Sustainable Solid Waste Management and Reduction in Carbon Footprints in Pakistan

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(2024)

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A thesis submitted to the National University of Sciences and Technology, Islamabad,
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Bachelor of Science in
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Supervisor: Dr. Naim Rashid

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(2024)

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No part of this thesis has been submitted anywhere else for any other degree. This thesis is submitted to the Department of Water Resources and Engineering, Military College of Engineering, Risalpur in partial fulfillment of the requirements for the degree of Bachelor's in Civil Engineering

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DEDICATION

To Almighty Allah for giving us the strength to undertake this project. And to our parents, whose dedication and teachings have been a beacon of light all our lives.

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

AD	Anaerobic Digestion
ASTM	American Society for Testing and Materials
ISWM	Integrated Solid Waste Management
MSW	Municipal Solid Waste
MRFs	Material Recovery Facilities
BTU	British Thermal Unit
COD	Chemical Oxygen Demand
MBT	Mechanical Biological Treatment
VM	Volatile Matter
FC	Fixed Carbon
MC	Moisture Content
GPS	Global Positioning System
RDF	Residue Derived Fuel
SDGs	Sustainable Development Goals
GWP	Global Warming Potential
kWh	Kilo Watt Hour
WtE	Waste-to-Energy
SNS	School of Natural Sciences

ABSTRACT

This study addresses the critical need for effective waste management strategies in urban areas, focusing on the Cadets Battalion in Military College of Engineering, Risalpur, and Hayatabad, Peshawar. The escalating challenges of rapid urbanization and population growth have amplified the complexities of solid waste management, demanding innovative solutions. Our research aims to analyze and compare the waste composition in Cadets Battalion and Hayatabad to understand the underlying factors contributing to waste generation and management inefficiencies. The primary challenge lies in the increasing volumes and diverse nature of waste streams, coupled with inadequate waste management infrastructures. This study seeks to identify these challenges comprehensively to propose sustainable solutions that align with global sustainability goals. Existing remedies primarily focus on Integrated Solid Waste Management (ISWM) approaches, emphasizing waste reduction, recycling, and resource recovery. However, the implementation of these strategies faces numerous obstacles, including limited resources and infrastructure. Our proposed approach involves detailed waste characterization, proximate analysis, and CHNS analysis to understand the composition, energy potential, and environmental impacts of solid waste. By conducting research and analysis, we aim to provide evidence-based recommendations for optimizing waste management practices in Cadet Battalion and Hayatabad, contributing to environmental sustainability, economic efficiency, and social well-being. This study utilized systematic data collection methods, including waste sampling, segregation, weighing, and analysis, following ASTM standards and best practices in waste management research. The results and insights generated from this study are essential for policymakers, urban planners, and waste management practitioners to develop and implement effective strategies tailored to the unique challenges and contexts of Cadets Battalion and Hayatabad.

Keywords: Integrated Solid Waste Management (ISWM), Waste Characterization, Proximate Analysis, CHNS Analysis, Biogas Yield, Energy Potential, Carbon Footprint, Global Warming Potential, Sustainable Development.

CHAPTER 1: INTRODUCTION

1.1 Background

The challenge of managing solid waste in urban areas has become increasingly complex and urgent in recent years, driven by the forces of rapid urbanization, population growth, and escalating environmental concerns. With a growing proportion of the global population residing in cities, the effective management of urban waste has emerged as a critical component of sustainable urban development. One promising avenue for addressing this challenge and simultaneously advancing sustainability goals is the production of energy from solid waste.

Urbanization, marked by the migration of people from rural to urban areas, has led to a significant surge in solid waste generation. The modern urban lifestyle, characterized by increased consumption and a higher rate of disposability, has amplified the quantities and types of waste produced. In many cases, traditional waste management systems have struggled to keep pace with this rapid increase, resulting in inadequate collection, open dumping, and inefficient disposal practices.

Open dumping and improper disposal of waste pose grave environmental and health risks. They can contaminate soil and water sources, release harmful pollutants into the air, and create unsightly and unsanitary conditions within urban areas. Additionally, the mismanagement of waste contributes to greenhouse gas emissions, exacerbating climate change and global warming.

Recycling and waste reduction efforts have made strides in some regions, but these practices alone are insufficient to manage the volume and diversity of urban waste. This reality has spurred the exploration of alternative waste management strategies that not only reduce the environmental footprint of waste disposal but also generate valuable resources.

One such strategy is the conversion of solid waste into energy, a process commonly referred to as waste-to-energy (WtE). WtE technologies encompass a range of approaches, including incineration, anaerobic digestion, and landfill gas capture, all of which can transform organic and non-recyclable waste materials into electricity, heat, or biogas. These technologies not only offer an environmentally responsible means of waste disposal but also contribute to energy production, addressing the ever-present challenge of energy security in urban environments.

Energy production from solid waste not only helps alleviate the burden on landfills but also presents economic and environmental advantages. It reduces the need for fossil fuel-based energy sources, lowering greenhouse gas emissions and air pollution. Moreover, it can provide a localized source of clean and renewable energy, contributing to the resilience and sustainability of urban areas.

1.1.1 Integrated Solid Waste Management (ISWM)

Integrated Solid Waste Management (ISWM) is a comprehensive and holistic approach designed to address the multifaceted challenges associated with solid waste. At its core, ISWM aims to manage solid waste throughout its lifecycle, from generation to disposal, in a manner that is environmentally sustainable and socially responsible. This approach recognizes that solid waste management is not just about collecting and disposing of waste but also about implementing strategies that prioritize waste reduction, resource recovery, and pollution prevention.

The key components of ISWM include:

1.1.1.1 Waste Collection

Efficient and organized collection systems are essential for gathering solid waste from households, businesses, and institutions. ISWM emphasizes the importance of optimized collection routes, proper waste segregation, and the use of suitable collection vehicles to minimize transportation costs and environmental impact.

1.1.1.2 Waste Transportation

Once collected, solid waste needs to be transported to processing facilities or disposal sites. ISWM advocates for efficient transportation practices that reduce fuel consumption, emissions, and traffic congestion. This may involve using modern vehicles, route optimization technologies, and scheduling methods to streamline the transportation process.

1.1.1.3 Waste Processing

ISWM promotes the use of environmentally friendly and sustainable methods for processing solid waste. This includes technologies such as composting, anaerobic digestion, and mechanical-biological treatment (MBT) to recover valuable resources from waste streams. These processes not only reduce the volume of waste sent to landfills but also generate renewable energy, compost, or recycled materials.

1.1.1.4 Recycling and Resource Recovery

A fundamental aspect of ISWM is the promotion of recycling and resource recovery initiatives. This involves separating recyclable materials from the waste stream, such as paper, plastics, glass, and metals, and diverting them to recycling facilities. By recovering and reusing these materials, ISWM conserves natural resources, reduces energy consumption, and minimizes greenhouse gas emissions.

1.1.1.5 Waste Disposal

For residual waste that cannot be recycled or recovered, ISWM advocates for responsible and environmentally sound disposal methods. This may include modern landfilling practices that incorporate liners, leachate collection systems, and gas recovery systems to minimize environmental contamination. ISWM also explores alternative disposal options, such as waste-to-energy facilities, to harness the energy potential of waste while reducing landfill reliance.

1.1.1.6 Environmental and Social Responsibility

ISWM places a strong emphasis on environmental protection and social responsibility. This involves implementing measures to mitigate air and water pollution, reduce greenhouse gas emissions, protect natural habitats, and promote public health and safety. ISWM also considers the social impacts of waste management, including community engagement, education, and equity in service provision.

Overall, Integrated Solid Waste Management (ISWM) represents a paradigm shift towards more sustainable and holistic waste management practices. By integrating waste collection, transportation, processing, recycling, and disposal in an environmentally responsible manner, ISWM strives to create cleaner, healthier, and more resilient communities for present and future generations.

1.1.2 Rationale for Studying ISWM:

The rationale for conducting research on ISWM stems from the growing challenges posed by rapid urbanization, population growth, and industrialization. As cities expand, the volume of waste generated increases significantly, straining existing waste management systems and leading to environmental degradation. Understanding and implementing effective ISWM strategies is crucial to mitigate these challenges and promote sustainable urban development.

1.1.3 Challenges in Conventional Waste Management

Conventional waste management practices often rely heavily on landfilling and incineration, which can have detrimental environmental and health consequences. Landfills contribute to groundwater contamination, greenhouse gas emissions, and land degradation, while incineration raises concerns about air pollution and toxic ash disposal. These challenges underscore the need for more sustainable and environmentally friendly waste management solutions.

1.1.4 Shift Towards Sustainable Waste Management

The paradigm shift in waste management philosophy marks a fundamental transformation in how society perceives and handles waste. Traditionally, waste was often viewed as a burden, necessitating disposal methods that prioritized removal and containment without much consideration for resource recovery or environmental consequences. However, with growing environmental awareness and the recognition of finite resources, there has been a significant transition towards sustainable waste management practices.

