula, the 14,636 university population was used to calculate the sample size for this study. Leslie Kish's formula is as follows:

$$n = \frac{z^2 Pq}{d^2}$$

where;

n is the required population sample size.

Z stands for the standard normal deviation, was set at 1.96, representing the 95% confidence level.

P is estimated proportion in the target population, which was set at 0.5

q is population not expected to have good sanitation behavior, which was set at 1-p (1-0.5) = 0.5 d is degree of accuracy desired, which was set at 0.05

n = 1.962 x 0.5 x 0.5

0. 0

52

0.9604

0.0025

= 384.16 = 384

For easy calculations, 384 respondents were selected.

3.3.2 Sampling Technique

Simple random sampling techniques were used to select the sample size from the population. For this study, a selection of respondents was made using the Leslie Kish formula.

3.3.3 Research Layout

This research was divided into four (4) phases viz:

Phase One: Questionnaire administration

Phase Two: Waste characterization and quantification

Phase Three: Laboratory analysis/investigations (Proximate Analysis)

Phase Four: Design and construction of adaptive indigenous landfill (Bio-digester)

3.3.3.1 Phase One - Questionnaire Administration

Total numbers of the students living in the hostels (3,892) were gotten from the university authority. A semi structured questionnaire was administered to the three hundred and eighty-four (384) respondents, the questions are to obtain demographical information (age, gender, educational background, occupation and locations of the respondents). The questionnaire was pre-tested on twenty (20) students who were not residing in the university hostel in order to give opportunity to make improvements to the final edition of the questionnaire that was used to gather the data.

3.3.4 Description of the Research Instrument

3.3.4.1 Validity of the Research Instrument

A variety of measures were taken to improve the validity of the data collection instrument as follows;

1. Its contents
2. The instruments (carefully examined by my supervisor)

Second, training was provided for the four (4) research assistants—two men and two women— who were responsible for data collecting. The men worked as interviewers in a long-term dementia study that had been using the region as a study site for the previous five years. Therefore, they were quite knowledgeable about the area. Female students helped to assist them. They were all native Yoruba and English speakers. The Faculty of Public Health building served as the site of the research assistants' training. Their instruction covered the extent of the background, goals, and methodology of the study, after which they were given an item-by-item introduction to the data gathering tools. The training took place for two (2) hours, after which the research assistants were taken to the university's open waste site to conduct a mock evaluation using the study materials. Following that, decisions regarding specific recordings were taken. We saw and talked about intra-observer differences. The purpose of this activity was to give the researcher a chance to evaluate the research assistants' level of observational and recording skills. Each of the research assistants received a copy of each study instrument to read at home and understand better. The following day, the issues raised were discussed.

3.3.4.2 Reliability of the Research Tool

The following actions were made to ensure the instrument more reliable:

To verify repeatability, twenty (20) respondents from five (5) university residence halls completed pre-test versions of the questionnaires. The final draft of the questionnaire used for data collection was then subjected to analysis using the Statistical Package for Social Sciences' (SPSS) Cronbach's Alpha correlation coefficient.

3.3.5 Data Collection

From the questionnaire survey and the waste composition analysis, two sets of data were collected. Microsoft Excel for Windows was used for the analysis of the data and the Statistical Package for the Social Sciences (SPSS) was used for the analysis of the data from the questionnaire survey. The analyzed data were then compiled and displayed in tables and charts.

3.3.5.1 Procedure for Collecting Qualitative Data

Focus Group Discussion (FGD) was utilized to engage the management of the university and Oyo State Solid Wastes Management (OYSWMA) prior to the questionnaires being distributed to discuss the goals of the qualitative phase of the study.

3.3.5.2 Procedure for Collecting Quantitative Data

Two research assistants were engaged on daily trips to each of the university's sources of waste generation at around nine (9am) in the morning and around five (5pm) in the evening for two weeks.

3.3.6 Data Analysis

Data analysis was performed as follows:

i. coding guide: This was created for data input on every information obtained from the field (raw data) and analysis was conducted with the aid of SPSS software version 15.

ii. The generated data were then compiled and displayed in tables and charts. Thematic-content analysis was used to manually group together similar themes in each transcript and identify emerging trends and differences found across the transcripts to analyze quantitative information items from Focus Group Discussions (FGD), interviews with waste management authority, and university management.

3.3.7 Phase Two – Waste Characterization and Quantification

3.3.7.1 Materials Used

The following materials were used for the measurement of wastes:

a) a weighing balance of capacity up to 120kg,

b) mackintosh polythene bags for collecting and weighing waste materials,

c) shovels and forks for collecting and storing wastes in bags,

d) gloves, boots and face-masks as Personal Protective Device (PPE).

3.3.7.2 Methods Employed

This study employed using the following two methods;

(a) Key informant interview and interactions with LCU waste handlers and collectors

(b) Personal field investigation, observation and measurements. The study estimated the daily waste generation from 11 sources of waste generation in the university and the current management practices as regards the routine and method of collection, transportation, and disposal.

3.3.8 Measurement of the daily solid waste generation from the university

The solid waste generated from eleven (11) different sources in the university were easily assessed and measured since each of the source was stored in bags by the researcher ready for collection by university trucks for disposal. The wastes stored in black mackintosh polythene bags were weighed using weighing balance. This was done for all the sources and the number of bags and average weight when filled was recorded and used to estimate the daily amount of waste generated from each respective sources.

3.3.8.1 Per capital wastes assessment/determinations

In order to determine the per capital waste generation, the following procedures were followed;

(i) Determination of the net weight of solid waste (w) stored in each of the mackintosh polythene bags at each source of generation.

(ii) Determination of the interval (ts) in days, during which the waste was stored and the number of people (p) who contributed to the waste generation.

(iii) Waste generation rate (W G) = $\frac{w\ (kg)}{p \times t(s)}$ (kg/capital/day)

Table 3.3: Detailed Material Classifications (ASTM D 5231—92, 2003).

Category	Descriptions
Mixed Paper	Office paper, computer paper, magazines, glossy paper, waxed paper, and other materials that don't fall under the newspaper or corrugated categories
Newsprint and corrugated	Newspapers, cardboard boxes and cartons, brown (Kraft) paper (corrugated) bags, and corrugated medium
Plastic	Every plastic
Yard waste	Twigs, branches, leaves, grass, and other plant components
Food waste	Except bones, all food waste
Wood	Furniture, pallets, wood items, and lumber
Other organics/combustibles	Leather, rubber, and other primarily burnable materials
Ferrous	Tin, bio-metal, iron, and steel cans

Aluminum	Metal, cans made of metal, and aluminum foil
Glass	Glasses only
Other inorganics and noncombustibles	Stone, sand, dirt, plaster, pottery, non-ferrous metals (copper, brass, etc.), and bones

Source: Field survey conducted in 2023 by the researcher

Since the sampling technique would have a significant impact on the quality of the waste composition data, this study strictly adhered to the recommended sampling procedure:

Throughout the procedure, the Standard-Test-Method for Determining the Composition of Municipal Solid Waste was used. This included determination of the average composition of solid waste as follows;

(i) Municipal solid waste: that has not been processed, or waste that has not been size-reduced or otherwise processed;

(ii) Composite item: An object found in waste that is made of various waste components or different materials (such as disposable diapers and pads for women, bi-metal beverage containers, metallic electrical wires covered with plastic insulation, etc.);

(iii) Solid waste composition or waste composition: the breakdown of a combination into specific waste components based on weight percent for the purpose of characterizing solid trash; a 200–300 lb (91–136 kg) piece that is thought to represent the traits of a waste generator is used as the sorting sample;

(iv) Waste component: A class of solid waste made up of substances with comparable physical and chemical characteristics that is used to describe the chemical make-up of solid trash (e.g., ferrous, glass, aluminum, etc.)

3.3.9 Survey and collation of primary data

3.3.9.1 Existing waste management facilities

A tour around LCU hostels was conducted to determine the type and number of waste collection materials available in each of the source of generation and also around the study area in general as follows;

(i) The waste collection facilities were counted manually

(ii) The waste collection and disposal per capital per day(p/c/d)

(iii) The following information were also obtained from the LCU waste handlers and collectors.

(a) Quantification of wastes (solid) at source (Monday to Sunday)

(i) At each collection point, sampling analysis was performed between the hours of 9am in the morning and 5pm in the evening (Monday to Thursday). This was also done on Friday to Sunday between the hours of 12pm and 5pm.

(ii) Sorting into different components was also established at the same time as in (i) above.

3.4 Phase Three – Proximate Analysis of the organic MSW

3.4.1 Analytical Study using Proxies

Proximate analysis was used. The following steps are taken to determine the moisture, volatile matter, fixed carbon, and ash gross components of institutional solid waste:

3.4.1.1 Moisture

Moisture content oven-dried as follows:

a) ASTM E1756-01 standard was followed in determining the moisture content.

b) A 105°C oven was used to dry/evaporate one gram of institutional solid trash for two hours. After cooling in the desiccator,

c) the sample would be reweighed. The difference in weight following evaporation is a percentage representation of the sample's moisture content.

3.4.1.2 Volatile Organic Compound (VOC)

The vapour that was produced during volatilization of water moisture in organic waste was the source of the volatile organic compounds (VOC) in a institutional solid waste. The following methods were adopted to determine VOC:

a) ASTM standard E-872. To prevent air contact during volatilization (the previous sample that was used to determine the amount of moisture was heated once more in a covered crucible inside a furnace).

b) Furnace was set at 950°C for two hours,

c) the covered crucible dish was placed. The crucible was removed and allowed to cool in a desiccator. Volatile matter is defined as the weight difference caused by volatilization.

3.4.1.3 Ash

Ash is the inorganic solid residue that remains after the fuel has burned all the way through. Ash was measured using the ASTM D1102 2013 and ASTM D1102 24 procedures. The final sample from the calculation of volatile matter would be burned for one hour at 575 °C in the furnace.

The sample would be cooled and reweighed once all the carbon had been burned.

3.4.1.4 Fixed Carbon

Using the difference in the concentrations of moisture, volatile matter, and ash, fixed carbon in fuel was calculated.

FC= 100 - M - VM - ASH

Where: FC - Fixed carbon, M - Moisture, VM -

Volatile matter and ASH – remaining ash

Fixed carbon is the solid carbon in MSW that is still present in the char after the volatilization process.

The following actions were taken to prepare the waste samples for measurement:

1. Place the waste from each waste-generating unit in a separate area (such as a table or a marked-off area of the floor) where it won't mix with other samples.
2. Remove any food from the packaging, then group the packaging into a different pile.
3. Classify the garbage according to the study's parameters.
4. Sorting the non-decomposable trash into several categories, such as paper, plastic, metals, etc., might be interesting to the study.

Weigh and note the information

Different types of wastes components were weighed as follows;

a) Separately weigh each type of waste. Based on the dietary categories chosen for the study, enter the weight data in a prepared spreadsheet.
b) Get rid of the used-up samples.

The samples can be discarded after they have been sorted, weighed, and recorded. It can be required to hire a waste management business for a customized garbage retrieval if the study has a big scope.

3.5 Phase Four – Adaptive Sanitary Landfill

3.5.1 Composition of Adaptive Indigenous Sanitary Landfill

Basic parts of a landfill include:

a. the leachate collection system that gathers liquids produced from the waste,

b. the storm-water management system that collects rainwater before it percolates in the waste mass and

c. the gas collection and removal system.

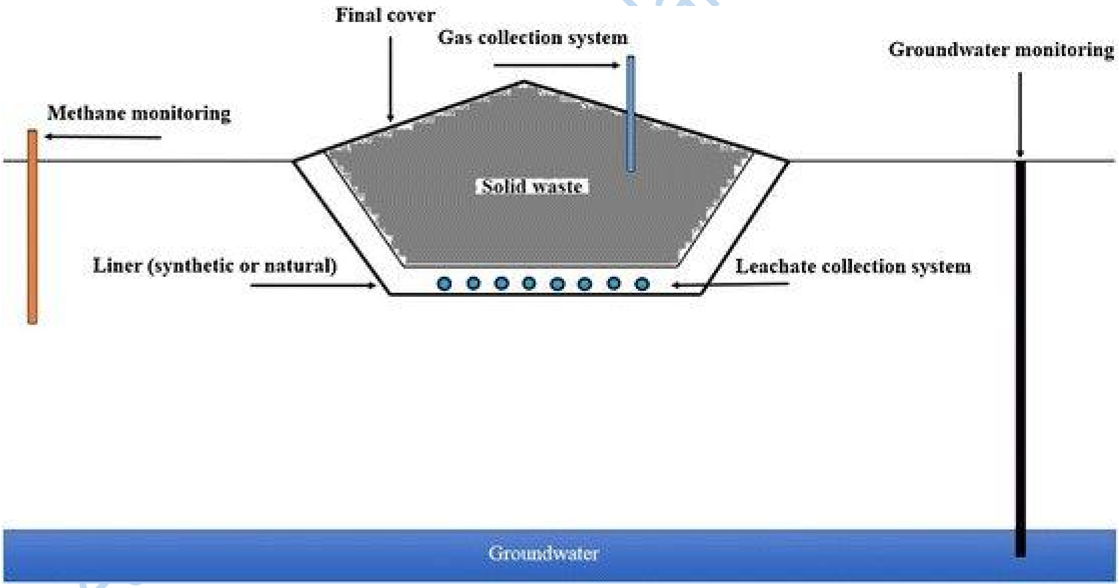

Fig 3.2: Drawing of the Adaptive Sanitary Landfill

3.5.2 Building/construction a Prototype Adaptive Indigenous Landfill (BIODIGESTER) for the Lead City University

Construction of prototype adaptive indigenous landfill for the university was categorized into six stages.

First stage

a) 15 feet in length

b) 6 feet in width and

c) 3 feet in height of the topsoil was removed (at first, this created a significant depression or pit).

Second stage

From the standard 50 kg nylon rice bags, a non-perforated nylon sack was created. To act as an intended putrescible waste container that can stop waste materials from leaking, twelve (12) pieces of rice nylon bags were sewn together to form a large sack measuring 12 feet in length, 6 feet in width, and 2 feet in height.

Third stage

Perishable waste was deposited and thoroughly crushed using manual compressors (perishable wastes were dumped into the sack).

Fourth stage

This involves insertion of waste water pipes (Pipes were inserted to drain off waste water that is released after compression and into a separate, specially built deep pit for evacuation.

Fifth stage

This is methane gas collection, which involves collecting the methane gas created by the anaerobic decomposition of waste into a separate pipe and directing it through an activated charcoal chamber to filter out contaminants including carbon dioxide (CO_2) and hydrogen sulfide (H_2S) before measuring the methane (CH_4). The methane intensity was determined by combustion with ignition by matches.

Sixth Stage

2mm plastic pipes are installed to drain off wastewater or runoff from rain and storms in order to enhance effective aesthetic sanitary condition of the project site.

To redirect and manage water runoff from rain and storms, specialized storm water pipes of 2mm are installed.

3.5.3 Design Process of adaptive indigenous sanitary landfill

Adaptive sanitary landfills is an indigenous technology sanitarily designed for disposal/ management of institutional wastes in LCU. It adopts indigenous procedures that guarantee waste control and none surface water infiltrations through the placement of well-designed and well-constructed surface drainage system. It is made up of five (5) stages as follows:

Stage 1: Digging of top soil:

a. Length – 5m.

b. Width – 3m

c. Height – 1m

Stage 2: 12 pieces of standard 50kg of rice nylon were sown to make a non-perforated nylon sack of the following measurements:

a. 4m in length,

b. 2m width and

c. 1m in height.

Stage 3: Application of manual compressor

Biodegradable wastes are dumped into the sack and compressed using manual compressor for 20 – 30 mins.