Sustainable waste management is guided by principles that emphasize the intrinsic value of waste as a potential resource. Rather than simply discarding waste, sustainable approaches seek to extract value from it through various methods:

1.1.5 Importance of Research in ISWM

Research in Integrated Solid Waste Management (ISWM) plays a pivotal role in advancing waste management practices and addressing critical challenges on multiple fronts. It serves as a cornerstone for developing evidence-based strategies that are essential for optimizing waste management processes and achieving sustainable outcomes. Through rigorous research, valuable insights are gained into various aspects of waste management, including waste characterization, treatment technologies, and policy frameworks.

One of the primary objectives of ISWM research is to bridge knowledge gaps that exist within the waste management domain. This includes understanding the composition of waste streams, identifying emerging contaminants, assessing the efficacy of different waste treatment methods, and evaluating the environmental impacts of waste management practices. By addressing these gaps, researchers contribute to the development of innovative solutions and best practices that can enhance the efficiency and effectiveness of waste management systems.

Furthermore, ISWM research encompasses a comprehensive analysis of the environmental, economic, and social dimensions of waste management. Environmental aspects focus on issues such as pollution prevention, resource conservation, and mitigation of greenhouse gas emissions. Economic considerations include cost-benefit analyses, financial viability of waste management projects, and potential revenue streams from waste-to-energy initiatives. Social dimensions involve community engagement, stakeholder participation, and public awareness campaigns to promote responsible waste management behaviours.

The outcomes of ISWM research are instrumental in informing decision-making processes at various levels, from local municipalities to national governments and international organizations. Research findings contribute to evidence-based policy formulation, regulatory frameworks, and strategic planning for sustainable waste management. By leveraging research insights, policymakers can design interventions that prioritize environmental sustainability, promote circular economy principles, and address socio-economic disparities related to waste management.

In essence, ISWM research serves as a catalyst for driving positive change in waste management practices, fostering innovation, and building resilience in the face of global waste challenges. It empowers stakeholders with the knowledge and tools needed to create a more sustainable and environmentally conscious future.

1.1.6 Role of ISWM in Sustainable Urban Development

Integrated Solid Waste Management (ISWM) serves as a cornerstone in advancing sustainable urban development by addressing waste-related challenges comprehensively. Its multifaceted approach encompasses minimizing pollution, conserving resources, promoting circular economy practices, and enhancing overall quality of life in urban areas. By implementing effective waste collection, recycling, and disposal methods, ISWM mitigates environmental pollution, safeguards public health, and fosters economic resilience through resource recovery and waste-to-energy initiatives. Additionally, ISWM aligns with global sustainability goals such as the United Nations Sustainable Development Goals (SDGs), contributing significantly to environmental sustainability, economic prosperity, and social well-being in communities.

1.2 Problem Statement

This project seeks to address the challenge of solid waste management by developing a sustainable solution that not only minimizes the environmental impact by reducing greenhouse gas emissions but also explores the potential for generating energy from solid waste. The goal is to contribute to resource-efficient urban development by integrating waste management practices that are environmentally friendly and harness the energy potential inherent in solid waste.

1.3 Objectives

Thus, on the basis of the problem statement following objectives were set for the study:

- To determine the composition of solid waste generation in Cadets Battalion and Hayatabad
- To assess the energy potential of solid waste
- To calculate Global Warming Potential (GWP), carbon footprints and earning carbon credits

CHAPTER 2: LITERATURE REVIEW

2.1 Historical Evolution of Waste Management Practices

Throughout history, people have always had to deal with waste, but the ways we handle it have changed a lot over time. Long ago, in ancient civilizations like Egypt and Mesopotamia, they didn't have organized systems for waste. They often just threw it away wherever they could, sometimes in water or in specific areas. As societies grew and became more structured, they started making rules about waste. For example, in ancient Athens, they made laws against dumping waste in public places, which was a big step towards more organized waste management.

The industrial revolution brought even bigger changes. Cities grew larger, and more people meant more waste. So, they started creating systems to collect and dispose of waste more efficiently. By the 20th century, many cities had basic waste collection services, and they mainly used landfills to dispose of waste. But these methods weren't always good for the environment.

The mid-20th century brought about a greater awareness of environmental issues, leading to the development of modern waste management practices. The 1970s saw the emergence of recycling programs as a response to growing concerns about resource depletion and pollution. Governments and organizations worldwide began promoting waste reduction, reuse, and recycling as core principles of sustainable waste management.

Today, waste management is a complex and multifaceted field that encompasses a range of strategies, from waste minimization and recycling to advanced technologies like anaerobic digestion and waste-to-energy. Case studies from different regions offer valuable insights into the diverse approaches to waste management, highlighting successes, challenges, and lessons learned. As we continue into the 21st century, the focus is shifting towards more holistic and sustainable waste management practices that prioritize environmental protection, resource conservation, and community engagement.

2.2 Global Perspective of Waste Management Practices

In the global perspective of waste management, there has been a significant evolution from rudimentary disposal methods used by early civilizations to the development of sophisticated integrated systems in modern societies. In ancient times, waste disposal was often basic, with waste being discarded in designated areas or bodies of water without much consideration for environmental impact or long-term consequences. However, as populations grew and industrialization accelerated, waste management practices became more complex and organized.

Modern waste management systems are characterized by comprehensive infrastructures that encompass waste collection, transportation, treatment, and disposal. These systems often incorporate advanced technologies and processes such as recycling, composting, landfilling, and waste-to-energy initiatives. The aim is not only to manage waste efficiently but also to minimize environmental pollution, conserve resources, and promote sustainability.

Despite advancements in waste management, challenges persist on a global scale. One of the primary challenges is the increasing rate of waste generation, particularly in urban areas experiencing rapid population growth and industrial development. This surge in waste production poses logistical and environmental challenges, requiring innovative strategies for waste reduction and management.

Another challenge is the diverse composition of waste, which includes organic, recyclable, hazardous, and non-recyclable materials. Managing this heterogeneous waste stream effectively requires tailored approaches and specialized facilities for sorting, processing, and disposing of different waste types.

Furthermore, inadequate waste management infrastructure in many regions, especially in developing countries, exacerbates issues such as open dumping, pollution, and public health risks. Improper disposal practices, including illegal dumping and burning of waste, contribute to environmental degradation and health hazards.

In response to these challenges, there is a growing emphasis on sustainable waste management practices worldwide. This includes promoting waste reduction at the source, encouraging recycling and reuse initiatives, investing in modern waste treatment technologies, and implementing stringent regulations and policies to enforce responsible waste disposal.

Overall, the global perspective on waste management underscores the need for continuous improvement, innovation, and collaboration among governments, industries, communities, and environmental organizations. By adopting holistic and integrated approaches to waste management, societies can strive towards a cleaner, healthier, and more sustainable future for all.

2.3 Current State of Waste Management Practices

An in-depth examination of present-day waste management practices worldwide unveils a richly varied scenario marked by differences in infrastructure, regulatory frameworks, and technological advancements. The literature delves into detailed studies on the rates of waste generation, analyses of waste composition, and the methods employed for waste disposal, which typically include landfilling, incineration, and recycling. Furthermore, significant attention is devoted to assessing the environmental repercussions and social consequences associated with these waste management practices. This comprehensive approach encompasses a wide spectrum of factors contributing to the complexity of waste management on a global scale.

Within this extensive review, case studies play a pivotal role in offering a nuanced perspective on waste management challenges and opportunities across diverse settings. These case studies span urban, rural, developed, and developing areas, shedding light on the unique dynamics and intricacies faced by different communities. By exploring real-world scenarios and examining the successes and limitations of various waste management strategies, this analysis aims to provide a holistic understanding of the multifaceted nature of contemporary waste management practices. Such a comprehensive assessment is crucial for identifying best practices, addressing shortcomings, and fostering sustainable waste management solutions tailored to specific contexts.

2.4 Limitations of Solid Waste Management

In the ongoing quest for sustainable waste management solutions, it's imperative to acknowledge and address the inherent limitations of current practices. While significant progress has been made in reducing, treating, and disposing of solid waste, several challenges persist, necessitating a nuanced approach to tackle them effectively.

One key limitation lies in the sheer volume and diversity of solid waste generated by human activities. As populations grow and consumption patterns evolve, the amount of waste produced continues to rise, straining existing infrastructure and resources. Additionally, the composition of solid waste varies widely, encompassing everything from organic matter to hazardous materials, each requiring tailored management strategies.

Furthermore, the global nature of waste management presents logistical and regulatory hurdles. Disparities in waste management capabilities and practices between regions can result in unequal distribution of environmental burdens and hinder collaborative efforts towards sustainable solutions. Additionally, regulatory frameworks governing waste management may be inadequate or inconsistently enforced, undermining efforts to mitigate environmental impacts. Technological limitations also play a significant role in shaping the effectiveness of solid waste management practices. While advances in recycling, composting, and WtE technologies offer promising avenues for resource recovery, implementation challenges such as high capital costs and technological complexity may impede widespread adoption.

Moreover, social and behavioral factors contribute to the complexities of solid waste management. Public awareness, attitudes, and behaviors surrounding waste disposal and recycling vary widely, influencing participation rates in waste reduction initiatives and the success of recycling programs. Addressing these socio-cultural dynamics requires targeted education, outreach, and community engagement efforts.

In light of these limitations, it's clear that a multifaceted approach is needed to address the challenges of solid waste management comprehensively. By acknowledging the constraints imposed by infrastructure, technology, regulations, and societal norms, stakeholders can work collaboratively to develop innovative, context-specific solutions that promote sustainability, resource efficiency, and environmental stewardship.

2.5 Waste Management Practices

Solid waste management is a critical aspect of environmental sustainability, ensuring that the waste generated by human activities is handled responsibly and efficiently. From the production of everyday items to the disposal of packaging and materials, effective management of solid waste is essential for safeguarding public health, preserving natural resources, and mitigating environmental pollution.

This explores the diverse array of techniques and methods employed in solid waste management, ranging from source reduction and recycling to advanced treatment technologies and responsible disposal practices. Each method plays a unique role in addressing the challenges posed by solid waste, offering opportunities to minimize waste generation, recover valuable resources, and minimize environmental impact.

By understanding and implementing these techniques, communities and organizations can work towards a more sustainable approach to managing solid waste, contributing to the well-being of both present and future generations.

2.5.1 Collection and Transportation

Efficient collection and transportation systems are pivotal in managing solid waste effectively, ensuring prompt removal from communities to processing facilities. These advancements underscore a more streamlined and eco-friendly approach to solid waste management, emphasizing resource optimization and sustainability.

2.5.2 Landfilling

Landfills serve as engineered sites designed for the disposal of non-recyclable and residual waste. These facilities play a crucial role in waste management by providing a designated area for the safe and controlled disposal of materials that cannot be recycled or reused. Modern landfills are equipped with advanced features such as liners and leachate collection systems to mitigate environmental risks. Liners act as barriers between the waste and the surrounding soil, preventing potential leachate from contaminating groundwater sources. Leachate collection systems further enhance environmental protection by capturing and treating any liquid that seeps out of the landfill, reducing the risk of groundwater pollution. Additionally, modern landfills often incorporate systems to capture and utilize methane gas produced during waste decomposition, contributing to renewable energy generation and minimizing greenhouse gas emissions.

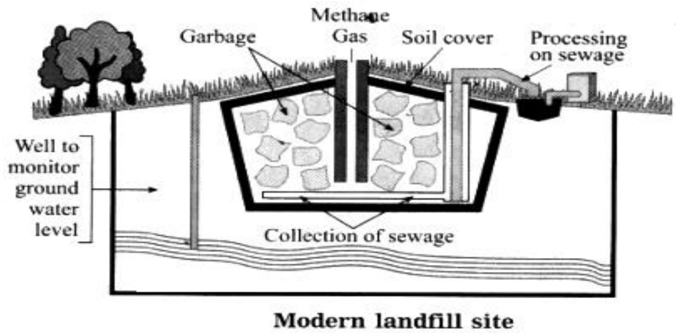

Figure 1: Schematic Diagram of Landfill

2.5.3 Incineration (Waste-to-Energy)

Incineration is a waste management process that involves the combustion of waste materials at high temperatures, typically in specialized facilities known as incinerators. This method is employed to reduce the volume of waste and generate energy through the combustion process. Modern incineration technologies, particularly those used in waste-to-energy plants, have advanced significantly to not only reduce waste volume but also capture the heat produced during incineration for electricity generation. Waste-to-energy plants utilize this captured heat to produce steam, which then drives turbines to generate electricity, contributing to sustainable energy production. Furthermore, these advanced technologies incorporate emission control systems such as scrubbers and filters to minimize the release of pollutants and ensure compliance with environmental regulations. As a result, incineration, when implemented with modern technologies, represents a viable approach to waste management that can simultaneously reduce waste volume, generate renewable energy, and minimize environmental impact.

2.5.4 Recycling

Recycling plays a crucial role in sustainable waste management by transforming waste materials into new products, thereby conserving resources and reducing waste. Common recyclables include paper, plastics, glass, and metals, which undergo a series of steps including sorting, cleaning, and processing to prepare them for reuse. This process not only diverts waste from landfills but also conserves raw materials and reduces the energy and resources required for manufacturing new products. Recycling initiatives contribute significantly to environmental protection and resource conservation, making it an essential component of modern waste management practices.

Figure 2: Recycling Process of Solid Waste

2.5.5 Composting

Composting is a sustainable waste management practice that involves the conversion of organic waste, such as food scraps and yard trimmings, into nutrient-rich compost. This process promotes soil enrichment and supports sustainable agriculture by providing essential nutrients for plant growth. By diverting organic waste from landfills, composting helps reduce methane emissions, a potent greenhouse gas generated during the decomposition of organic materials in anaerobic conditions. Composting not only benefits the environment by mitigating greenhouse gas emissions but also contributes to soil health, water retention, and overall ecosystem sustainability.

Figure 3: The Compost Cycle of Organic Waste

2.5.6 Source Reduction

Source reduction focuses on minimizing the amount of waste generated at the very beginning, often through changes in product design, manufacturing processes, or consumer habits. It can involve strategies such as designing products to be more durable or reusable, using less packaging, encouraging consumers to buy in bulk to reduce packaging waste, and promoting the use of digital documents to reduce paper waste.

2.5.7 Anaerobic Digestion

Anaerobic digestion (AD) is a biological process that breaks down organic materials in the absence of oxygen, producing biogas (mostly methane) and nutrient-rich digestate. Anaerobic digesters can be used to treat organic waste from various sources, including food waste, agricultural residues, and wastewater sludge. Biogas produced during anaerobic digestion can be used as a renewable energy source for electricity generation, heating, or transportation fuel, while the digestate can be used as a fertilizer or soil amendment.

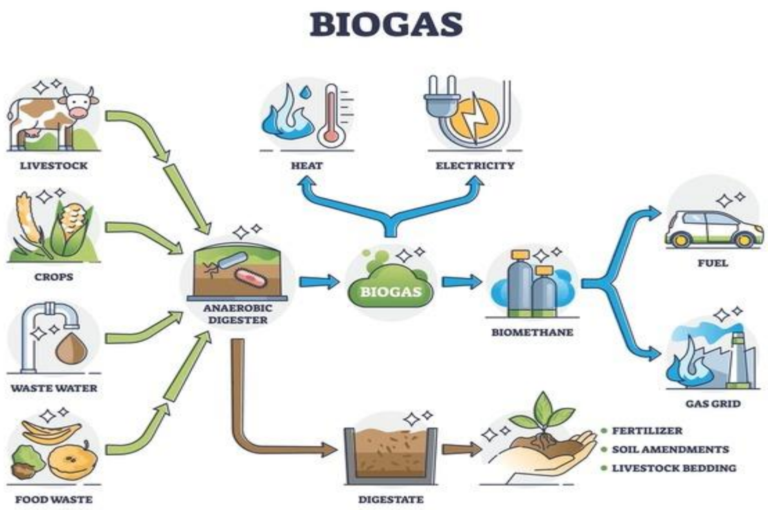

Figure 4: Biogas Production Process using Solid Waste as a Feedstock

2.5.8 Segregation

Segregation in waste management is the systematic sorting of waste into different categories based on its type, composition, and recyclability. This process is crucial for efficient resource recovery and environmental sustainability. Source segregation, where individuals separate waste at the point of generation into bins for recyclables, organic waste, and non-recyclables, is a primary method. Material recovery facilities (MRFs) further refine segregation by using automated systems to separate recyclable materials like paper, plastic, glass, and metals from mixed waste streams. Proper segregation not only enhances recycling rates and reduces landfill waste but also minimizes environmental pollution and promotes a circular economy by facilitating the reuse and recycling of valuable materials.

2.5.9 Public Awareness

Promoting responsible waste management practices like recycling, composting, and waste reduction involves engaging the public through awareness campaigns, education programs, and incentives. These initiatives aim to educate individuals about the benefits of proper waste disposal and encourage behavioural changes towards sustainable practices. By raising awareness and offering incentives, communities can actively participate in recycling efforts, compost organic waste, and reduce overall waste generation, contributing to a cleaner environment and resource conservation.

CHAPTER 3: METHODOLOGY

3.1 Study Area and Period

Our study comprises two distinct study areas: first area, represented by Cadets Battalion in the Military College of Engineering, Risalpur, and second area, represented by Hayatabad in Peshawar. These locations are chosen to provide a comprehensive analysis of solid waste management practices in contrasting settings: a military institution and a residential area within a major city.

1. **Cadets Battalion, Military College of Engineering, Risalpur**

   Cadets Battalion is situated within the Military College of Engineering in Risalpur, representing an institutional setting with unique waste management dynamics. As part of a military institution, Cadets Battalion may have specific waste generation patterns related to training activities, administrative functions, and infrastructure maintenance. The waste generated here may include institutional waste (e.g., office paper, packaging materials), food waste from mess facilities, and potentially hazardous waste from training exercises or equipment maintenance.

   The waste management infrastructure in Cadets Battalion may be tailored to meet the institution's needs, potentially incorporating waste segregation practices, recycling initiatives for specific materials (e.g., paper, plastics), and proper disposal methods for hazardous waste. The study will delve into the specifics of waste generation, segregation practices, collection mechanisms, and disposal procedures within Cadets Battalion, providing insights into institutional waste management challenges and best practices.