Stage 4: Installation of PVC Pipes

2mm PVC pipes were installed to drain off leachates or storm water from the system (almost 3m length).

Stage 5: methane chamber

a) A 50kg keg was jnstalled as methane chamber to collect biogas (i.e. methane, CO_2, H_2S and water) coming up from the decomposed waste in the sack.

b) Charcoals were put inside the methane chamber to filter out CO_2, H_2S and H_2O (Impurities)

3.5.4 Biogas Generation from Adaptive Sanitary Landfill (ASL)

3.5.4.1 Determination of Methane

Handheld Sewerin Multitec 540 was used to measure methane, CO_2, H_2S and H_2O. For the purposes of this study, four (4) major LFGs—methane (CH4, measured in%), carbon dioxide (CO_2, measured in%), ammonia gas (NH_3, measured in PPM), and hydrogen sulfide (H_2S, measured in PPM was measured with a gas monitoring meter on a weekly basis, in the morning at around 9am and in the afternoon at around 5pm at four different sites before the construction of an adaptive sanitary landfill (i.e., The same four (4) major LFGs would also be measured after the building/ construction of the adaptive sanitary landfill and compared to the earlier measurement.

3.6 Time Line of the Research

Due to the complexity of the project work, it commenced on November 2022 and expected to be completed by April 2023.

3.7 Project Budget

S/N	Items	Quantities	Price (N)
1	Production of questionnaire	380	**34,000**
2	Administration of questionnaires	380	**24,000**
3	Clearing, digging and engineering works of Sanitary Landfill	-	**102,000**
4	Purchasing of Sanitary Landfill accessories	-	**64,000**
5	Weighing and Loading of the wastes and	-	**72,000**
6	Supervision and monitoring of the Sanitary Landfill	-	**22,000**
	Total		**318,000**

Source: Research field work 2023

3.8 Ethical Approval

The Lead City University Human Research Ethics Committee authorized the research proposal when it was presented to them for review.

Endnotes

1. ASTM International: *A Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste. In ASTM D5231 (Reapproved 2003).* **American Society for Testing and Materials,** *USA.2008*

2. EPA: *Environmental Protection Agency: Municipal Waste Characterization. Published by the Environmental Protection Agency, Ireland. 1996*

3. G. Tchobanoglous, H. Theisen, S. Vigil: *Integrated Solid Waste Management:* **Engineering Principles and Management Issues**. *McGraw-Hill Book Co, Singapore. 1993.*

4. *M. Sharma, E McBean: A methodology for solid waste characterization based on diminishing marginal returns.* **Waste Management** *27, pp. 337–344. 2007.*

5. *G. Bernache-Perez, S. Sanchez-Colon, A. Garmendia, A. Davila-Villarreal, M.E. Sanchez-Salazar: Solid waste characterization study in the Guadalajara Metropolitan Zone, Mexico.* ***Waste Management and Research*** *19, pp. 413–424.2001.*

6. *Fehr, M., de Castro, M., Calcado, M.D.R: A practical solution to the problem of household waste management in Brazil.* **Resources, Conservation and Recycling** *30, pp. 245–257. 2000.*

7. *Ojeda-Benitez, S., Armijo de Vega, C., Ramirez-Barreto, M.E: Characterization and quantification of household solid wastes in a Mexican city.* **Resources, Conservation and Recycling** *39, pp. 211–222. 2003.*

Chapter Four

Results and Discussion of Findings

4.1: Socio-Demographic Data Analysis and lecturers and students practical environmental knowledge and awareness to waste management.

Demographic data analysis shows frequencies and percentage distribution of age, gender, education background, occupation, location of the respondents as well as the lecturers and students practical environmental knowledge and awareness to waste management. The general information (socio-demographic distribution) about the retrieved three hundred and eighty-four (384) out of the four hundred and twenty-seven questionnaires distributed (427) across the various sections in the university are presented.

4.2: Socio-Demographic distribution of the respondents and lecturers and students practical environmental knowledge and awareness to waste management

	SOCIO-DEMOGRAPHIC PARAMETERS	FREQUENCY	PERCENTAGE (%)
A	**Age**		
	Below 20 years	246	64.1
	20 years and above	138	35.9
	Total		100
B	**Gender**		
	Male	185	48.2
	Female	199	51.8
	Total	384	100
C	**Educational Background**		
1	Below school certificates	14	3.6
2	School certificates	163	42.4
3	First degrees	168	43.8
4	Above first degrees	39	10.2
	Total	384	100
D	**Occupation**		
1	Students	122	31.8
2	Academics	132	34.4
3	Non-academics	130	33.8
	Total	384	100
E	**Locations**		
1	Male hostel	58	15.1
2	Female hostel	137	35.7
3	Senate building	123	32.0
4	Guest house	32	8.3
5	College of Medicine	2	0.5
6	Eateries	4	1.0
7	Faculty of Public Health	6	1.6
8	Faculty of Pharmacy	9	2.3
9	CHEW & EHS	6	1.6
10	Sport complex	6	1.6
11	Staff quarter	1	0.3
	Total	**384**	**100**

	Lecturers and students practical environmental knowledge and awareness to waste.	FREQUENCY	PERCENTAGE (%)
F	**Lecturers practical environmental knowledge and awareness to waste management**		
1	Solid waste management issue is one of the major issues confronting university authority	48	**12.54**
2	Solid waste collection and disposal methods formed basic steps in waste management	68	**17.70**
3	Nigeria has implemented a series of laws and regulations on solid waste management	36	**9.34**
4	Current waste disposal system in Lead City University, Ibadan is bad	46	**11.98**
5	Nigeria has initiated national programs to promote energy conservation awareness and environmentally responsible lifestyle in recent years.	24	**6.25**
6	The best wider spectrum of waste management behavior are reuse, reduce and recycle.	30	**7.81**
7	Open dump system practices in Lead City University, Ibadan have positive environmental impacts	76	**19.79**
8	It is not necessary to concern about the economic feasibility of transitioning to an adaptive sanitary landfill system from open dump system	26	**6.77**
9	There would be changes in waste management costs if adaptive sanitary landfills is implemented	16	**4.17**

10	The costs associated with adaptive sanitary landfills are justified considering the potential environmental benefits	14	**3.65**
	Total	**384**	**100**
G	**Student's environmental attitudes to waste management**		
1	The ideal waste management alternative is to prevent/reduce waste generation in the first place	102	**26.56**
2	The best way to tackle waste problem is sorting from generation before collection and disposal	120	**31.25**
3	Students participated in any programs aimed at promoting sustainable waste management practices is essential.	34	**8.85**
4	The major five steps in waste management are; reducing waste at the source, reuse of materials, recycling, energy recovery and land-filling.	104	**27.09**
5	Among students, a similar hierarchy of waste management was stabilized known as ARRE strategy; avoid, reduce, recycle and eliminate.	24	**6.25**
	Total	**384**	**100**

Source: Research work 2023

4.1.1 Age

The largest percentage of respondents fall within (64.1%) under 20 years old, and the remaining percentage (35.9%) fall above 20 years of age.

4.1.2 Gender disparity

It was evident on Table 4.3 that female students were the largest percentage of 51.8% compared to the male students of percentage of 48.2%.

4.1.3 Education

It was revealed that first-degree holders had the largest percentage among all respondents (43.8%) because the research was carried out in the institution, followed by those with school certificates (42.4%), those with above-first-degree holders (10.2%), and the remainder 3.6% falling below those with school certificates (Table 4.1).

4.2.4 Occupation

The occupational status of the respondents indicated largest number of percentage of 34.4 (34.4%), followed by non-academics (33.8%), and students (31.8%).

4.1.5 Location

According to table 4.1, the respondents from the female hostel have the highest percentage (35.7%); the senate building have 32.0%; male hostel has 15.1%; guest house have 8.3%; faculty of pharmacy has 2.3%; college of medicine and staff quarters were responsible for only 1.0%; other respondents those from the college of medicine has 0.5%; staff quarter have 1.0%, 0.5% and 0.3% respectively.

4.1.6 Lecturers and students practical environmental knowledge and awareness to waste.

Majority of the lecturers (19.79%) agreed that Open dump system practices in Lead City University, Ibadan have positive environmental impacts while majority of the students (31.25%) agreed that the best way to tackle waste problem is sorting from generation before collection and disposal.

4.2: Presentation of Data

Composition of solid waste/location in each of the twenty-seven (27) hostels in the university were presented, results obtained from the waste sorting, characterization and quantification from different sources within the university are also presented here. These include results of proximate analysis of the organic municipal solid wastes in the University. Lastly, design and construction (with indigenous technology) of adaptive sanitary landfill and measurements of Landfill Gases (LFG); such as methane (CH_4, measured in %), carbon dioxide (CO_2, measured in %), ammonia gas (NH_3, measured in PPM), and hydrogen sulfide (H_2S, measured in PPM) were equally presented. Effects of animal manures and activated charcoal added to bio-digester sack and gas chamber respectively were also presented.

4.2.1 Composition of solid waste/location

A weighing balance was used to measure and record the weight of each composition that had been sorted. The individual weights were added at the conclusion of each sorting to determine the average daily total weight of municipal solid waste (MSW) at that location. The measured weight was divided by the number of days the waste remained at a place before sorting and quantification in those instances when it lingered longer than a day. Differences between biodegradable and non-biodegradable wastes were estimated, along with the percentage makeup of each component.

At each location, investigations and sorting were done as described above and total summation were found every week as shown in table 1 to 27 in appendix 2

At the end of the week, total summation of the wastes generated in the twenty-seven (27) halls in the university were added based on the components to arrive at the total wastes generated (Table 28) as shown in fig 4.1 and appendix 2.

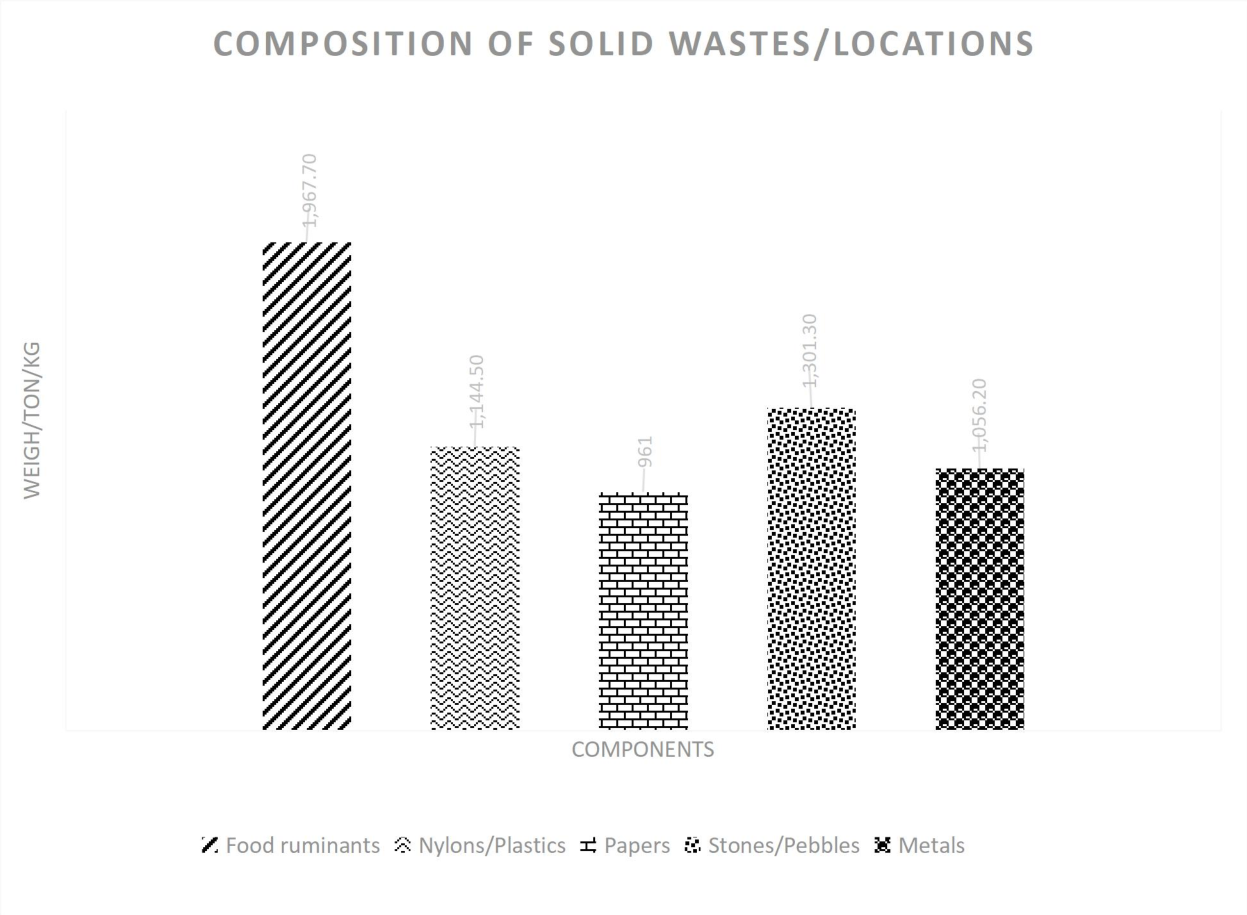

Fig 4.1: Overall composition of solid wastes based on different components in all the 27 halls in the university

4.2.2 Population Distribution in LCU (in%)

Students living outside the school premises (non-residential) have the highest percentage (80.60%), distantly followed by the number of residential students of 12.64%. From the same table, it was further revealed that the percentage of non-teaching staff (2.72%) is more than academic staff (2.28%). Other population in school ranging from visitors, researchers and transporters have the least percentage (1.76%).

Table 4.2: Percentage (%) distribution of population in Lead City University, Ibadan

Distribution	**Population**	**Percentage (%)**
Non-teaching staff	398	**2.72**
Academic staff	334	**2.28**
Number of students living in the hotel (Residential)	1,850	**12.64**
Total number of students living outside school (Non-residential students)	11,797	**80.60**
Other population in school	257	**1.76**
Total	**14,636**	**100**

Source: Research work 2023

4.2.3 Distribution of waste characterization and quantification in LCU

Dump site and hostel have highest number of biodegradable wastes of 31.14% and 41.16% respectively, followed by paper and cardboard waste of 42.12% and 24.14%. However, metals and glass waste have least number in all category sampled.

Table 4.3 Distribution of waste characterization and quantification in LCU, Ibadan by %

Category	Dump Site	Office complex	Lecture Halls	Hostels
Biodegradable	31.14	09.18	04.16	41.16
Paper and cardboard	42.12	74.26	83.10	24.14

Plastics	12.44	13.22	09.44	22.44
Metals	08.18	02.16	02.18	07.13
Glass	06.12	01.18	01.12	05.13
Total	**100**	**100**	**100**	**100**

Source: Researcher's field work (2023).

4.2.4 Proximate analysis of the Organic MSW produced at LCU

Moisture content has the highest percentage of 65.2% in food waste (mixed) and fixed carbon have the least percentage of 4.0%, volatile matter has the highest percentage of 65% in wood/leaves and ash have the least percentage of 0.8% volatile matter have the highest percentage of 95% in plastic and moisture content have the least percentage of 0.3% while volatile matter has the highest percentage of 69% in textiles/rubber/leather and ash have the least percentage of 7.0%. This was collaborated with research work carried out in University of Nigeria, Nsukka[5] where average daily solid waste generation in the university was estimated to be 2,218.66kg during the 6-month study period from 24th February to 18th August in 2017/2018 academic session with organic and polythene representing the largest portion at 32.36% and 34.29%, respectively. Glass/bottle, textiles/leather, rubber, wood, e-waste, sanitary, medical, polystyrene food pack and metal wastes represented 0.97%, 2.69%, 0.28%, 0.82%, 0.98%, 2.16%, 0.16%, 1.04% and 1.67%, respectively. The campus has a per capita solid waste generation rate of about 0.06kg/day. About 96.58% of the total waste is recyclable, and has about 51.85% biomass potential. Analysis of variance showed that differently dominated areas of the campus have different quantities and compositions of wastes mainly due to significant variation of organic and polythene components across the differently dominated areas[5]. The barriers against effective solid waste management and recommendations for integrated solid waste management strategies in Lead City University, Ibadan were made to include solid waste generation reduction, re-usage, recycling, composting, and proper training and provision of incentive and other fiscal policies.