2. **Hayatabad, Peshawar**

   Hayatabad is a residential and commercial area located in Peshawar, representing a less developed setting with diverse waste generation patterns typical of a major city. As a densely populated area, Hayatabad experiences significant waste generation from households, commercial establishments, educational institutions, and healthcare facilities. The waste streams in Hayatabad may include household waste (e.g., kitchen waste, packaging materials), commercial waste (e.g., paper, plastics from businesses), and potentially construction and demolition waste from development projects.

The waste management infrastructure in Hayatabad may include formal waste collection services, waste segregation initiatives, recycling facilities, and landfill or waste treatment sites. However, challenges such as inadequate collection coverage, improper disposal practices, and informal waste handling methods may also be prevalent in certain areas of Hayatabad. The study aims to assess the effectiveness of waste management practices, identify challenges faced by residents and authorities, and propose solutions for improving solid waste management in Hayatabad.

The study period from November 2023 to March 2024 will allow for a comprehensive analysis of waste generation trends, seasonal variations, operational challenges, and potential improvements in both Cadets Battalion and Hayatabad. By examining these two distinct study areas, our research aims to contribute valuable insights into optimizing waste management practices in diverse urban and institutional settings.

3.2 Collection and Segregation of Waste

Waste collection and segregation in Hayatabad and Cadets Battalion employ diverse methods tailored to their respective urban and military settings. In Hayatabad, households participate in waste separation, utilizing curb side collection with categorized bins and community bins for public use. Informal waste pickers, including donkey cart owners and bike loaders, contribute to collection efforts. Segregation practices involve residents separating organic and recyclable waste. Similarly, Cadets Battalion manages waste through military-administered collection, ensuring organized schedules and segregated bins. The cadets in Cadets Battalion conducted a waste collection and segregation activity. The cadets organized teams and designated areas within the battalion premises for waste collection. They used designated bins for different types of waste, such as organic, recyclable, and non-recyclable materials. The activity included educating fellow cadets and personnel about the importance of waste segregation for efficient waste management and environmental sustainability.

Figure 5: Solid Waste Collection in Cadets Battalion

Figure 6: Solid Waste Collection in Cadets Battalion

Figure 7: Separation of Solid Waste Components

3.3 Weighing of Waste Components

Following the thorough segregation process, we took the separated components and measured their weights using a highly accurate scale. Each amount was precisely recorded for further analysis. With this data, we conducted a comprehensive calculation to determine the percentage composition of each component within the waste. This detailed breakdown not only provided insights into the current composition but also allowed us to observe trends in the generation of these components over a specific period.

Figure 8: Weighing Machine to Determine Weight of Solid Waste Components

3.4 Sun Drying of Sample

The waste sample designated for further processing underwent sun drying as the subsequent step. Over a period of 6 to 8 hours, the sample was exposed to open air to reduce its natural moisture content. This process improved the quality of the waste sample for subsequent procedures such as size reduction and handling.

3.5 Set up for Shredding

The reduction in size of waste is crucial to enhance the quality and suitability of the waste sample. Given the heterogeneous nature of municipal solid waste, robust mechanical equipment is required to effectively shred it.

Figure 9: Setup for Shredding

3.6 Proximate Analysis

Proximate analysis is a vital assessment for fuels like coal, providing insights into key parameters such as moisture content, volatile matter, ash, and fixed carbon. These parameters are crucial for understanding how a fuel will perform during combustion. In our study, we conducted proximate analysis on the prepared samples following ASTM (American Society for Testing and Materials) standards.

3.6.1 Moisture Content

To determine moisture content, a known sample weight was dried in a ceramic vessel in a lab oven at 110°C for one hour, followed by weighing after cooling in a desiccator. Dry and weight process was performed and with weight difference moisture content was found.

3.6.2 Volatile Matter

Volatile matter was assessed by placing a dried sample in a covered crucible in a muffle furnace at 925°C for 7 minutes, then weighed after cooling in a desiccator. The difference in weight provided the volatile matter percentage.

3.6.3 Ash Content

Ash content, an indicator of fuel quality, was determined by heating a dried sample in a ceramic vessel in a muffle furnace at 750°C for one hour, then weighing after cooling in a desiccator. The difference in weight allowed calculation of ash content as a percentage of the sample weight.

3.6.4 Fixed Carbon

Fixed carbon was calculated by subtracting the sum of moisture content, volatile matter, and ash percentages from 100, providing a measure of the carbon content in the pellets. This comprehensive analysis aids in understanding the combustion characteristics and suitability of waste samples as a fuel source.

FC = 100 – (M.C+V.M+Ash)

Figure 10: Muffle Furnace used for Proximate Analysis

3.7 CHNS Analysis

CHNS analysis, encompassing Carbon, Hydrogen, Nitrogen, and Sulfur, forms a cornerstone of organic compound analysis, vital for environmental science, chemistry, and waste management studies. This method allows precise determination of elemental composition in various samples, aiding in understanding chemical structures, assessing environmental impacts, and developing sustainable strategies.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 SW Characterization Results

In the previous chapter the details of working method were explained for the process of waste characterization. Waste characterization results for each category will be shown and discussed in this chapter.

4.1.1 Cadets Battalion, Risalpur

For low income area, selected from the area of study characterization/manual sorting was done as per method explained in the previous chapter. Contribution of the waste components found in samples were as in graph below.

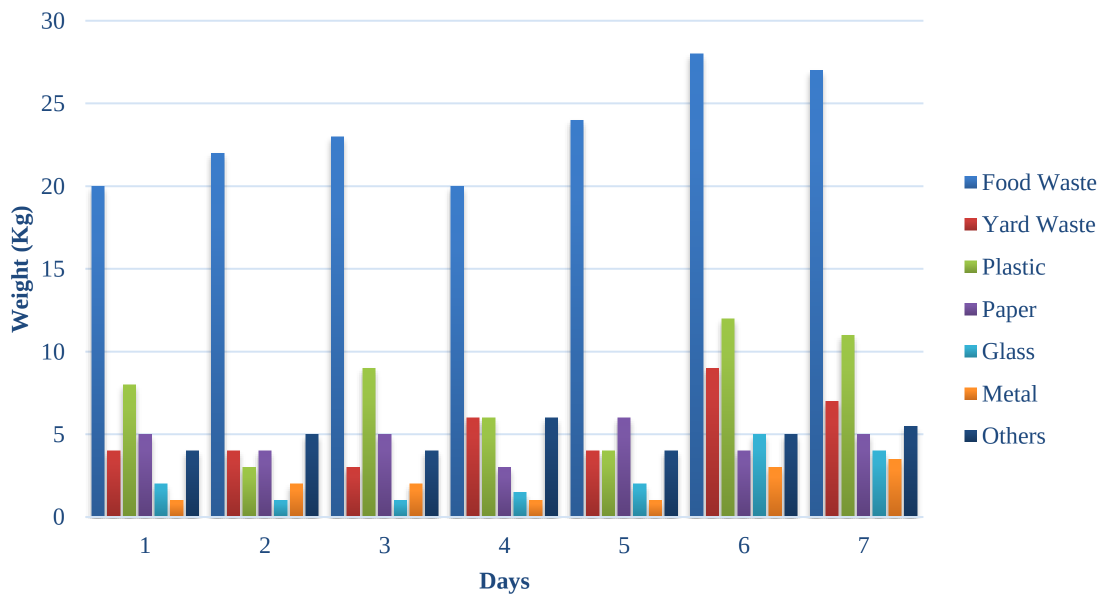

Figure 11: Waste Characterization for Cadets Battalion

The graph is between the weight contributions of each waste component of each sample against each day for a week. Percentage contribution of each component of the waste was explained by pie chart as below.

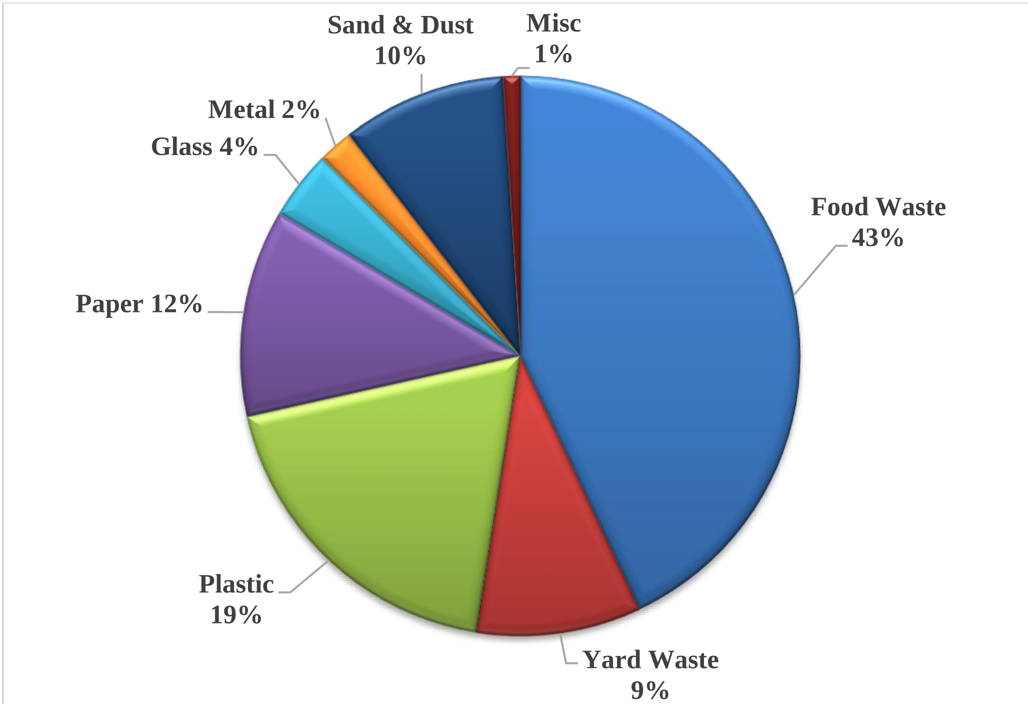

Figure 12: Percentage Weight Composition of MSW for Cadets Battalion

The distribution of waste components in Cadets Battalion is depicted in the following pie chart, showcasing the proportions of organic and inorganic waste.