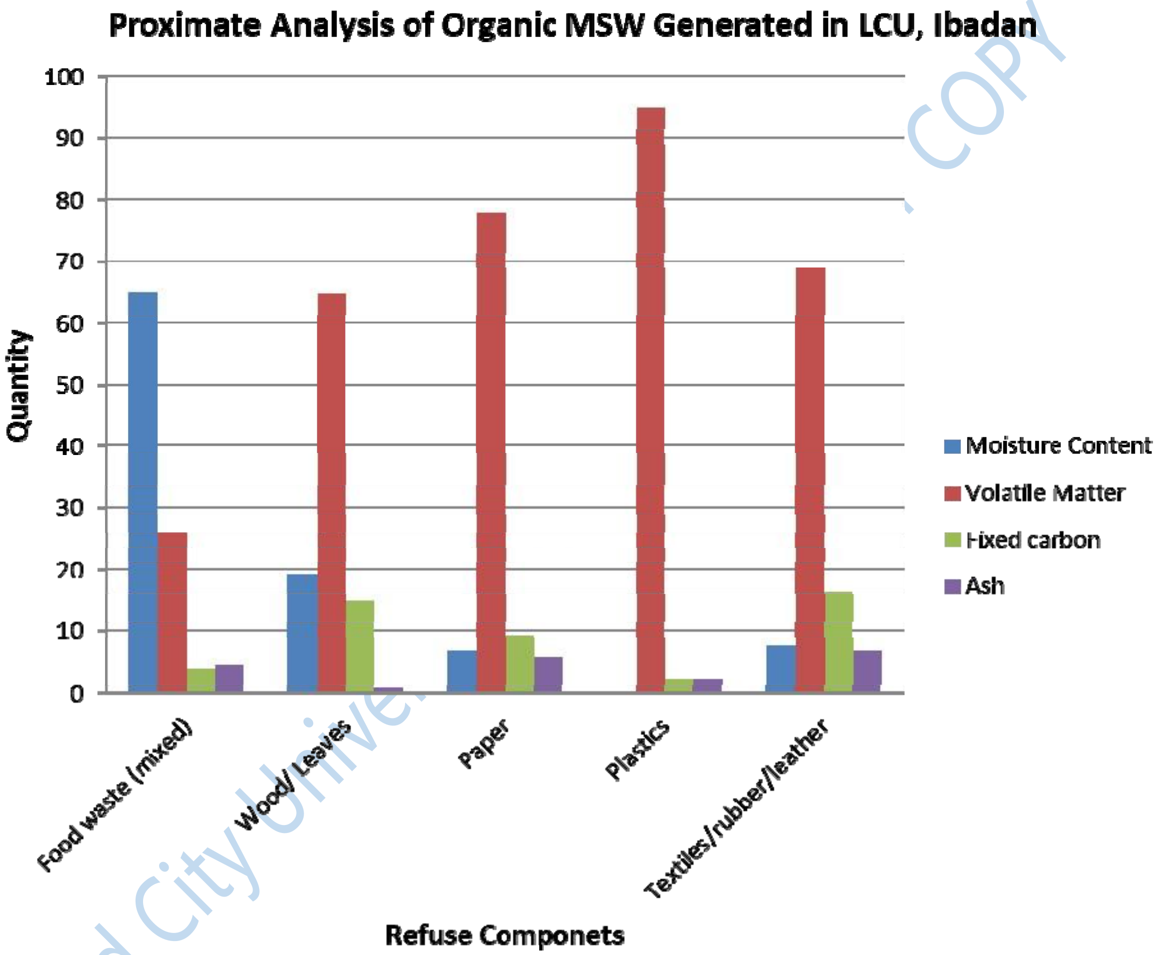

Fig 4.2: Proximate analysis of municipal solid waste generated in Lead City University

4.2.5 Overall Composition of Waste at LCU

There are three main forms of solid waste at Lead City University in Ibadan;

i. Domestic garbage is the solid waste produced by households, grocery stores, marketplaces, and business establishments like hotels, shops, and restaurants. This is responsible for the LCU's larger percentage of organic matter (73%).

ii. Institutional waste includes the solid garbage produced by hospitals, classrooms, recreation centers, public development initiatives, and other office buildings. This is responsible for other waste fractions with the lowest percentage.

iii. Industrial waste is anything that isn't toxic or hazardous and needs specific care, treatment, or disposal. Ibadan's Lead City University does not apply this.

According to a few variables, waste content varies at Lead City University in Ibadan:

1. Season: Waste has a higher organic composition during the rainy season since there is a higher volume of food, fruit, and vegetable waste.
2. Social status - Similar to the majority of developing countries, rural areas with poorer populations produce solid waste with a larger percentage of organic matter, between 70 and 80 percent. Contrary to urban regions with wealthy residents, the garbage has a lower percentage of non-biodegradable elements including plastic, metal, and glass, with an average organic content of 72.74%.
3. Location: Hostels produce more organic garbage than commercial spaces.
4. Cultural Activities: It is noteworthy that not only has the composition of waste changed, but the amount of waste generated also varies in Lead City University, Ibadan, with Women's Day, Christmas, and New Year celebrations and other celebrations resulting in more organic waste generation due to the amount of flowers, trees, etc. bought for the occasion.

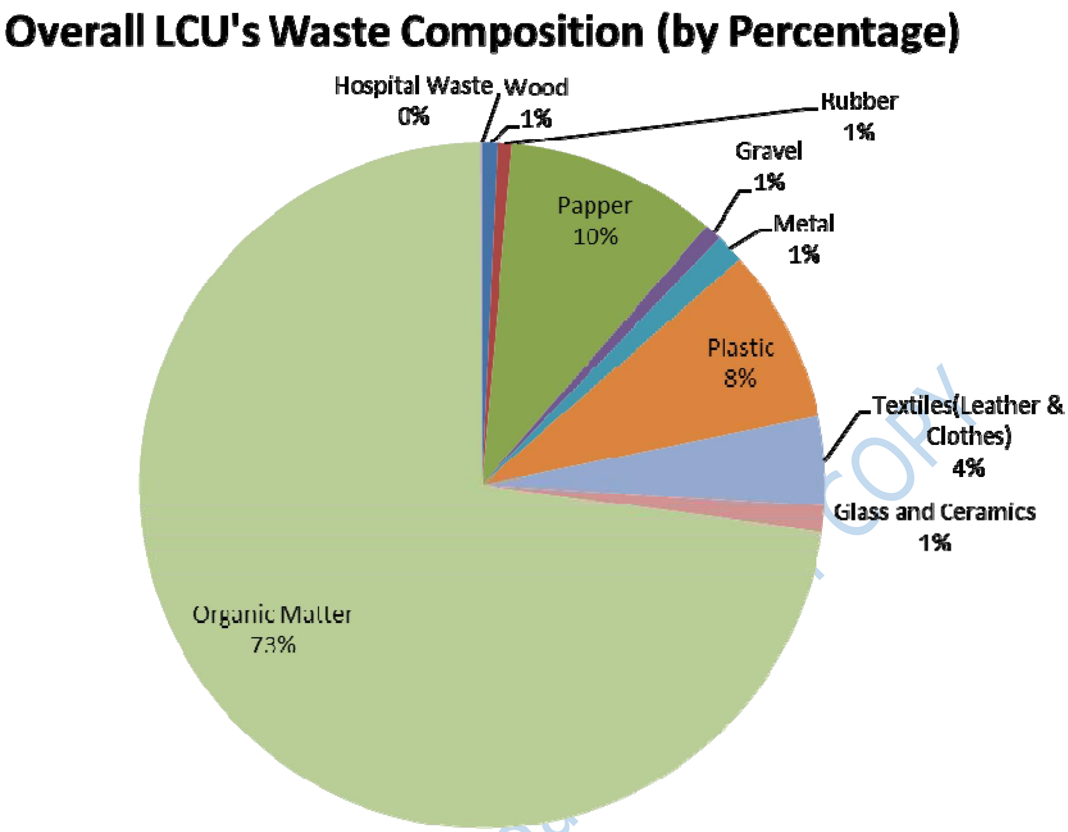

Fig 4.3: Overall Lead City University waste composition by percentage

4.2.6 Estimated Quantity of deposited waste at the LCU dump sites.

From the fig 4.4 below, it was revealed that as the population of the Lead City University, Ibadan increases yearly so also the waste generated increased. Also wastes generated during the rainy season is greater than that of dry session because there is a high amount of food, fruit and vegetable waste in rainy session compared to that of dry session as shown in fig 4.3 below where between 2800kg to 3800kg were recorded within July to December in both years 2021 and 2022.

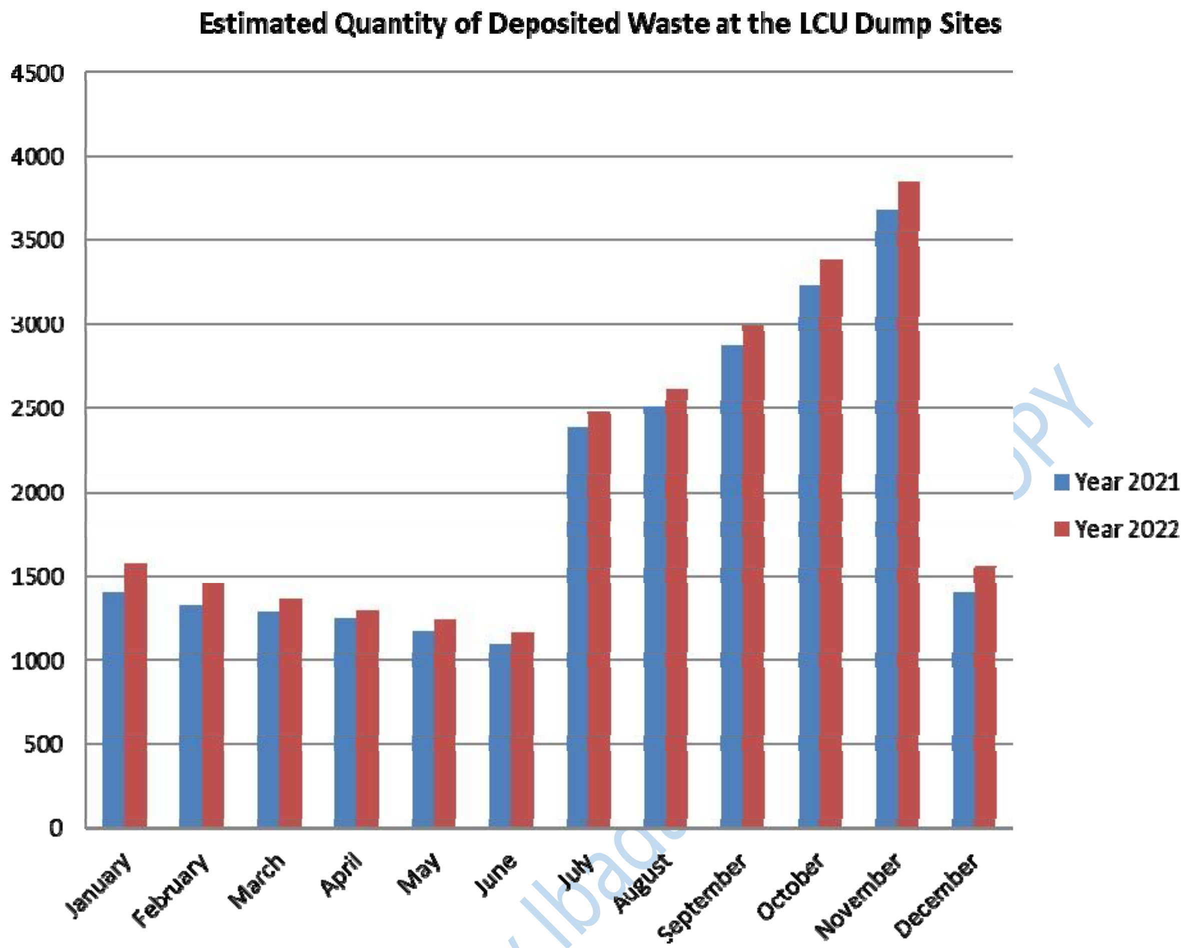

Fig 4.4: Estimated Quantity of deposited waste at Lead City University dump site

4.2.7 Description of solid waste at the point of generation. (i.e Sorting)

The number of main categories and subcategories depends on the goals and scope of a particular study, as well as the resources available[10]. In light of this, the material classification listed in Table 3.3 of chapter three was changed. Glass, plastic, mixed and corrugated paper, ferrous and non-ferrous materials, textile waste, and E waste were the categories used to separate the waste streams from each generator or source.

Table 4.4 revealed that eateries have the highest number of sorted-samples per trip per location of 40.62kg out of the total of 255.30kg.

Table 4.4: Number of sorting-samples per trip per location

Source: Researcher's field work (2023).

Locations	Newsprint (Kg)	Corrugated (Kg)	Plastic (Kg)	Garden waste (Kg)	Wasted food (Kg)	Wood (Kg)	Other organics (Kg)	Ferrous, Aluminum and glass (Kg)	Other (Kg)	Total
Male Hostel	2.60	1.73	3.40	2.84	12.80	2.34	0.56	0.04	0.06	**26.37**
Female Hostel	2.20	1.60	3.78	2.98	16.50	1.36	0.42	0.02	0.04	**28.90**
Senate Building	8.72	3.74	2.60	4.94	0.40	8.87	0.98	0.12	0.08	**30.45**
Guest House	1.88	0. 67	1.89	3.67	8.44	1.67	0.45	0.02	0.08	**18.77**
College of Medicine	5.68	1.34	1.22	1.66	3.66	5.65	0.88	0.02	0.15	**20.26**
Eateries	1.33	0.90	4.54	3.67	24.66	4.76	0.66	0.04	0.06	**40.62**
Faculty of Public Health	4.56	1.22	1.08	1.68	3.68	5.34	0.86	0.15	0.18	**18.75**
Faculty of Pharmacy	3.87	0.98	1.02	1.23	3.43	5.09	0.67	0.10	0.15	**16.54**

Nursing, CHEW and EHS Buildings	4.98	1.76	1.67	1.45	4.78	6.12	0.86	0.23	0.20	**22.05**
Sport Complex	1.20	0.20	0.88	1.08	2.09	4.11	0.34	0.05	0.10	**10.05**
Staff Quarter	4.87	1.09	2.08	2.44	4.67	6.12	0.88	0.18	0.21	**22.59**
Total	**41.89**	**15.23**	**24.16**	**27.64**	**85.11**	**51.43**	**7.56**	**0.97**	**1.31**	**255.30**

Waste quantification.

The quantification of solid waste is an important issue in waste management. It affects the density of the waste, the proposed methodology of disposal and is necessary for examining reuse, reduction and recycle of waste. Self-reported waste generation rates at the campus ranged from 0.14 to 1.4 kilograms per day for students and an average of 1.7 kilograms per day for vendors, which is comparable to estimates for waste generation rates in sub-Saharan Africa[11]. In contrast, National Polytechnics have the lowest per capita trash creation at 0.28 kg/week/student, while Institutes of Technology generate the most garbage per capita at 0.71 kg/week/student[12]. These rates are lower; according to data on global solid waste generation by region, the Sub-Saharan Africa region produces between 0.5 and 0.65 kg per person per day. In sub-Saharan Africa, trash generation rates per person are generally modest, averaging 0.65 kg per person per day, although they can vary greatly depending on economic position, from 0.09 to 3.0 kg per person per day. The rate of 0.5 kg/capita/day was chosen in order to further calculate the campus's waste generation rates because there was a lack of reliable data on waste collection and to minimize any conflicts with earlier research. For instance, the overall enrollment at Lead City University in Ibadan has increased, as reported by the university administration, from 23,653 students during the academic year 2020–2021 to 25,010 students during the following year (see table 4.7). In the event that this pattern persists, Lead City University in Ibadan will generate a similarly greater amount of waste.

Table 4.5: Lead City University Waste Quantification

Year	Population	Formulation	Amount (Ton/Year)
		(GRXMX0.001X365)	
2020/2021	23,653	0.625 x 23,653 x 0.001 x 5,395.840625 x 365	
2021/2022	25,010	0.625 x 25,010 x 0.001 x 5,705.406250 x 365	
	Average		**5,550.623438**

Table 4.6: Forecast Student Population (3% Growth Rate)

Year	Population	Formulation	Amount (Ton/Year)
		(GRXMX0.0002X3650	
2022/2023	25,760.30	0.625 x 25,760.30 x 0.001 x 5,876.568438 x 365	
2023/2024	26,533.11	0.625 x 26,533.11 x 0.001 x 6,052.865719 x 365	
	Average		**5,964.717079**

Source: Researcher's field work (2023).

Plate 4.1: Open dump site practice by Lead City University, Ibadan

Plate 4.2: Cleaning of sanitary landfill prototype for easy passage of water by the researcher

Plate 4.3: Researcher testing the flame coming out of the methane chamber with lighter

Plate 4.4: Researcher using herbicide to control weeds at the sanitary landfill

Plate 4.5: Researcher weighing the decomposable waste after sorting before loading

4.2.9 Evaluation of Biogas Generations (Liquefied Gases (LFG) concentrations) from the Adaptive Sanitary Landfill in LCU

For the purpose of this research work, four (4) major LFGs, that is, Methane (CH4, measured in %), Carbon dioxide (CO_2, measured in %), Ammonia gas (NH_3, measured in PPM) and Hydrogen sulphide (H_2S, measured in PPM) was measured with Gas Monitoring Meter before the construction of adaptive sanitary landfill.

Table 4.9 revealed that Liquefied Gases (LFG) concentrations measured in the afternoon was lower compared to the one measured in the afternoon before construction of LCU Landfills and this was due to increase in temperature in the afternoon and decrease in relative humidity in the afternoon. This was collaborated with a research work conducted where a decrease in temperature range and increase in relative humidity enhancing biodegradation of refuse[6].

Table 29 and 30 in appendix 2 and fig 4.5 and 4.6 revealed that Liquefied Gases (LFG) concentrations measured in the afternoon was lower compared to the one measured in the afternoon after construction of LCU Landfills and this was due to increase in temperature in the afternoon and decrease in relative humidity in the afternoon. It was also deducted that Liquefied Gases (LFG) concentrations measured after the construction of LCU Landfill was higher in both morning and afternoon compared to before construction of LCU Landfill and this was due to assembled of Liquefied Gases (LFG) at the adaptive sanitary landfill.

LFG measured after the construction of sanitary landfill was higher because fresh putriscible wastes were assembled in the sanitary landfill which resulted in the generation of more LFGs and this was collaborated with the research work conducted for the determination of landfill gas generation potential from lignocellulose biomass contents of municipal solid waste[7].

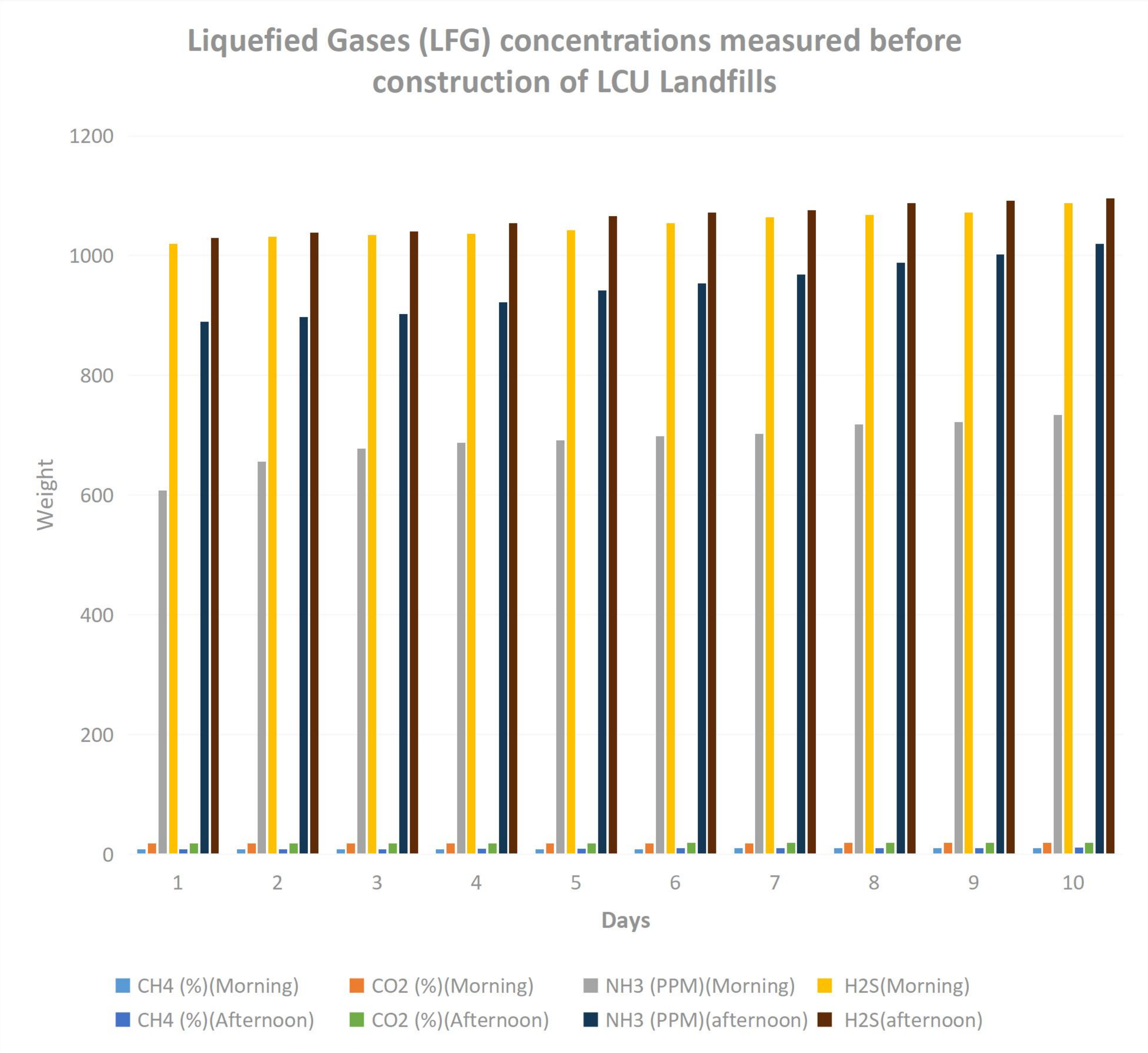

Fig 4.5: Liquefied Gases (LFG) concentrations measured before construction of LCU Landfills

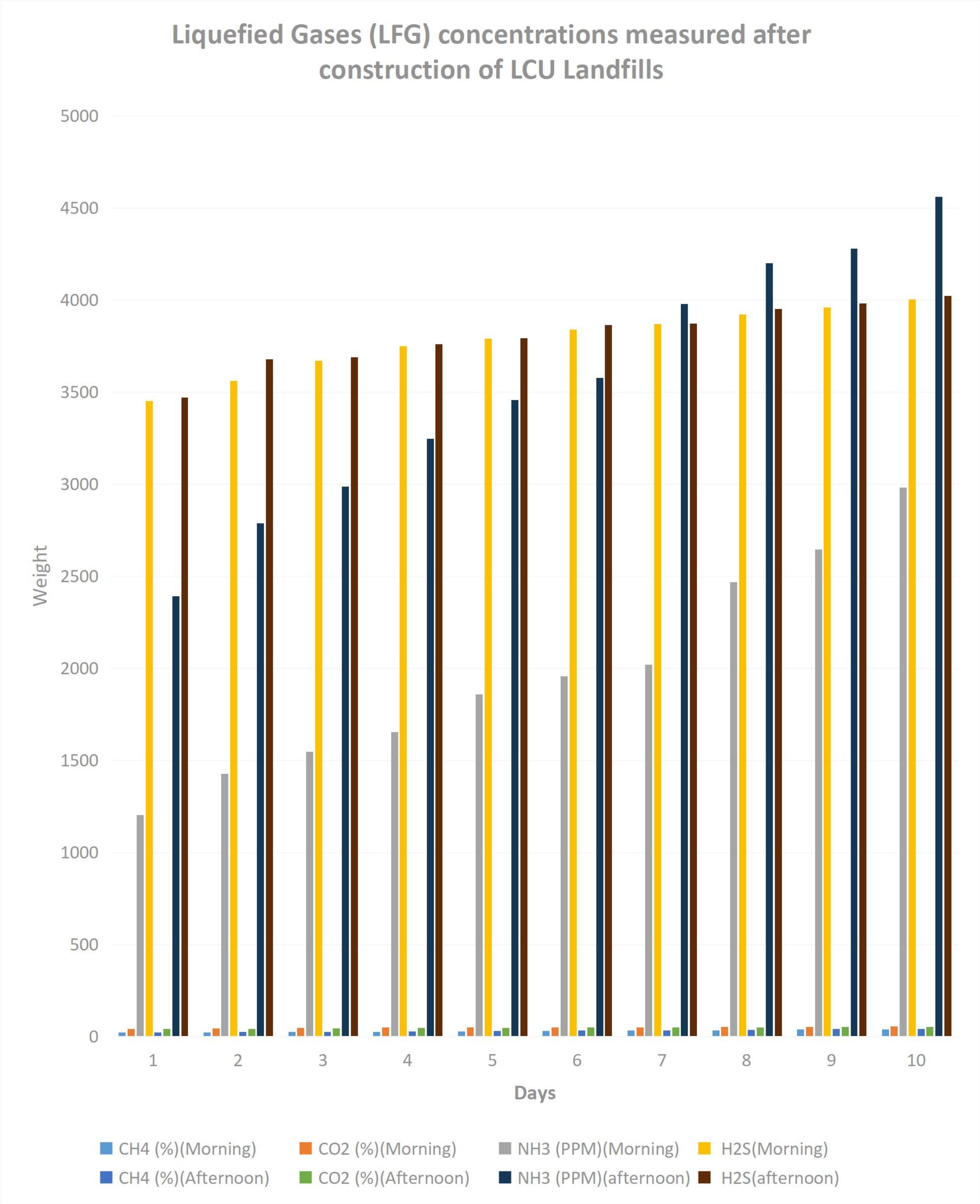

Fig 4.6: Liquefied Gases (LFG) concentrations measured after construction of LCU Landfills

4.2.10 Utilizing activated charcoal to remove pollutants, such as carbon dioxide (CO_2) and hydrogen sulfide (H_2S),

In order to eliminate pollutants like carbon dioxide (CO_2) and hydrogen sulfide (H_2S) before measuring the methane (CH_4), an activated charcoal chamber was added to the adaptive sanitary landfill. Now that the explosion risk has been reduced, methane can be burned to provide heat and energy.

This research results that addition of activated charcoal both in morning and afternoon have tremendous effects by increasing the amount of LFG generated was collaborated in a research work where effects of biochar and activated carbon on biogas generation were demostrated[8].

Table 31 in appendix 2 and fig 4.7 below showed the effect of addition of activated charcoal which made the amount of liquefied gases (LFG) to increased compared to when no activated charcoal was added.

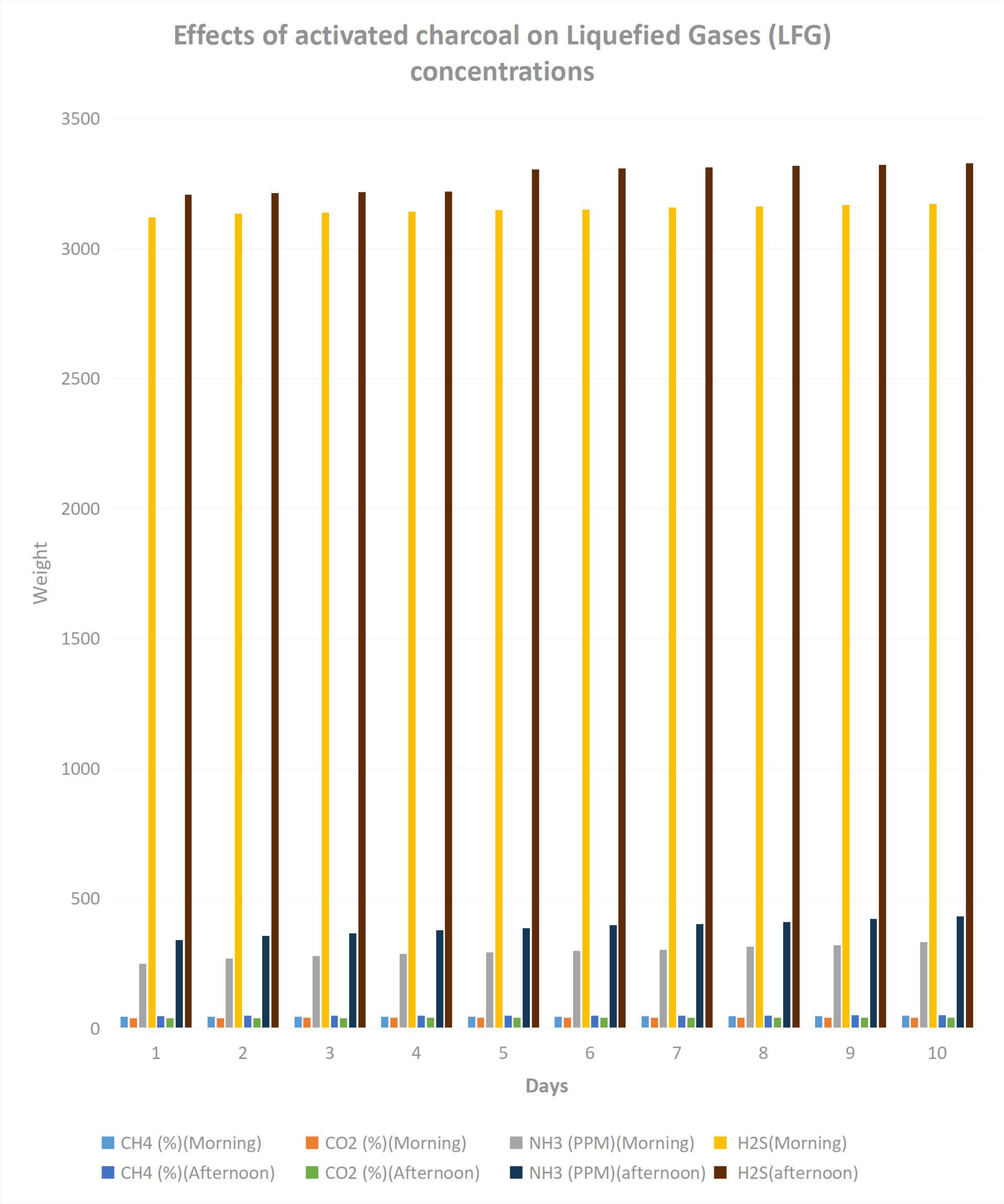

Fig 4.7: Effects of activated charcoal on Liquefied Gases (LFG) concentrations

4.2.11 Influence of Animal Manures added on Liquefied Gas production in LCU Landfill

Animal manure and other composted organic materials, such as cow dung, boost nutrient content and bioavailability. This encourages microbial activity and the production of complex organic polymers and chemical metabolites, which act as ties and bonding agents to cement flocculated clay particles into aggregates.