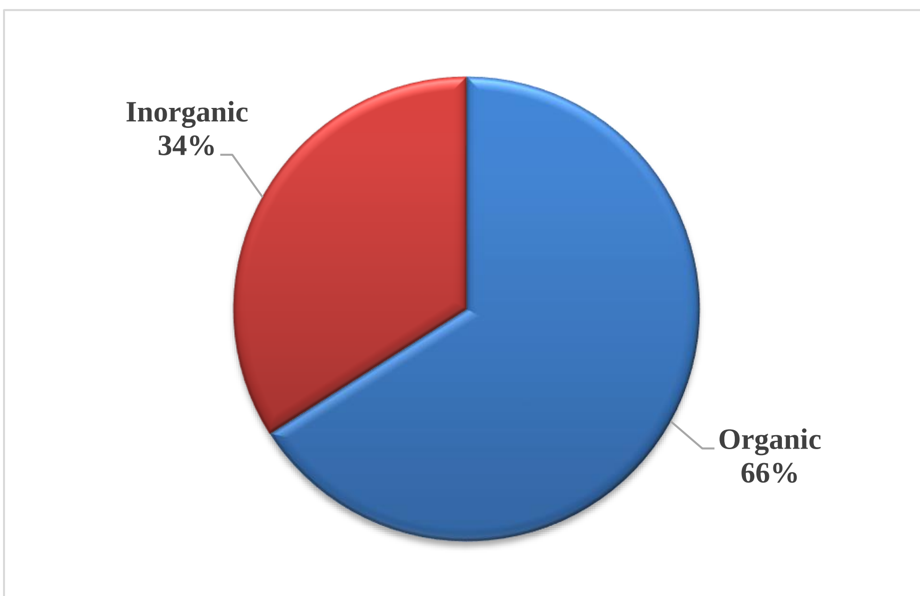

Figure 13: Percentage of Organic and Inorganic MSW in Cadets Battalion

Organic waste in Cadets Battalion predominantly consists of food waste, garden trimmings, and paper, forming a significant portion of the total waste generated in the area as shown by the pie chart below.

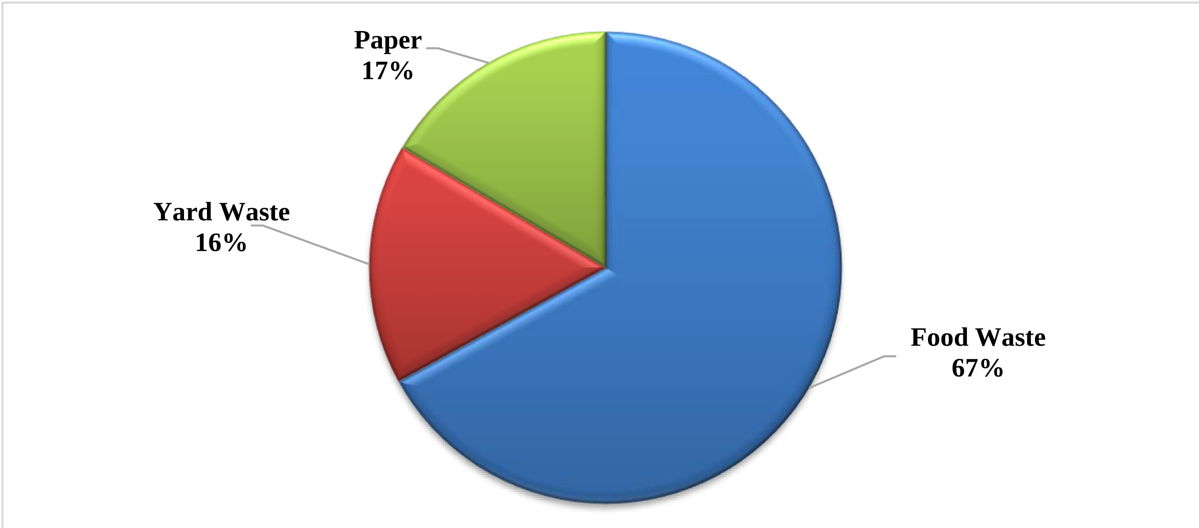

Figure 14: Composition of Organic Waste for Cadets Battalion

Similarly, inorganic waste in Cadets Battalion predominantly consists of plastic, glass, metals and other waste, forming a noteworthy portion of the total waste generated in the area as shown by the pie chart below.

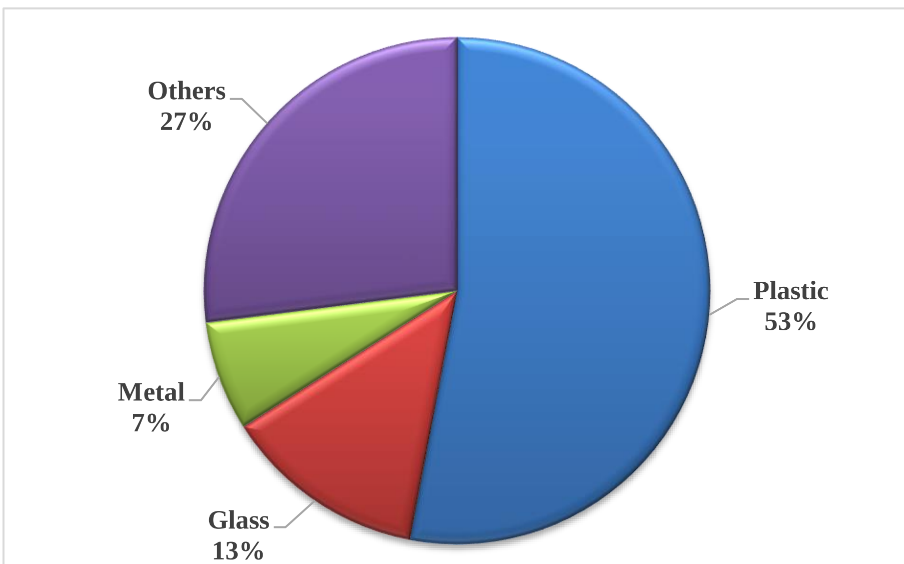

Figure 15: Composition of Inorganic Waste for Cadets Battalion

4.1.2 Hayatabad, Peshawar

For this category of area, waste composition results were calculated after manual sorting. Results are expressed in bar graph for the samples of whole week.

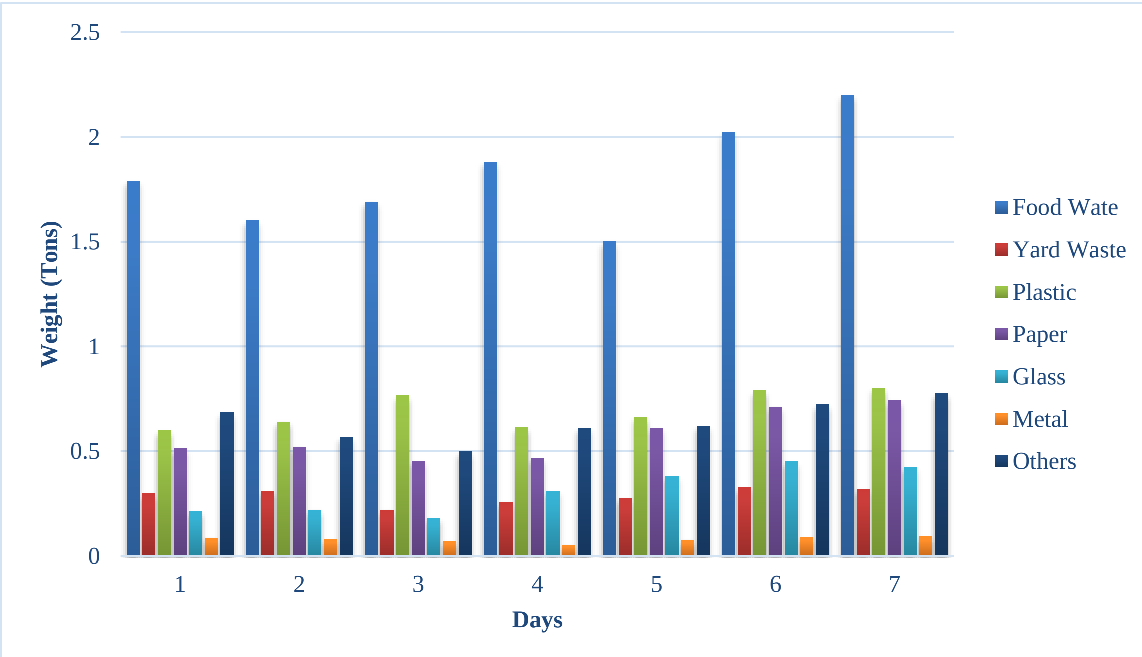

Figure 16: Waste Characterization for Hayatabad

This graph is generated against weight of waste components on vertical and days of sampling on horizontal axis to show the trend of waste composition for the week. Percentage composition by weight is shown in pie chart below.