Plate 4.6: Animal manure added to the waste to hasten the digestion and decomposition

Table 32 in appendix 2 and fig 4.7 below revealed the importance of animal manures in boost the generation of liquefied gases (LFG) in the adaptive sanitary landfill. The amount of liquefied gases (LFG) generated after the addition of animal manures was higher compared to when it was not added. This was in line with research work conducted in development[9].

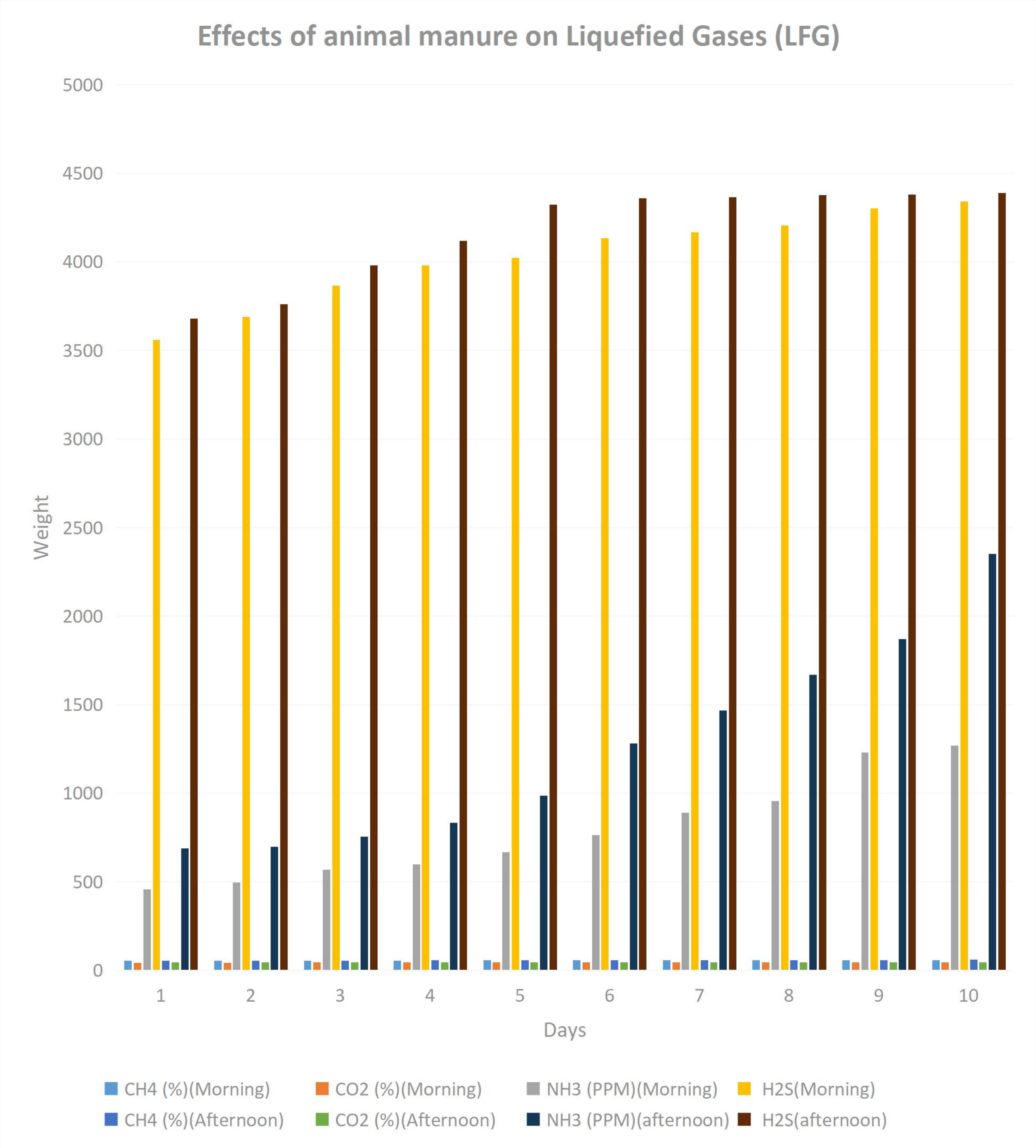

Fig 4.7: Effects of animal manures on Liquefied Gases (LFG) concentrations

Correlations

		CH_4(%)(Morning)	CH_4(%)(Afternoon)	CH_4(Morning After Construction)	CH_4(Afternoon After Construction)	CH_4(Effect of Charcoal Morning)	CH_4(Effect of Charcoal Afternoon)	CH_4(Effect of Animal Manure Morning)	CH_4(Effect of Animal Manure Afternoon
CH4(%)(Morning)	Pearson Correlation	1	.900**	.962**	.934**	.882**	.896**	.938**	.915**
	Sig. (2-tailed)		.000	.000	.000	.001	.000	.000	.000
	N	10	10	10	10	10	10	10	10
CH4(%)(Afternoon)	Pearson Correlation	.900**	1	.934**	.944**	.714*	.907**	.916**	.847**
	Sig. (2-tailed)	.000		.000	.000	.020	.000	.000	.002
	N	10	10	10	10	10	10	10	10
CH4(Morning After Construction)	Pearson Correlation	.962**	.934**	1	.994**	.904**	.943**	.987**	.960**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000	.000
	N	10	10	10	10	10	10	10	10
CH4(Afternoon After Construction)	Pearson Correlation	.934**	.944**	.994**	1	.879**	.939**	.985**	.949**
	Sig. (2-tailed)	.000	.000	.000		.001	.000	.000	.000
	N	10	10	10	10	10	10	10	10
CH4(Effect of Charcoal Morning)	Pearson Correlation	.882**	.714*	.904**	.879**	1	.811**	.925**	.958**
	Sig. (2-tailed)	.001	.020	.000	.001		.004	.000	.000
	N	10	10	10	10	10	10	10	10
CH4(Effect of Charcoal Afternoon)	Pearson Correlation	.896**	.907**	.943**	.939**	.811**	1	.920**	.884**

	Sig. (2-tailed)	.000	.000	.000	.000	.004		.000	.001
	N	10	10	10	10	10	10	10	10
NH4(Effect of Animal Manure Morning)	Pearson Correlation	.938**	.916**	.987**	.985**	.925**	.920**	1	.986**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000		.000
	N	10	10	10	10	10	10	10	10
NH4(Effect of Animal Manure Afternoon	Pearson Correlation	.915**	.847**	.960**	.949**	.958**	.884**	.986**	1
	Sig. (2-tailed)	.000	.002	.000	.000	.000	.001	.000	
	N	10	10	10	10	10	10	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The Table above shows the correlation results of interaction of CH_4 in the morning and afternoon before the construction of adaptive sanitary landfill. It also shows the result of activated animal charcoal.

The results of the correlation shows a statistically significant result all through the measurements.

Correlations

		CO_2(%)(Morning)	CO_2(%)(Afternoon)	CO_2(Morning After Construction)	CO_2(Afternoon After Construction)	CO_2(Effect of Charcoal Morning)	CO_2(Effect of Charcoal Afternoon)	CO_2(Effect of Animal Manure Morning)	CO_2(Effect of Animal Manure Afternoon)
CO2(%)(Morning)	Pearson Correlation	1	.991**	.982**	.990**	.980**	.977**	.958**	.972**
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.000	.000
	N	10	10	10	10	10	10	10	10
CO2(%)(Afternoon)	Pearson Correlation	.991**	1	.962**	.977**	.968**	.978**	.949**	.978**
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.000	.000
	N	10	10	10	10	10	10	10	10
CO2(Morning After Construction)	Pearson Correlation	.982**	.962**	1	.989**	.969**	.930**	.952**	.925**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000	.000
	N	10	10	10	10	10	10	10	10
CO2(Afternoon After	Pearson Correlation	.990**	.977**	.989**	1	.987**	.948**	.981**	.938**

Construction)	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000	.000
	N	10	10	10	10	10	10	10	10
CO2(Effect of Charcoal Morning)	Pearson Correlation	.980**	.968**	.969**	.987**	1	.960**	.989**	.949**
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000	.000
	N	10	10	10	10	10	10	10	10
CO2(Effect of Charcoal Afternoon)	Pearson Correlation	.977**	.978**	.930**	.948**	.960**	1	.921**	.998**
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000	.000
	N	10	10	10	10	10	10	10	10
CO2(Effect of Animal Manure Morning)	Pearson Correlation	.958**	.949**	.952**	.981**	.989**	.921**	1	.906**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000		.000
	N	10	10	10	10	10	10	10	10
CO2(Effect of Animal Manure Afternoon)	Pearson Correlation	.972**	.978**	.925**	.938**	.949**	.998**	.906**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	
	N	10	10	10	10	10	10	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

The Table above shows the correlation results of interaction of CO_2 in the morning and afternoon before the construction of adaptive sanitary landfill. It also shows the result of activated animal charcoal.

The results of the correlation shows a statistically significant result all through the measurements.

Correlations

		NH_3(PPM)(Morning)	NH_3(Afternoon)	NH_3(Morning After Construction)	NH_3(Afternoon After Construction)	NH_3(Effect of Charcoal Morning)	NH_3(Effect of Charcoal Afternoon)	NH_3(effect of Animal Manure Morning)	NH_3(Effect of Animal Manure afternoon)
NH3(PPM)(Morning)	Pearson Correlation	1	.889**	.898**	.945**	.970**	.951**	.847**	.822**
	Sig. (2-tailed)		.001	.000	.000	.000	.000	.002	.004
	N	10	10	10	10	10	10	10	10
NH3(Afternoon)	Pearson Correlation	.889**	1	.984**	.984**	.972**	.983**	.976**	.977**
	Sig. (2-tailed)	.001		.000	.000	.000	.000	.000	.000
	N	10	10	10	10	10	10	10	10
NH3(Morning After Construction)	Pearson Correlation	.898**	.984**	1	.970**	.974**	.970**	.978**	.978**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000	.000
	N	10	10	10	10	10	10	10	10
NH3(Afternoon After Construction)	Pearson Correlation	.945**	.984**	.970**	1	.990**	.991**	.951**	.946**
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000	.000
	N	10	10	10	10	10	10	10	10
NH3(Effect of Charcoal	Pearson Correlation	.970**	.972**	.974**	.990**	1	.994**	.943**	.933**

Morning)	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000	.000
	N	10	10	10	10	10	10	10	10
NH3(Effect of Charcoal Afternoon)	Pearson Correlation	.951**	.983**	.970**	.991**	.994**	1	.953**	.943**
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000	.000
	N	10	10	10	10	10	10	10	10
NH3(effect of Animal Manure Morning)	Pearson Correlation	.847**	.976**	.978**	.951**	.943**	.953**	1	.981**
	Sig. (2-tailed)	.002	.000	.000	.000	.000	.000		.000
	N	10	10	10	10	10	10	10	10
NH3(Effect of Animal Manure afternoon)	Pearson Correlation	.822**	.977**	.978**	.946**	.933**	.943**	.981**	1
	Sig. (2-tailed)	.004	.000	.000	.000	.000	.000	.000	
	N	10	10	10	10	10	10	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

The Table above shows the correlation results of interaction of NH_3 in the morning and afternoon before the construction of adaptive sanitary landfill. It also shows the result of activated animal charcoal.

The results of the correlation shows a statistically significant result all through the measurements.

Correlations

		H_2S(Morning)	H_2S(Afternoon)	H_2S(Morning After Construction)	H_2S(Afternoon After Construction)	H_2S(Effect of Charcoal Morning)	H_2S(Effect of Charcoal Afternoon)	H_2S(Effect of Animal Manure Morning)	H_2S(Effect of Animal Manure Afternoon
NH2(Morning)	Pearson Correlation	1	.963**	.939**	.949**	.974**	.886**	.937**	.839**
	Sig. (2-tailed)		.000	.000	.000	.000	.001	.000	.002
	N	10	10	10	10	10	10	10	10
NH2(Afternoon)	Pearson Correlation	.963**	1	.973**	.965**	.978**	.945**	.971**	.925**
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.000	.000
	N	10	10	10	10	10	10	10	10
NH2(Morning After Construction)	Pearson Correlation	.939**	.973**	1	.983**	.982**	.898**	.998**	.958**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000	.000
	N	10	10	10	10	10	10	10	10
NH2(Afternoon After Construction)	Pearson Correlation	.949**	.965**	.983**	1	.986**	.878**	.977**	.914**
	Sig. (2-tailed)	.000	.000	.000		.000	.001	.000	.000
	N	10	10	10	10	10	10	10	10
NH2(Effect of Charcoal Morning)	Pearson Correlation	.974**	.978**	.982**	.986**	1	.896**	.977**	.904**

	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000	.000
	N	10	10	10	10	10	10	10	10
NH2(Effect of Charcoal Afternoon)	Pearson Correlation	.886**	.945**	.898**	.878**	.896**	1	.900**	.924**
	Sig. (2-tailed)	.001	.000	.000	.001	.000		.000	.000
	N	10	10	10	10	10	10	10	10
NH2(Effect of Animal Manure Morning)	Pearson Correlation	.937**	.971**	.998**	.977**	.977**	.900**	1	.960**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000		.000
	N	10	10	10	10	10	10	10	10
NH2(Effect of Animal Manure Afternoon	Pearson Correlation	.839**	.925**	.958**	.914**	.904**	.924**	.960**	1
	Sig. (2-tailed)	.002	.000	.000	.000	.000	.000	.000	
	N	10	10	10	10	10	10	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

The Table above shows the correlation results of interaction of H_2S in the morning and afternoon before the construction of adaptive sanitary landfill. It also shows the result of activated animal charcoal.

The results of the correlation shows a statistically significant result all through the measurements.

4.3 Discussion of Findings

Discussion of findings were presented based on the objectives of the study, the general information (i.e socio-demographic distribution, lecturers and students knowledge and awareness about the waste management) about the retrieved three hundred and eighty-four (384) out of the four hundred and twenty-seven questionnaires distributed (427) across the various sections in the university are discussed.

Also, characterization and quantification of solid waste/location from specific sources in each of the twenty-seven (27) hostels within Lead City University were presented, results of proximate analysis of the organic municipal solid wastes in the university were also discussed. Thereafter, the total weight of the putrescible waste after sorting, characterization and quantification was used to design and construct (with indigenous technology) adaptive sanitary landfill and measurements of Landfill Gases (LFG); such as methane (CH_4, measured in %), carbon dioxide (CO_2, measured in %), ammonia gas (NH_3, measured in PPM), and hydrogen sulfide (H_2S, measured in PPM) were equally presented. Lastly, effects of animal manures and activated charcoal added to bio-digester sack and gas chamber respectively were also discussed accordingly.

4.3.1 Socio-demographic distribution, lecturers and students knowledge and awareness about the waste management

From the socio-demographic distribution table of the respondents and lecturers and students practical environmental knowledge and awareness to waste management. It was revealed that the largest percentage of respondents fall within (64.1%) under 20 years old, and the remaining percentage (35.9%) fall above 20 years of age and this implies that younger students produced more waste than old one. This is in contrary to research work in higher educational institutions in Makurdi Metropolis Benue State, Nigeria[1]. This may be as result that Lead City University, Ibadan is a private institution compared to government owned institutions where the research work was carried out. Female students have the largest percentage of 51.8% compared to the male students of percentage of 48.2%, and this was in contrary to research work carried out in three tertiary institutions namely; Joseph Saawuan Tarkaa University, Makurdi; Benue State University, Makurdi; and Alfred Akawe Torkula Polytechnic, Makurdi, Nigeria[1]. The reason may be that Lead City University, Ibadan is a private institution compared to Government owned institutions where the research work was carried out. It was revealed that first-degree holders had the largest percentage among all respondents (43.8%) because the research was carried out in the institution, followed by those with school certificates (42.4%), those with above-first-degree holders (10.2%), and the remainder 3.6% falling below those with school certificates. This revealed that educational status does not significantly relate with solid waste management[2]. The occupational status of the respondents indicated largest number of percentage of 34.4 (34.4%), followed by non-academics (33.8%), and students (31.8%)., The result was corroborated by research work carried out in Cross River and Akwa Ibom States[3]. It was also revealed that the respondents from the female hostel have the highest percentage (35.7%); the senate building have 32.0%; male hostel has 15.1%; guest house have 8.3%; faculty of pharmacy has 2.3%; college of medicine and staff quarters were responsible for only 1.0%; other respondents those from the college of medicine has 0.5%; staff quarter have 1.0%, 0.5% and 0.3% respectively. And this was in conformity with research work carried out in Sokoto metropolis[4].

Lastly. majority of the lecturers (19.79%) agreed that Open dump system practices in Lead City University, Ibadan have positive environmental impacts while majority of the students (31.25%) agreed that the best way to tackle waste problem is sorting from generation point before collection and disposal. The result was corroborated by research work carried out in Cross River and Akwa Ibom States[3].

4.3.2 Characterization and quantification of wastes from specific sources within Lead City University

From the total summation of the wastes generated in the twenty-seven (27) halls in the university, it was revealed that food ruminants have the highest weight of 1,967.70kg followed by stones/pebbles (1,301.30kg). Nylons/plastics has 1,144.50kg, followed by metals with 1,056.20kg and papers has lowest weight of 961.00kg. The implication of this is that the university stands to boost their internal generated fund from waste to wealth concept. This was in conformity with research work carried out in three tertiary institutions namely; Joseph Saawuan Tarkaa University, Makurdi; Benue State University, Makurdi; and Alfred Akawe Torkula Polytechnic, Makurdi, Nigeria[1]. The reason may be as a result of most students living in the hostels were females and female generated more putrescible wastes compared to their male counterpart. Also, low weight of metals in the hostels was because most students living in the hostel do not does not engaged in metal production compared to students living outside the hostel.

Distribution of waste characterization and quantification in LCU revealed that dump site and hostel have highest number of biodegradable wastes of 31.14% and 41.16% respectively, followed by paper and cardboard waste of 42.12% and 24.14%. However, metals and glass waste have least number in all category sampled and this supported the necessity of turning this putrescible wastes to wealth by generating biogas. Also, proximate analysis of the organic MSW produced at LCU revealed that different dominated areas of the university have different quantities and compositions of wastes mainly due to significant variation of organic and polythene components across the differently dominated areas of the university and this was collaborated with research work carried out in University of Nigeria, Nsukka[5] where average daily solid waste generation in the university was estimated to be 2,218.66kg during the 6-month study period from 24th February to 18th August in 2017/2018 academic session with organic and polythene representing the largest portion at

32.36% and 34.29%, respectively. Glass/bottle, textiles/leather, rubber, wood, e-waste, sanitary, medical, polystyrene food pack and metal wastes represented 0.97%, 2.69%, 0.28%, 0.82%, 0.98%, 2.16%, 0.16%, 1.04% and 1.67%, respectively.

4.3.3 Proximate analysis of the organic institutional solid waste in the Lead City University

Moisture content has the highest percentage of 65.2% in food waste (mixed) and fixed carbon have the least percentage of 4.0%, volatile matter has the highest percentage of 65% in wood/leaves and ash have the least percentage of 0.8% volatile matter have the highest percentage of 95% in plastic and moisture content have the least percentage of 0.3% while volatile matter has the highest percentage of 69% in textiles/rubber/leather and ash have the least percentage of 7.0%. This was collaborated with research work carried out in University of Nigeria, Nsukka[5] where average daily solid waste generation in the university was estimated to be 2,218.66kg during the 6-month study period from 24th February to 18th August in 2017/2018 academic session with organic and polythene representing the largest portion at 32.36% and 34.29%, respectively. Glass/bottle, textiles/leather, rubber, wood, e-waste, sanitary, medical, polystyrene food pack and metal wastes represented 0.97%, 2.69%, 0.28%, 0.82%, 0.98%, 2.16%, 0.16%, 1.04% and 1.67%, respectively. The campus has a per capita solid waste generation rate of about 0.06kg/day. About 96.58% of the total waste is recyclable, and has about 51.85% biomass potential. This was in conformity with the analysis of variance carried out in a related research work that showed that differently dominated areas of the campus have different quantities and compositions of wastes mainly due to significant variation of organic and polythene components across the differently dominated areas[5]. The implications of these revealed that several barriers against effective solid waste management and recommendations for integrated solid waste management strategies in Lead City University, Ibadan include solid waste generation reduction, re-usage, recycling, composting, and proper training and provision of incentive and other fiscal policies.

4.3.4 Design and construction of an adaptive indigenous landfill for the management of institutional biodegradable organic wastes in Lead City University.

From the total weight of putrescible wastes generated weekly and monthly in all the twenty-seven (27) halls in the university, that was used to estimates the volume of the indigenous adaptive sanitary landfill used for the project and this can be replicated by the university management for the effective and sustainable management of waste.

4.3.5 Evaluate the biogas generation from adaptive indigenous landfill in Lead City University, Ibadan

Four (4) major LFGs, that is, Methane (CH_4, measured in %), Carbon dioxide (CO_2, measured in %), Ammonia gas (NH_3, measured in PPM) and Hydrogen sulphide (H_2S, measured in PPM) measured with Gas Monitoring Meter before and after the construction of adaptive sanitary landfill revealed the importance of indigenous adaptive sanitary landfill. Liquefied Gases (LFG) concentrations measured in the morning was lower compared to the one measured in the afternoon before construction of LCU Landfills and this was due to increase in temperature in the afternoon and decrease in relative humidity in the afternoon. Also, liquefied Gases (LFG) concentrations measured in the afternoon was lower compared to the one measured in the afternoon after construction of LCU Landfills and this was due to increase in temperature in the afternoon and decrease in relative humidity in the afternoon. It was also deducted that Liquefied Gases (LFG) concentrations measured after the construction of LCU Landfill was higher in both morning and afternoon compared to before construction of LCU Landfill and this was due to assembled of Liquefied Gases (LFG) at the adaptive sanitary landfill. This was collaborated with a research work conducted where a decrease in temperature range and increase in relative humidity enhancing biodegradation of refuse[6].

LFG measured after the construction of sanitary landfill was higher because fresh putriscible wastes were assembled in the sanitary landfill which resulted in the generation of more LFGs and this was collaborated with the research work conducted for the determination of landfill gas generation potential from lignocellulose biomass contents of municipal solid waste[7].

In order to eliminate pollutants like carbon dioxide (CO_2) and hydrogen sulfide (H_2S) before measuring the methane (CH_4), an activated charcoal was added to the indigenous adaptive sanitary landfill. Now that the explosion risk has been reduced, methane can be burned to provide heat and energy.

This research revealed that addition of activated charcoal both in morning and afternoon have tremendous effects by increasing the amount of LFG generated was collaborated in a research work where effects of biochar and activated carbon on biogas generation were demostrated[8]. Animal manure and other composted organic materials, such as cow dung, boost nutrient content and bioavailability. This encourages microbial activity and the production of complex organic polymers and chemical metabolites, which act as ties and bonding agents to cement flocculated clay particles into aggregates. The amount of liquefied gases (LFG) generated after the addition of animal manures was higher compared to when it was not added. This was in line with research work conducted in development[9].

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Chapter Five

Conclusion

5.1: Summary of Findings

This study was carried out in the Lead City University, Ibadan that highlighted the current situation of the solid waste management (SWM) systems from the point of generation, storage, collection, transportation and disposal with possibility of providing solutions to associated problems. Furthermore, it is the first municipal solid waste (MSW) characterization study conducted that analyzed the quantity of the different MSW components produced in the institution.

Total numbers of students in Lead City University were 13,647, of which 1,850 of them were residents in the hostel while the remaining 11,797 stayed off campus. Non-teaching staff were 398 and teaching staff were 334. The overall population of Lead City University as at the time of this project work was 14,636.

The study discovered that university eateries have the highest number of waste generation per week of 6 tons, followed by male and female hostels of 4 tons and staff quarters with 2 tons out of the total waste generated in a week that was 15,851.46 tons. Distribution of waste characterization in Lead City University indicated that dump site and hostel had highest number of biodegradable wastes of 31.14% and 41.16% respectively. These were closely followed by paper and cardboard waste of 42.12% and 24.14%. Metals and glass waste had least number in all category sampled. However, reduction in volume of SWM disposed of in landfill is highly dependent on source separation of waste, which is not in practice currently. To enhance the sustainability of SWM, public awareness, funding, expertise, equipment and facilities as well as other provisions that are currently lacking or inappropriate must be provided.

Furthermore, since the envisaged SWM practices call for some behavioral changes, there is a need for student's/lecturers participation on related issues. As a result of the liquefied gases (LFGs) produced at the sanitary landfill, increased university community involvement not only reduces the likelihood of conflicts that have hampered the economic and environmental effects of waste management, but also lowers capital expenditures for waste management and boosts internal university generated revenues. It was discovered that waste streams at LCU have enormous resource potential. Not all of the waste generated by hostels, restaurants, guest houses, and institutions was disposed of in the same container. Findings also made it clear that the majority of biodegradable waste produced at the university was produced by the hostels, restaurants, and guest houses, and that when these wastes were deposited in adoptive landfill, it often results into the production of biogas.

The study found that waste output peaked in 2021–2022, when there were 25,010 students, at 5,705.406250 tons/year, up from the preceding session's average (2020/2021) of 5,550.623438 tons/year at 23,653 students. The research work showed that a significant amount of liquefied gases were produced at the adoptive landfill at Lead City University in Ibadan.

The effectiveness of activated charcoal in removing hydrogen sulphide from liquefied gases in landfills was demonstrated in the research where the amount of methane generated increased when adding activated charcoal in a chamber for catalytic effect. Therefore, it is vital to extract methane using activated charcoal in order to increase its formation in landfills. The research also showed that adding animal manures to organic waste in landfills has a positive effect by increasing the amount of methane produced. It confirmed that biological pretreatments were shown to improve methane production from animal manure by 74%, chemical pretreatments by 45%, heat pretreatments by 41%, and physical pretreatments by 30%[1]. Pretreatments often enhance the anaerobic digestion of the lignocellulosic content of animal manure and thus raise methane yield[2].

In all, correction results of measurement of CH_4, NH_3. CO_2 and H_2S with the introduction of activated charcoal and animal manures shown that the interactions are statistically significant.

5.2: Conclusion

The introduction of indigenous adaptive landfill at Lead City University, Ibadan, strengthens the management of solid wastes. It also serves as the inclusive waste management structural model and planning tool for creating a cohesive, financially secure, environment friendly and socio-economic drive of the university environment through sustainable waste management.

5.3: Recommendations

According to the analysis of study findings at LCU, adequate university community engagement and a sense of participation are essential for effective and sustainable waste management.

All waste management system ultimate goal is to esthetically and safely dispose of solid waste on land. To reduce the hazards to human health and the environment, waste landfills must be appropriately constructed and maintained. As a result, the lists of recommendations for efficient landfill management are provided below. It is hereby recommended that:

i. Lead City university management should increase the number of waste collection points, waste collection vehicles and waste management staff.

ii. The Nigerian government must acknowledge solid waste management as a serious issue and commit sufficient financial and other resources to finding an effective solution. Additionally, university management may research the costs and advantages of outsourcing waste collection and disposal operations to private operators if the available resources at the university are insufficient.

iii. Environmental Impact Statements (EIS) for the proposed adaptive sanitary landfill sites at Lead City University in Ibadan are crucial to produce. Not only should the environmental and material components of development be taken into account in the EIS, but also the groups in university contexts that are likely to be impacted by the development proposals.

iv. Intentional landfill sites should be planned and run in accordance with the relevant engineering and physical planning requirements. These requirements cover the movement of solid waste, accessibility, disposal, the amount and depth of sand (15 cm) that must be spread within 24 hours of disposal, and the installation of fencing around the sites.

5.4 Contribution to the Knowledge

With the completion of this project work, most of the universities in West African Countries and world at large will now have perfect understanding of how to manage their waste in sustainably manners.

5.5 Suggested Areas for further Research

Management of healthcare waste in university can also be carried out in nearest future.

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APPENDIX I

QUESTIONNAIRE

INVITATION TO PARTICIPATE IN A STUDY: INNOVATIVE APPROACH TO SOLID WASTE MANAGEMENT IN LEAD CITY UNIVERSITY, IBADAN: ADAPTIVE LANDFILL TECHNOLOGY

I, Olanrewaju John Adedayo, PhD student in the Department of Public Health, Lead City University, Ibadan is conducting a research study titles: Innovative Approach to Solid Waste Management in Lead City University, Ibadan: Adaptive Landfill Technology supervised by Dr. Tairu T.T. Specifically, the research aim is to develop a sustainable and effective waste management system for Lead City University, Ibadan and to develop adaptive sanitary landfill of waste management for Lead City University, Ibadan Nigeria. In addition to prescribing methods that will guide future policy and investment decisions for the institution, the project will develop parameters for evaluating advances in waste management starting at the site of generation and ending with the disposal method.

Your involvement in this initiative is entirely optional. If you could complete the questionnaire in its entirety, that would be greatly appreciated. There are four (4) components to the questionnaire.

General socio-demographic background information is requested in Section A, while lecturer's practical environmental knowledge and awareness to waste management are requested in Section B.

Requests for information about waste to wealth techniques are made in Sections C and D.

Please be aware that we will treat any information you supply in the utmost of confidence. All paper records will be destroyed after this study is over, and electronic records will only be accessible to those who need to know them.

I am aware that the questionnaire will take some of your precious time, but it will also yield a lot of useful data that will help Lead City University in Ibadan, Nigeria, improve its waste management. Upon request, we will provide you with any additional information we have as well as the study's final results.

In light of this, i would like to really appreciate your attention.

Olanrewaju John Adedayo

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Section A: General information

A1: Information about you

Name of respondent (Optional) ____

Contact address (Optional) ____

Tel. (Optional) ____

A2: Which area of Lead City University do you reside or work (Please tick the right option)

Male Hostel ☐ Female Hostel ☐University Guest house, halls and event centers ☐University eateries ☐University shop operators'/business centers ☐ University microfinance bank

☐University hospital ☐University faculties' buildings and classrooms ☐University offices

☐University's building under construction ☐ University staff quarters ☐University sporting unit

and allied ☐ Others (specify)…………………… ☐

A3: Using the scale 1-6 (1=excellent, 2=very good, 3=good 4=fair 5=poor, 6=very poor), please as a lecturer, identify your practical environmental knowledge and awareness to waste management of the under listed waste management subjects (tick Ö correct response)

1. Waste generation ☐
2. Sorting ☐
3. Reduce ☐
4. Recycle ☐
5. Reuse ☐
6. Composting ☐

7. Oyo State Waste Management Authority (OYSWMA) activities ☐

A4: Using the scale 1-6 (1=excellent, 2=very good, 3=good 4=fair 5=poor, 6=very poor), could you point out how well you have done in managing waste.