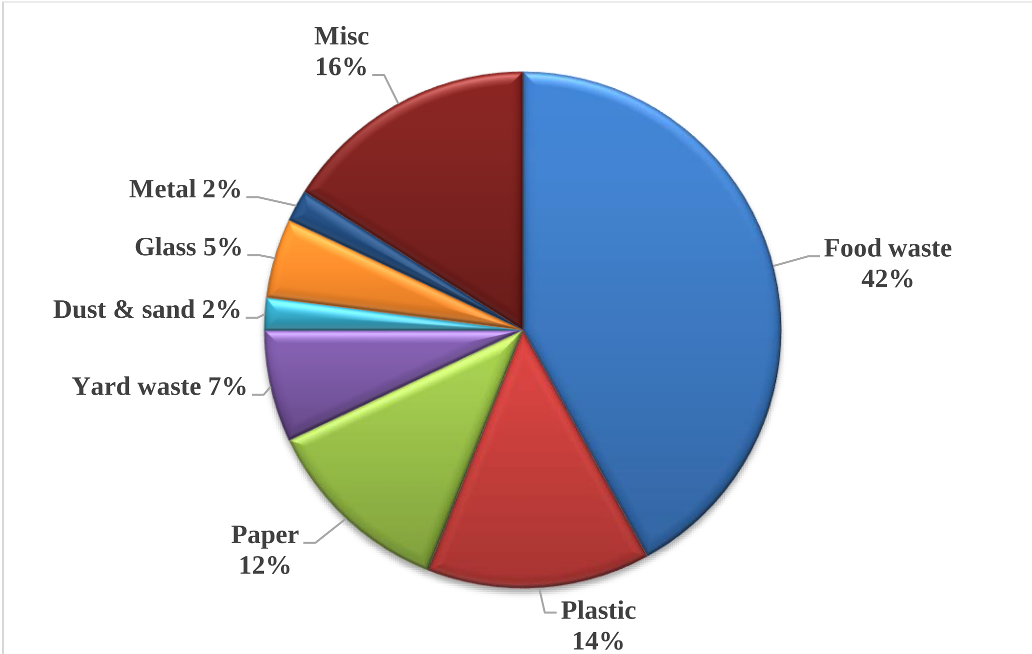

Figure 17: Percentage Weight Composition of MSW for Hayatabad

The distribution of waste components in Hayatabad is depicted in the following pie chart, showcasing the proportions of organic and inorganic waste.

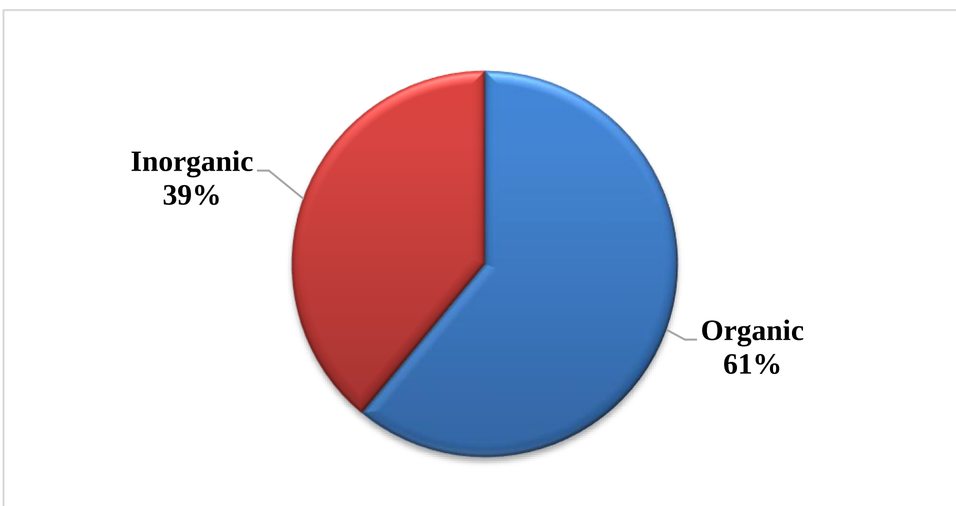

Figure 18: Percentage of Organic and Inorganic MSW in Hayatabad

Organic waste in Hayatabad consists of food waste, garden trimmings, and paper, forming a significant portion of the total waste generated in the area as shown by the pie chart below.

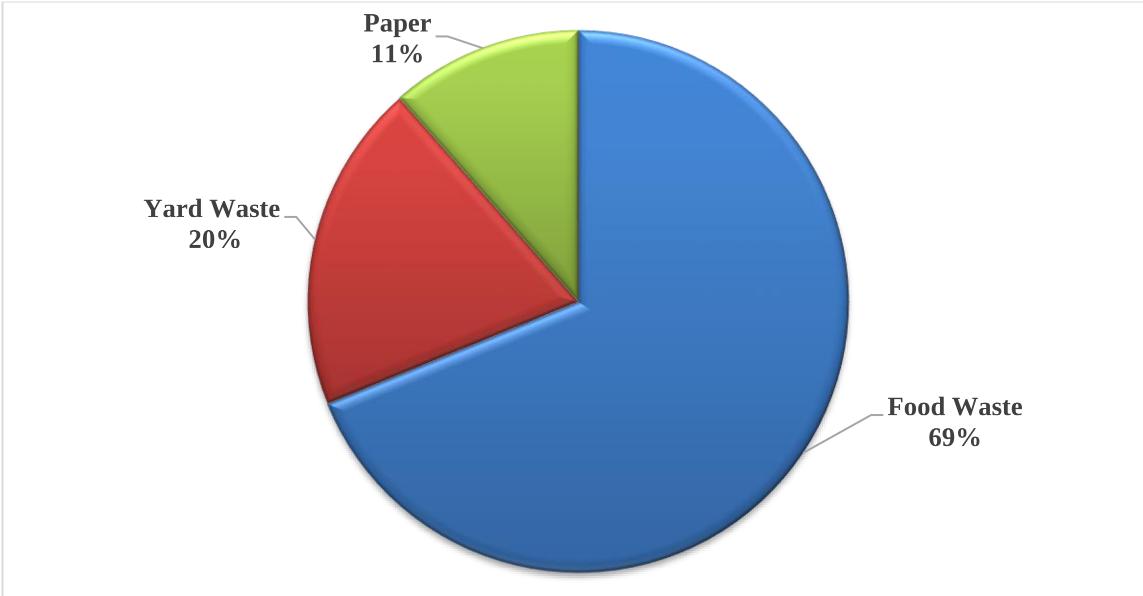

Figure 19: Composition of Organic Waste for Hayatabad

Similarly, inorganic waste in Hayatabad consists of plastic, glass, metals and others, forming a significant portion of the total waste generated in the area as shown by the pie chart below.

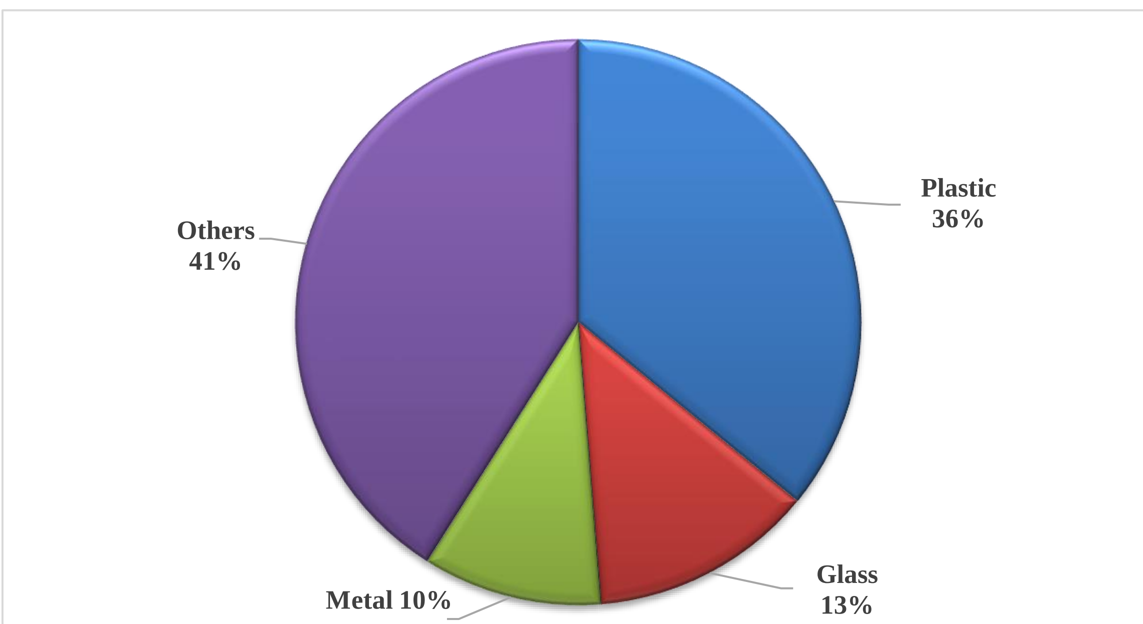

Figure 20: Composition of Inorganic Waste for Hayatabad

4.2 Results of Proximate Analysis

Proximate analysis for fuels like coal and RDF is of core importance as it includes the approximation of parts like volatile matter and moisture content. Analysis was done as per ASTM standards. Results found in analysis are

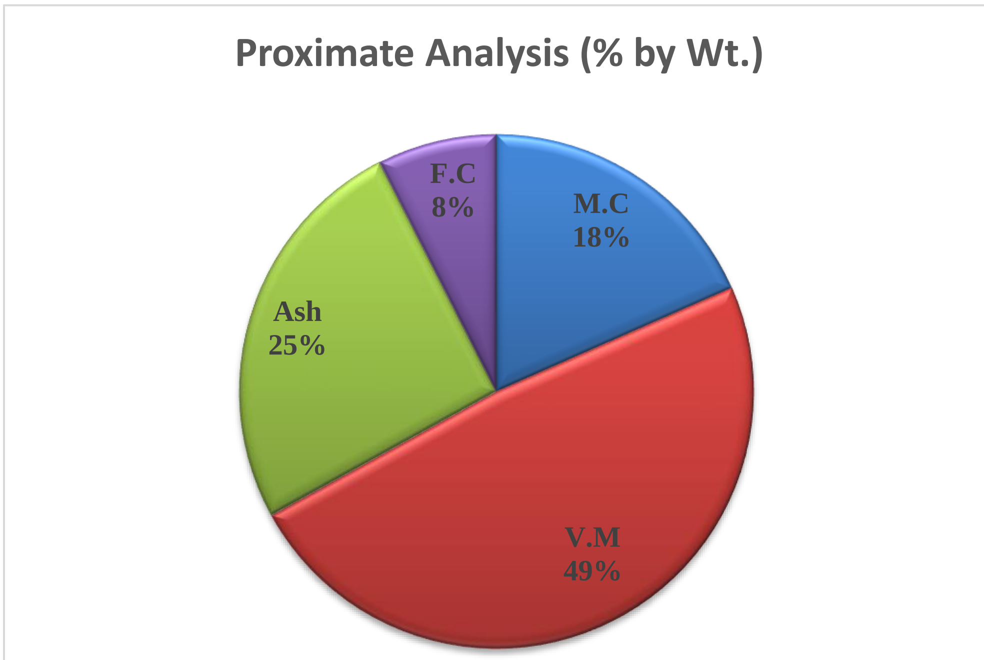

Figure 21: Proximate Analysis of Solid Waste Sample (Avg% by Weight)

Average data of parameters of proximate analysis is shown in pie chart above in percentage by weight. Data shows that the main contribution is of volatile matter which is 49%. Higher amount of volatile matter is considered good to some extent in term of fuel as it provides instant burning but in excess it generates smoke and fumes so beyond a specific range it is undesirable. Excessive amount of volatile matter depicts presence of volatile materials like paper and plastic. Removal of inert materials from MSW is also the reason behind high proportion of VM (Akdağ, Atımtay et al. 2016). Data shows the average moisture content of 18% which lies in range of good fuels. RDFs with moisture content less than 20% are considered to be good fuel alternatives and demanded in cement industry (Brás, Silva et al. 2017).

4.3 Results of CHNS Analysis

Following results were obtained after testing of our sample was carried out in NUST H-12, School of Natural Sciences (SNS).

Table 1: Comparison of Carbon, Hydrogen, Nitrogen and Sulphur Compositions

Sr #	Sample	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Sulphur (%)
1	**Cadets Battalion**	47.9	6.5	3.0	0.378
2	**Hayatabad**	51.4	6.7	2.9	0.394

From these approximate CHNS values for different waste types and a combined waste mixture, several conclusions can be drawn:

1. **Carbon Content:** The significant carbon content across various waste types indicates the presence of organic materials, such as food waste, paper, and yard waste, which are rich in carbon-based compounds.

2. **Hydrogen and Nitrogen:** The presence of hydrogen and nitrogen suggests the inclusion of organic matter and proteins in the waste, commonly found in food waste and yard trimmings.

3. **Sulphur Content:** The sulphur content, though relatively low, indicates the presence of materials like plastics (which may contain sulphur-based compounds) or other industrial waste.

4. **Oxygen and Other Elements:** The remaining percentage is likely composed of oxygen and other elements like phosphorus, metals, and trace elements present in the waste materials.

5. **Combustibility:** The high carbon content suggests that the waste mixture would be combustible, which is relevant in terms of waste-to-energy processes like incineration or gasification.

6. **Organic Nature:** Overall, the CHNS composition highlights the predominantly organic nature of municipal solid waste, highlighting the potential for organic decomposition, biogas production, and energy recovery through appropriate waste management techniques.

7. **Environmental Impact:** Understanding the CHNS composition of waste is crucial for assessing its environmental impact, such as greenhouse gas emissions during decomposition or incineration, and for designing efficient waste management and energy recovery systems.

4.4 Biogas Yield, Energy Potential and Carbon Footprints

It is the major part of the study to meet final objective by finding biogas yield, energy potential and carbon footprints generated by solid waste for Cadets Battalion and Hayatabad. Theoretical calculations have been carried out to calculate these parameters.

4.4.1 Estimation of Biogas Yield

Biogas yield of organic waste for the two areas is calculated as follows.

4.4.1.1 Cadets Battalion

1. Food Waste

Total Food Waste = 487 kg/month

20% Water of Waste = 97.4 L

Total Inflow = 487+97.4 = 584.4 L/month

(Chemical Oxygen Demand (COD) of kitchen waste = 0.242 kg/L)

Total COD of Inflow Waste = (0.242 kg/L) x (584.4 L/month)

= 141.42 kg = 0.1414 tons

(4 g of COD = 1.4 L of CH_4)

CH_4 Produced from Food waste = 49490 L/month

= 49.49 m3/month

2. Paper Waste

Total Paper Waste = 121 kg/month

(COD of Paper = 0.43 kg/L)

Total COD of Inflow Waste = (0.43 kg/L) x (121 L/month)

= 52.03 kg = 0.05203 tons

(4 g of COD = 1.4 L of CH_4)

CH_4 Produced from Paper Waste = 18150 L/month

= 18.15 m3/month

3. Yard Waste

Total Yard Waste = 104.8 kg/month

(COD of Yard Waste = 1.28 kg/L)

Total COD of Inflow Waste = (1.28 kg/L) x (104.8 L/month)

= 134.144 kg = 0.1341 tons

(4 g of COD = 1.4 L of CH_4)

CH_4 Produced from Yard Waste = 47160 L/month

= 47.16 m3/month

4.4.1.2 Hayatabad

1. Food Waste

Total Food Waste = 53890 kg/month

20% Water of Waste = 10778 L

Total Inflow = 53890+10778 = 64668 L/month

(COD of kitchen waste = 0.242 kg/L)

Total COD of Inflow Waste = (0.242 kg/L) x (64668 L/month)

= 15650 kg =15.65 tons

(4 g of COD = 1.4 L of CH_4)

CH_4 Produced from Food waste = 5477500 L/month

=5477.50 m^3/month

2. Paper Waste

Total Paper Waste = 15390 kg/month

(COD of Paper = 0.43 kg/L)

Total COD of Inflow Waste = (0.43 kg/L) x (15390 L/month)

= 6617.7 kg =6.6177 tons

(4 g of COD = 1.4 L of CH_4)

CH_4 Produced from Paper Waste = 2308500 L/month

= 2308.5 m^3/month

3. Yard Waste

Total Yard Waste = 8980 kg/month

(COD of Yard Waste = 1.28 kg/L)

Total COD of Inflow Waste = (1.28 kg/L) x (8980 L/month)

= 11494.4 kg = 11.4944 tons

(4 g of COD = 1.4 L of CH_4)

CH_4 Produced from Yard Waste = 4041100 L/month

= 4041.1 m^3/month

4.4.2 Calculation of Energy Potential

Energy potential of Cadets Battalion and Hayatabad are calculated as follows.