1. Environmental sanitation ☐
2. Recycling ☐
3. Composting ☐
4. Waste to wealth ☐

Section B: Operations B1: Lecturers practical environmental knowledge and awareness to waste management

Please respond to the following questions relating to waste generation (By choosing (1) Yes (2) No)

1. Solid waste management issue is one of the major issues confronting university authority
2. Solid waste collection and disposal methods formed basic steps in waste management
3. Nigeria has implemented a series of laws and regulations on solid waste management
4. Current waste disposal system in Lead City University, Ibadan is bad

5. Nigeria has initiated national programs to promote energy conservation awareness and environmentally responsible lifestyle in recent years.

6. The best wider spectrum of waste management behavior are reuse, reduce and recycle.

7. Open dump system practices in Lead City University, Ibadan have positive environmental impacts

8. It is not necessary to concern about the economic feasibility of transitioning to an adaptive sanitary landfill system from open dump system

9. There would be changes in waste management costs if adaptive sanitary landfills is implemented

10. The costs associated with adaptive sanitary landfills are justified considering the potential environmental benefits

B2: Student's environmental attitudes to waste management

Please respond to the following statements as honestly as possible by choosing (1) Yes (2) NO

11. The ideal waste management alternative is to prevent/reduce waste generation in the first place

12. The best way to tackle waste problem is sorting from generation before collection and disposal

13. Students participated in any programs aimed at promoting sustainable waste management practices is essential.

14. The major five steps in waste management are; reducing waste at the source, reuse of materials, recycling, energy recovery and landfilling.

15. Among students, a similar hierarchy of waste management was stabilized known as ARRE strategy; avoid, reduce, recycle and eliminate.

3. Please list other factors that could constitute barriers to sustainable waste management in the Lead City University, Ibadan

1.………………………………………………………………………………………………

2.………………………………………………………………………………………………

3.………………………………………………………………………………………………

D: Waste management strategy (please tick correct response)

1. How would you rate the effectiveness of current practice for managing municipal solid waste in Lead City University, Ibadan: excellent ☐ good ☐ poor ☐ I don't know☐?
2. Please suggest an environmentally friendly way to manage solid and hospital wastes in Lead City University, Ibadan: waste minimization ☐recycling/composting/incineration ☐energy generation ☐ landfilling ☐
3. In your opinion who is best equipped to manage the waste problem in the Lead City University, Ibadan: government agencies ☐ private organizations ☐ joint government and private ☐ individuals ☐
4. Waste facilities in the Lead City University, Ibadan are at times located without proper environmental consideration: Yes ☐ No ☐ I Don't know ☐

ANY OTHER COMMENTS

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

Will you be available for a brief follow-up confidential interview? Yes ☐ No ☐

Thank you for completing the questionnaire.

APPENDIX 2

Table 1: Composition of solid wastes/locations

	Exodus Hall (495)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	145.50
2	Nylons/Plastics	111.90
3	Papers	118.20
4	Stones/Pebbles	123.80
5	Metals	116.10
Total		**615.50**

Table 2: Composition of solid wastes/locations

	PG Hall (206)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	175.80
2	Nylons/Plastics	61.60

3	Papers	58.40
4	Stones/Pebbles	72.60
5	Metals	52.40
Total		**420.80**

Table 3: Composition of solid wastes/locations

	Hibiscus Hall (62)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	35.30
2	Nylons/Plastics	13.80
3	Papers	17.30
4	Stones/Pebbles	24.60
5	Metals	19.40
Total		**110.4**

Table 4: Composition of solid wastes/locations

	Block U Hall (228)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	74.90
2	Nylons/Plastics	59.20
3	Papers	53.80
4	Stones/Pebbles	62.60
5	Metals	56.80
Total		**307.30**

Table 5: Composition of solid wastes/locations

	Block I Hall (135)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	67.90
2	Nylons/Plastics	27.80

3	Papers	39.80
4	Stones/Pebbles	42.90
5	Metals	39.80
Total		**218.20**

Table 6: Composition of solid wastes/locations

	Maintenance Hall (27)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	12.80
2	Nylons/Plastics	10.60
3	Papers	13.40
4	Stones/Pebbles	14.60
5	Metals	16.90
Total		**68.30**

Table 7: Composition of solid wastes/locations

Independence Champion and Wisdom Hall (548)		
S/N	**Components**	**Weigh/kg**
1	Food ruminants	160.90
2	Nylons/Plastics	124.80
3	Papers	126.60
4	Stones/Pebbles	136.60
5	Metals	128.60
Total		**677.50**

Table 8: Composition of solid wastes/locations

Proverb 1 Hall (48)		
S/N	**Components**	**Weigh/kg**
1	Food ruminants	15.40
2	Nylons/Plastics	11.60
3	Papers	12.70
4	Stones/Pebbles	14.20
5	Metals	12.80
Total		**66.70**

Table 9: Composition of solid wastes/locations

Proverb 2 Hall (48)		
S/N	**Components**	**Weigh/kg**
1	Food ruminants	14.80
2	Nylons/Plastics	10.90
3	Papers	13.10

4	Stones/Pebbles	13.40
5	Metals	13.40
Total		**65.60**

Table 10: Composition of solid wastes/locations

	Revelation 1 Hall (64)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	36.20
2	Nylons/Plastics	14.60
3	Papers	17.80
4	Stones/Pebbles	25.20
5	Metals	19.90
Total		**113.70**

Table 11: Composition of solid wastes/locations

	Revelation 2 Hall (64)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	36.40
2	Nylons/Plastics	14.80
3	Papers	16.90
4	Stones/Pebbles	26.40
5	Metals	20.50
Total		**115.50**

Table 12: Composition of solid wastes/locations

	Apple Hall (232)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	195.20
2	Nylons/Plastics	68.20
3	Papers	63.20

4	Stones/Pebbles	78.20
5	Metals	58.80
Total		**420.80**

Table 13: Composition of solid wastes/locations

	Olive Hall (459)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	146.80
2	Nylons/Plastics	113.70
3	Papers	120.50
4	Stones/Pebbles	132.60
5	Metals	118.80
Total		**632.40**

Table 14: Composition of solid wastes/locations

	Block L Hall (114)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	98.50
2	Nylons/Plastics	34.40
3	Papers	32.60
4	Stones/Pebbles	39.40
5	Metals	26.60
Total		**231.50**

Table 15: Composition of solid wastes/locations

	Block L Hall (114)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	98.30
2	Nylons/Plastics	34.20

3	Papers	31.80
4	Stones/Pebbles	39.90
5	Metals	25.80
Total		**260.00**

Table 16: Composition of solid wastes/locations

Achiever Hall (104)		
S/N	**Components**	**Weigh/kg**
1	Food ruminants	100.50
2	Nylons/Plastics	36.60
3	Papers	34.80
4	Stones/Pebbles	42.10
5	Metals	29.80
Total		**243.50**

Table 17: Composition of solid wastes/locations

Victory Hall (79)		
S/N	**Components**	**Weigh/kg**
1	Food ruminants	38.60
2	Nylons/Plastics	16.70
3	Papers	18.80
4	Stones/Pebbles	28.80
5	Metals	22.70
Total		**125.60**

Table 18: Composition of solid wastes/locations

Peace 1 Hall (64)		
S/N	**Components**	**Weigh/kg**
1	Food ruminants	38.40
2	Nylons/Plastics	16.30

3	Papers	18.40
4	Stones/Pebbles	26.20
5	Metals	22.30
Total		**121.60**

Table 19: Composition of solid wastes/locations

Peace 2 Hall (64)		
S/N	**Components**	**Weigh/kg**
1	Food ruminants	38.20
2	Nylons/Plastics	16.50
3	Papers	17.60
4	Stones/Pebbles	25.80
5	Metals	23.70
Total		**121.8**

Table 20: Composition of solid wastes/locations

Camp-David 1 Hall (98)		
S/N	**Components**	**Weigh/kg**
1	Food ruminants	45.20
2	Nylons/Plastics	24.50
3	Papers	23.80
4	Stones/Pebbles	29.60
5	Metals	25.80
Total		**148.90**

Table 21: Composition of solid wastes/locations

Camp-David 2 Hall (98)		
S/N	**Components**	**Weigh/kg**
1	Food ruminants	46.10
2	Nylons/Plastics	25.30
3	Papers	22.60
4	Stones/Pebbles	30.80
5	Metals	27.60
Total		**152.40**

Table 22: Composition of solid wastes/locations

Camp-David 3 Hall (98)		
S/N	**Components**	**Weigh/kg**
1	Food ruminants	46.40
2	Nylons/Plastics	25.80
3	Papers	24.60

4	Stones/Pebbles	29.80
5	Metals	26.60
Total		**153.20**

Table 23: Composition of solid wastes/locations

	Camp-David 4 Hall (98)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	44.80
2	Nylons/Plastics	26.20
3	Papers	24.60
4	Stones/Pebbles	29.80
5	Metals	26.90
Total		**152.30**

Table 24: Composition of solid wastes/locations

Camp-David 5 Hall (100)		
S/N	**Components**	**Weigh/kg**
1	Food ruminants	47.40
2	Nylons/Plastics	26.90
3	Papers	25.60
4	Stones/Pebbles	32.20
5	Metals	27.60
Total		**159.70**

Table 25: Composition of solid wastes/locations

Camp-David 6 Hall (100)		
S/N	**Components**	**Weigh/kg**
1	Food ruminants	46.80
2	Nylons/Plastics	27.60
3	Papers	26.40

4	Stones/Pebbles	31.80
5	Metals	27.80
Total		**160.40**

Table 26: Composition of solid wastes/locations

	Jackson Hall (97)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	45.60
2	Nylons/Plastics	26.80
3	Papers	25.80
4	Stones/Pebbles	30.90
5	Metals	27.90
Total		**157.00**

Table 27: Composition of solid wastes/locations

	Hibiscus Hall (48)	
S/N	**Components**	**Weigh/kg**
1	Food ruminants	15.60
2	Nylons/Plastics	11.80
3	Papers	12.90
4	Stones/Pebbles	14.50
5	Metals	12.90
Total		**67.70**

Table 28: Overall composition of solid wastes/locations

	Twenty-Seven Halls (3,892)	
S/N	**Components**	**Weigh/ton/kg**
1	Food ruminants	1,967.70
2	Nylons/Plastics	1,144.50
3	Papers	961.00

4	Stones/Pebbles	1,301.30
5	Metals	1,056.20
Total		**6,430.70=6tons,430.7kg**

Source: Research work 2023

Table 29: Liquefied Gases (LFG) concentrations measured before construction of LCU Landfills

Sampling	Morning				Afternoon			
Days	CH_4 (%)	CO_2 (%)	NH_3 (PPM)	H_2S	CH_4 (%)	CO_2 (%)	NH_3 (PPM)	H_2S (PPM)
Day 1	08.34	18.24	608	1020	08.54	18.56	890	1030
Day 2	08.56	18.35	656	1032	08.78	18.68	898	1038
Day 3	08.65	18.50	678	1034	08.82	18.78	902	1040
Day 4	08.72	18.68	688	1036	09.94	18.82	922	1054
Day 5	08.88	18.78	692	1042	09.98	18.98	942	1066
Day 6	09.08	18.86	698	1054	10.54	19.10	954	1072
Day 7	10.22	18.98	702	1064	10.83	19.22	968	1076
Day 8	10.34	19.12	718	1068	10.98	19.30	988	1088
Day 9	10.56	19.22	722	1072	11.10	19.42	1002	1092
Day 10	10.68	19.34	734	1088	11.22	19.54	1020	1096

Source: Researcher's field work (2023).

Table 30: Liquefied Gases (LFG) concentrations measured after construction of LCU Landfills

Sampling Date	Morning				Afternoon			
	CH_4 (%)	CO_2 (%)	NH_3 (PPM)	H_2S(PPM)	CH_4 (%)	CO_2 (%)	NH_3 (PPM)	H_2S (PPM)
Day 1	21.72	41.23	1202	3450	23.45	40.67	2390	3470
Day 2	23.24	44.56	1428	3560	24.30	42.34	2786	3678
Day 3	24.65	46.50	1546	3670	26.40	44.35	2986	3690
Day 4	26.23	48.89	1654	3750	28.30	46.78	3245	3760
Day 5	28.56	49.20	1858	3789	32.30	48.24	3456	3792
Day 6	30.09	50.56	1956	3840	33.20	49.80	3578	3865
Day 7	32.90	51.20	2021	3868	34.55	50.67	3978	3872
Day 8	34.39	52.50	2467	3920	36.30	51.34	4200	3950
Day 9	39.30	53.45	2645	3960	41.40	52.45	4278	3980
Day 10	40.20	54.70	2982	4002	42.50	53.67	4560	4022

Source: Researcher's field work (2023).

Table 31: Effects of activated charcoal on Liquefied Gases (LFG) concentrations

Sampling	Morning				Afternoon			
Date	CH_4 (%)	CO_2 (%)	NH_3 (PPM)	H_2S	CH_4 (%)	CO_2 (%)	NH_3 (PPM)	H_2S
Day 1	45.46	40.01	250	3120	46.56	40.04	340	3208
Day 2	45.56	40.22	268	3134	48.20	40.08	356	3212
Day 3	45.86	40.34	278	3138	48.24	40.12	365	3216
Day 4	45.14	40.65	287	3142	48.56	40.34	378	3219
Day 5	45.68	41.10	292	3148	48.86	40.56	386	3304
Day 6	45.86	41.15	298	3150	48.92	40.66	398	3308
Day 7	46.22	41.20	302	3158	49.24	40.68	402	3312
Day 8	46.64	41.50	314	3162	49.86	41.12	410	3318
Day 9	47.30	41.52	320	3168	50.40	41.24	422	3322
Day 10	48.20	41.60	332	3172	50.50	41.34	432	3328

Source: Researcher's field work (2023).

Table 32: Effects of animal manure on Liquefied Gases (LFG)

Sampling Date	Morning CH_4 (%)	Morning CO_2 (%)	Morning NH_3 (PPM)	Morning H_2S	Afternoon CH_4 (%)	Afternoon CO_2 (%)	Afternoon NH_3 (PPM)	Afternoon H_2S
Day 1	55.42	44.06	458	3560	56.10	45.08	689	3680
Day 2	55.58	44.24	498	3689	56.20	45.18	698	3760
Day 3	55.68	44.36	568	3867	56.24	45.22	756	3980
Day 4	56.14	44.68	598	3980	56.56	45.34	834	4120
Day 5	56.68	45.18	668	4023	56.86	45.56	987	4322
Day 6	56.86	45.34	765	4135	56.92	45.66	1280	4359
Day 7	57.22	45.45	890	4167	57.24	45.68	1467	4366
Day 8	57.64	45.50	956	4206	57.86	46.12	1668	4376
Day 9	58.30	45.52	1230	4302	58.40	46.24	1869	4380
Day 10	59.20	45.60	1270	4340	59.50	46.34	2350	4390

Source: Researcher's field work (2023).

APPENDIX 3

Administration of questionnaires with members of staff

Plate Field work by the researcher

Bio-Data

A. PERSONAL DATA

1. Full Name: -	**John Adedayo OLANREWAJU**
	No 25 Orisun-Ayo Estate, Adunkale, Agbofieti area, Gbekuba, Apata, Ibadan. Oyo State
	olanrewajudayo@yahoo.com
	olanrewaju.john@lcu.edu.ng
	08034101590 and 08052836225
2. Date/place of birth: -	19th February 1973/Lagos
3. Nationality: -	Nigerian
4. Marital status: -	Married
5. Number of children with ages: -	Three (3) - 15 years, 12 years and 9 years
6. Name and address of spouse: -	Deborah Olufunke OLANREWAJU
	No 25 Orisun-Ayo Estate, Adunkale, Agbofieti area, Gbekuba, Apata, Ibadan. Oyo State
	olanrewajuolufunke@yahoo.com
	08032727887
7. Name and address of next of kin: -	**OLANREWAJU** Deborah Olufunke

No 25 Orisun-Ayo Estate, Adunkale,
Agbofieti area, Gbekuba, Apata,
Ibadan. Oyo State
08032727887

8. Date of assumption of duty in current establishment: 1st of November 2019

9. Status of first appointment in current establishment: Lecturer II

10. Date of confirmation of appointment: 1st of November 2021

11. Present Position: Lecturer II

12.. Date of Last Promotion: Nil

B. EDUCATIONAL BACKGROUND

I. Educational Institutions attended with Dates and Qualifications:

1. C&S Primary School, Okeho, Oyo State 1981-1985

First School Leaving Certificate

2. Awoyemi Commercial High School, Okeho. Oyo State 1985 – 1989

Senior Secondary School Certificate

3. St Andrew College of Education, Oyo. Oyo State 1991 – 1995

Nigerian Certificate of Education (Biology/Chemistry)

4. University of Agriculture, Abeokuta. Ogun State 1995 – 2000

B.EMT Environmental Management and Toxicology

5. University of Ibadan, Ibadan. 2007 – 2009

M.ECPC Environmental Chemistry and Pollution Control

6. University of Ibadan, Ibadan. 2014 – 2016

MPH Environmental Health Science

7. Lead City University, Ibadan 2020- 2024

PhD, Public Health. Occupational and Environmental Health

C. AWARDS AND FELLOWSHIPS: Nil

D. WORK EXPERIENCE WITH DATES

1. Work Experience with Dates

1. Oyo State Ministry of Education and Technology

Secretariat, Ibadan 2013- 2019

2. Lead City University, Ibadan 2019 – Up to date

Lecturer II

Courses Taught and activities carried out within the period

1. Climate Change and Contemporary issues (EHS 203)
2. Introduction to Ecology and Environment (EHS 201)
3. Introduction to Environmental Health (EHS 211)
4. Environmental Health Economic (EHS 306)
5. Environmental Biotechnology (EHS 317)

6. Water Resources Management (EHS 318)

7. Environmental Health Administration and Planning (EHS 402)

8. Environmental Community Entry (EHS 421)

9. Environmental Health Laboratory Practices I (EHS 502)

10. Sewage and Waste Water Management (EHS 506).

11. Environmental Health (NSC 309)

12. Environmental Health (PHS 308)

13. Environmental Education (EHS 409)

14. Project supervision

15. Former Departmental Examination Officer

3. Jolad Environmental Consultancy, Ibadan 2010- 2019

Principal Consultant

- Oversee the company's operations
- Written of EIA, EAR, EMP and other reports
- Ensure quality Health, Safety and Environmental standard.
- Ensure good relationship between the employees and employers

4. Vertext Media Limited, Mokola, Ibadan. Oyo State. 2009-2010

Health, Safety and Environmental Officer

- Carrying out Health Risk Assessment Surveys and Writing detailed reports to the client

- Preparation and Presentation of Course Materials for workshops, seminars and programs organized by professional HSE Services Division
- Proposal Written in Assistance of Business Development Officer
- Presentation at NISP and Health related conferences and representing the organization at such events

5. National Fadama Development Programme, 2004-2009

Ministry of Agriculture and Natural Resources, Ibadan. Oyo State.

Project Facilitator,

- Sensitization and awareness creation of the project to the beneficiaries.
- Preparation of the Local Development Plan (LDP) for the beneficiaries.
- Monitoring and Evaluation of the Sub-projects.

6. Ministry of Environment and Water Resources, Ibadan. Oyo State. Jan-Dec 2003

Scientific Officer,

- Monitoring of the industrial compliance with the state environmental laws
- Enforcing the industries to write the Environmental Impact Assessment (EIA) and comply with it and Monitoring of the industries Environmental Audit Report (EAR).
- Supervising state beautification, aesthetic and tree planting across the state. Supervising monthly environmental sanitation exercises.

7. Iwajowa Local Government, Iwere-Ile, Oyo State. Nigeria Nov 2001-Jan 2003

Higher Environmental Health Officer

- Monitoring of the industrial compliance with the local environmental laws

- Enforcing the industries to write the Environmental Impact Assessment (EIA) and comply with it and Monitoring of the industries Environmental Audit Report (EAR).
- Supervising local beautification, aesthetic and tree planting across the Local Government Area
- Supervising Monthly Environmental Sanitation Exercises.

8. Nigerian Guinea Worm Eradication Programme. (Global 2000). 2000-2001

Katcha Local Government Area, Katcha, Niger State. Nigeria

N.Y.S.C Field Officer

- Sensitization and Awareness creation of the Programme to the peoples of Katcha Local Government Areas.
- Treatment of the infected ponds and victims of Guinea Worm infection.
- Educate people on how to prevent further infection of Guinea Worm.
- Serve as a link between the projects itself and the beneficiaries.

E. MEMBERSHIP OF ACADEMIC PROFESSIONAL BODIES

a. Member, Environmental Health Officers Registration Council of Nigeria (EHORECON-(EHO/SA/8499)

b. Member, Nigerian Institutes of Safety Professionals (NISP) (Reg ID. 4115)

c. Member, Nigerian Environmental Study Action Team (NEST)

d. Member, Teacher Registration Council of Nigeria (TRCN)

F. PUBLICATIONS:

1. **Papers accepted for publication**

1. Olanrewaju John Adedayo, Dorcas Oluwabukola Akinte, Adewale Allen Sokan-Adeaga and Micheal Ayodeji Sokan-Adeaga (2022): *A Survey on Faecal Management Practices and Associated Health Impacts among Residents in Selected Sub-Urban Communities in Ibadan, Nigeria.* **Journal of Applied Sciences ISSN 1812-5654 DOI: 10.3923/jas.2022.107.116.**
2. Olanrewaju John Adedayo, Adewale Allen Sokan-Adeaga, Kehinde Samuel Abiodun and Olagunju Franciscan Oladoyin (2022): *Sanitary compliance of public eating houses in Ibadan North Local Government Area of Oyo State, Nigeria.* **Quest Journals Journal of Research in Environmental and Earth Sciences Volume 8 ~ Issue 7 (2022) pp: 74-83 ISSN(Online) :2348-2532 www.questjournals.org**
3. Olanrewaju J.A and Ana Godson R. (2023). *Indoor Air Quality and Risks Connected to Laundry Operations in Ibadan Metropolis,* **Asian Journal of Environment & Ecology Volume 22, Issue 3, Page 115-122, 2023; Article No. AJEE.106574 ISSN: 2456-690X4. DOI: 10.9734/AJEE/2023/v22i3493. (October 10, 2023). Available at SSRN: https://ssrn.com/abstract=4643985 or http://dx.doi.org/10.2139/ssrn.4643985**
4. Olanrewaju, John, Adedayo, Sokan-Adeaga, Adewale Allen, Kehinde, Samuel Abiodun, Olabimiji, Bisola B and Oladeji, Francis O, *Toilet Functionality and Cleanliness Status of Major Motor Parks in Ibadan Metropolis, Nigeria.* **Journal of Materials Science Research and Reviews, Volume 6, Issue 4, Page 737-758, 2023; Article no. JMSRR.106575 (December 28, 2023). Available at SSRN: https://ssrn.com/abstract=4678107 or http://dx.doi.org/10.2139/ssrn.4678107**

5. **O**lanrewaju John A, Tairu Tajudeen T, Sokan-Adeaga Adewale A, Kehinde Samuel A, Tella Esther O, Jaiyeola Taiwo F, Olu-Owolabi Bamidele, Oladeji Francis O, Olabosoye Peter O and Amoo Olakunle M. (2023): *Physico-Chemical and Thermodynamic Adsorption Studies of a Few Soils from Delta and Oyo State,* **Asian Soil Research Journal, Volume 7, Issue 4, Page 1-11, 2023; Article no. ASRJ.108249. ISSN: 2582-3973. DOI: 10.9734/ASRJ/2023/v7i4136**

6. Olanrewaju John A, Olabosoye Peter O and Amoo Olakunle M (2023): *Evaluation and Impact of Stakeholders on the Sustainable Ibadan Project's (SIP): A Case Study of Potable Water Projects in Ibadan, Oyo State, Nigeria.* **Asian Journal of Geographical Research Volume 6, Issue 4, Page 32-43, 2023; Article no. AJGR.109489 ISSN: 2582-2985. DOI: 10.9734/AJGR/2023/v6i4201. (November 24, 2023). Available at SSRN: https://ssrn.com/abstract=4643963**

7. Olanrewaju John Adedayo, Tairu Tajudeen Tunde, Olowolafe Tubosun Alex, Amoo Olakunle M. and Laba Sunday Ademola (2023): *Critical Appraisal of Institutional Solid Waste Management: Case Study of Lead City University, Ibadan, Oyo State, Nigeria.* **Journal of Applied Life Sciences International, Volume 26, Issue 6, Page 58-74, 2023; Article no. JALSI.109937. ISSN: 2394-1103. DOI: 10.9734/JALSI/2023/v26i6628. (December 28, 2023). Available at SSRN: https://ssrn.com/abstract=4678104 or http://dx.doi.org/10.2139/ssrn.4678104**

8. Francis Olusegun Oladeji, Adepoju Adelola, Tawakalitu T. Abolayo, Oluwaseun Awodele, Ojedeji Kolawole Ayodeji and Olanrewaju John Adedayo (2023): *An Evaluation of the Presence of Heavy Metals in the Poultry Feeds Marketed in Ijebu Jesa, Osun State* **Asian Journal of Chemical Sciences, Volume 13, Issue 5, Page 71-77, 2023; Article no. AJOCS.105083. ISSN: 2456-7795. DOI: 10.9734/AJOCS/2023/v13i5254.**

9. Ejilude Dauda Adekunle, Olowolafe Tubosun Alex and Olanrewaju John Adedayo (2023): *Occupational Health Hazards among Petrol Station Workers in Ibadan, Oyo State, Nigeria.* **Asian Journal of Chemical Sciences, Volume 13, Issue 6, Page 248-258, 2023; Article no. AJOCS.110118, ISSN: 2456-7795. DOI: 10.9734/AJOCS/2023/v13i6278 Available at SSRN: https://ssrn.com/abstract=4678088**

10. Francis Olusegun Oladeji, Olanrewaju John Adedayo, Abolayo Tawakalitu Tope, Makanjuola Bosede Christiana and Olawuni Timothy Ifeoluwa (2023): *Fungi Associated with the Spoilage of Smoke Dried Fish in Open Market in Osogbo, Osun-State, Nigeria.* **Asian Journal of Food Research and Nutrition. Volume 2, Issue 4, Page 676-680, 2023; Article no. AJFRN.106962**

11. Ejilude Dauda Adekunle, Olowolafe Tubosun Alex and Olanrewaju John Adedayo (2023): *Knowledge of Occupational Hazards and Safety Practices among Petrol Station Workers in Ibadan Metropolis, Oyo State, Nigeria.* **Journal of Materials Science Research and Reviews, Volume 6, Issue 4, Page 858-870, 2023; Article no. JMSRR.110119. Available at SSRN: https://ssrn.com/abstract=4678086**

12. Olanrewaju John Adedayo and Akinyele-Williams Titilope Felicia (2024): *Knowledge and Attitude of Pregnant Women Attending Antenatal Clinic at University College Hospital towards Causes and Methods of Prevention of Cervical Cancer.* **Asian Oncology Research Journal Volume 7, Issue 1, Page 1-14, 2024; Article no. AORJ.11032**

13. Roy'lagbaja Fateemah Adekemi (Adebayo), Afolalu Olamide O and Olanrewaju John (2024): *Uptake of Cervical Cancer Screening Service and Associated Factors among Female Civil Servants in Oyo State Secretariat, Ibadan, Nigeria.* **International**

Research Journal of Oncology Volume 7, Issue 1, Page 21-38, 2024; Article no. IRJO.110320. Electronic copy available at: https://ssrn.com/abstract=4713990

14. Olanrewaju John Adedayo, Tairu Tajudeen Tunde, Olowolafe Tubosun Alex, Amoo Olakunle M and Alamu Sunday Olagbemiro (2024): *Quantification and Characterization of Solid Waste at Lead City University, Ibadan, Nigeria.* **Asian Journal of Geological Research Volume 7, Issue 1, Page 41-57, 2024; Article no. AJOGER.110042.**
15. Hammed T.B, Laniyan T.A and Olanrewaju J.A (2024): *Nutrient Chemical Forms, Storage Effects and Phyto-Toxicity of Organic Fertilizers to Selected Cereal and Legume Crops*. **Compost Science & Utilization, pp1-10 http://doi.org/10.1080/1065657X.2024.2391791.**

2. Publication Profile

GOOGLE: https://scholar.google.com?user=GtuJ2IEAAAAJ8hl=en

RESEARCHGATE: https://www.researchgate.net/profile/John-olanrewaju-3

ORCID: https://orcid.org/0000-0002-8913-4288

3. Books/Monographs

(a) Authored books:

a) Science Made Thing Easy. Published in 1995.

b) Environmental Education for Schools and Colleges. Published in 2002.

c) Silent Achiever- 365 Days of Meaningful Administration. The Executive Chairman. Hon Salami Isiaka Salami in Kajola Local Government Area.Okeho.Oyo State. Published in 2004 by Jolad Environmental Consultancy and Communication Network

d) The Giant strides of Hon Bamiji Kunle Nafiu. Executive Chairman, Atisbo Local Government, Tede. Oyo State. Published in 200 5 by Dele Sho Nig. Enterprise. Lagos.

(b) International Books Published: One (1)

1. John Adedayo Olanrewaju: Adaptive Sanitary Landfill: An Optional Approach for Effective Institutional Solid Waste Management. Publisher, Eliva Press (January 4, 2024). Language: English, Paperback: 253 pages. ISBN-10: 9999313914, ISBN-13: 978-9999313919 and ISBN:978-99993-1-391-9. https://www.elivabooks.com/en/book/book-9238304268, https://www.amazon.com/dp/9999313914

(c) Contribution to Books: One (1)

4. Published Referred Conference Proceedings: Nil

5. **Book Reviews and Commentaries in Scholarly Journals:** Eleven (11)

6. **Technical Reports:** Nil

7. **Other Publications:** Nil

8. **Creative Work:** Nil

G. **NOTABLE SCHOLARLY OR PROFESSIONAL ACCOMPLISHMENTS:** Nil

H. **MAJOR CONFERENCE/WORKSHOP ATTENDED AND COMMUNITY ASSIGNMENTS:**

i. Chairman, Golden Horse Estate, Adukanle Community, Agbofieti, Apata, Ibadan

J. EXTRA-CURRICULAR ACTIVITIES

Reading, writing and discussing social change in society with friend and families

K. OTHERS: Nil

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The University Compliance Certification

This is to certify that the thesis written by John Adedayo OLANREWAJU with matriculation number LCU/PG/001960 in the Department of Public Health, Faculty of Basic Medical and Health Sciences, Lead City University, Ibadan, Oyo State, is in full compliance with the approved University format and style.

Signature   Date