4.4.2.1 Cadets Battalion

1. Food Waste

3412 BTU = 1 kWh

10,247,230 BTU = 3003.1 kWh

2. Paper Waste

3412 BTU = 1 kWh

636,507 BTU = 186.5 kWh

3. Yard Waste

3412 BTU = 1 kWh

1,653,865 BTU = 484.7 kWh

4.4.2.2 Hayatabad

1. Food Waste

3412 BTU = 1 kWh

192,109,261 BTU = 56301.6 kWh

2. Paper Waste

3412 BTU = 1 kWh

80,947,860 BTU = 23731.4 kWh

3. Yard Waste

3412 BTU = 1 kWh

141,714,773 BTU = 41532.5 kWh

4.4.3 Calculation of Carbon Footprints

Carbon Footprint = Electricity Consumption (kWh) x Carbon Intensity (kg CO2/kWh)

Using the global average carbon intensity = *0.4 kg CO2/kWh*

4.4.3.1 Cadets Battalion

1. Food Waste

Carbon Footprint = 3003.1 kWh x 0.4 kg CO2/kWh

Carbon Footprint = 1201.24 kg CO2e

Carbon Footprint = 1.201 tons CO2e

2. Paper Waste

Carbon Footprint = 186.5 kWh x 0.4 kg CO2/kWh

Carbon Footprint = 74.6 kg CO2e

Carbon Footprint = 0.0746 tons CO2e

3. Yard Waste

Carbon Footprint = 484.7 kWh x 0.4 kg CO2/kWh

Carbon Footprint = 194 kg CO2e

Carbon Footprint = 0.194 tons CO2e

4.4.3.2 Hayatabad

1. Food Waste

Carbon Footprint = 56301.6 kWh x 0.4 kg CO2/kWh

Carbon Footprint = 22,520.64 kg CO2e

Carbon Footprint = 22.521 tons CO2e

2. Paper Waste

Carbon Footprint = 23731.4 kWh x 0.4 kg CO2/kWh

Carbon Footprint = 9492 kg CO2e

Carbon Footprint = 9.492 tons CO2e

3. Yard Waste

Carbon Footprint = 41523.5 kWh x 0.4 kg CO2/kWh

Carbon Footprint = 16613.4 kg CO2e

Carbon Footprint = 16.613 tons CO2e

	A	B	C	D	F	G	H	I
1	Composition	Daily (Tons)	Weekly (Tons)	Monthly (Tons)	Theoretical Gas(m3/month)	BTU	Energy (kWh)	Carbon Footprints (Tons)
2	Food Waste	0.02	0.14	0.487	49.49	10,247,230	3003.1	1.201
3	Paper	0.005	0.035	0.121	18.15	636,507	186.5	0.0746
4	Plastic	0.008	0.056	0.195	N/A			
5	Yard Waste	0.004	0.028	0.1048	47.16	1,653,865	484.7	0.194
6	Dust & Sand	0.0001	0.0007	0.003	N/A			
7	Glass	0.002	0.014	0.0487	N/A			
8	Metal	0.001	0.007	0.024	N/A			
9	Others	0.004	0.028	0.1048				

Figure 22: Extrapolation of Energy Potential for Cadets Battalion

	A	B	C	D	E	F	G	H	I
1	Composition	Daily Production (Tons)	Weekly Production	Monthly	COD(Tons)	Theoretical Gas(m3/month)	BTU	Energy(kWh)	Carbon Footprints(Tons)
2	Food Waste	1.79	12.59	53.89	15.65	5477.5	192,109,261	56301.6	22.521
3	Paper	0.513	3.59	15.39		2308.5	80,974,860	23731.4	9.492
4	Plastic	0.598	4.19	17.96		N/A			
5	Yard Waste	0.298	2.09	8.98		4041.1	141,714,773	41532.5	16.613
6	Dust & Sand	0.085	0.59	2.56		N/A			
7	Glass	0.213	1.49	6.41		N/A			
8	Metal	0.085	0.59	2.56		N/A			
9	Others	0.684	4.79	20.53					

Figure 23: Extrapolation of Energy Potential for Hayatabad

4.5 Calculation of Carbon Credits

Carbon Credits = Emission Reduction (in metric tons CO2e) x Price per Carbon Credit

Price per Carbon Credit = $18

4.5.1 Cadets Battalion

1. Food Waste

Carbon Credits = 1.201 metric tons CO2e x $18/ton CO2e

Carbon Credits = $21.618

2. **Paper Waste**

Carbon Credits = 0.0746 metric tons CO2e x $18/ton CO2e

Carbon Credits = $1.4

3. **Yard Waste**

Carbon Credits = 0.194 metric tons CO2e x $18/ton CO2e

Carbon Credits = $3.5

4.5.2 Hayatabad

1. **Food Waste**

Carbon Credits = 22.521 metric tons CO2e x $18/ton CO2e

Carbon Credits = $405.378

2. **Paper Waste**

Carbon Credits = 9.492 metric tons CO2e x $18/ton CO2e

Carbon Credits = $171

3. **Yard Waste**

Carbon Credits = 16.613 metric tons CO2e x $18/ton CO2e

Carbon Credits = $298.8

4.6 Calculation of Global Warming Potential (GWP)

It is known that *1 tons CO2e = 1 GWP*

4.6.1 Cadets Battalion

1. Food Waste

Carbon Footprints = 1.201 tons CO_2e

GWP = 1.201

2. Paper Waste

Carbon Credits = 0.0746 tons CO_2e

GWP = 0.0746

3. Yard Waste

Carbon Credits = 0.194 tons CO_2e

GWP = 0.194

4.6.2 Hayatabad

1. Food Waste

Carbon Credits = 22.521 tons CO_2e

GWP = 22.521

2. Paper Waste

Carbon Credits = 9.492 tons CO_2e

GWP = 9.492

3. Yard Waste

Carbon Credits = 16.613 tons CO_2e

GWP = 16.613

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The study highlights the critical challenges and opportunities in solid waste management in urban areas, particularly focusing on the Cadets Battalion in the Military College of Engineering, Risalpur, and the Hayatabad community in Peshawar. Through waste characterization and analysis, several key conclusions can be drawn:

a. **Waste Composition:** The waste composition analysis revealed that organic waste, including food waste, garden trimmings, and paper, constitutes a significant portion of the total waste generated in both study areas. The contrast in waste generation between Cadets Battalion and Hayatabad is a reflection of the substantial variance in population density and lifestyle practices within these areas. This underscores the importance of implementing effective organic waste management strategies. The results of waste composition analysis revealed a striking similarity in the waste composition between Cadets Battalion (Cadet BN) in the Military College of Engineering, Risalpur, and Hayatabad in Peshawar. Both areas exhibited a significant presence of organic waste components, primarily comprising food waste, garden trimmings, and paper. This similarity underscores the commonality in waste generation patterns despite the differing characteristics of these study areas.

b. **Energy Potential:** The estimation of biogas yield and energy potential from organic waste indicated a substantial opportunity for harnessing renewable energy sources. Biogas production from food waste, paper waste, and yard waste demonstrated the feasibility of waste-to-energy initiatives in reducing environmental impacts and promoting sustainable practices.

c. **Carbon Footprints:** The calculation of carbon footprints highlighted the environmental implications of current waste management practices. By quantifying the carbon emissions associated with waste disposal and energy generation, it became evident that optimizing waste management processes can contribute significantly to reducing greenhouse gas emissions.

5.2 Recommendations

Based on the findings and conclusions of this study, the following recommendations are proposed to enhance solid waste management practices:

a. There is a pressing need to adopt integrated solid waste management approaches that encompass waste collection, segregation, recycling, and energy recovery.
b. Encouraging the deployment of renewable energy technologies such as anaerobic digestion for biogas production and waste-to-energy systems can help mitigate the environmental impact of waste disposal while providing sustainable energy solutions.
c. Establishing robust monitoring and evaluation mechanisms to track waste generation, recycling rates, energy production from waste, and carbon emissions is essential for assessing the effectiveness of waste management interventions. Regular audits and data analysis can inform decision-making and drive continuous improvement in waste management strategies.
d. Review of existing policies is needed to promote sustainability and carbon footprint reduction in waste management.

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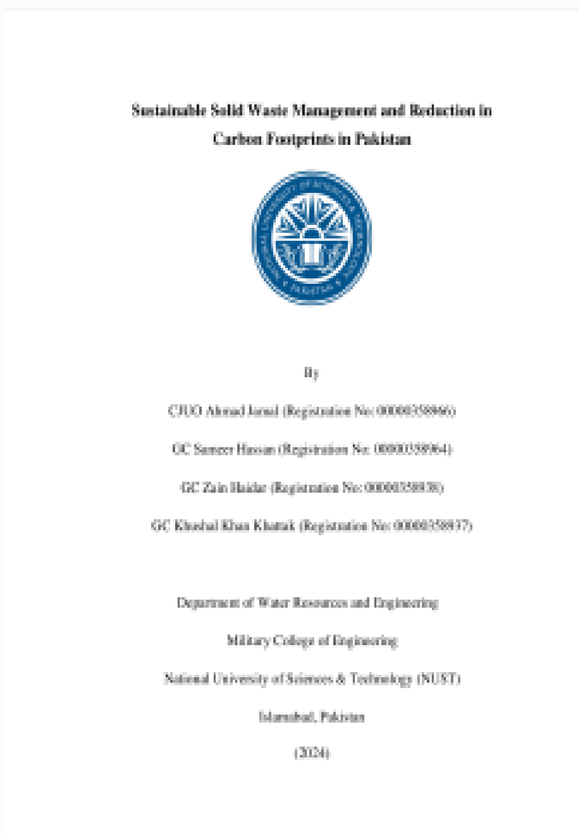

Sustainable Solid Waste Management and Reduction in Carbon Footprints in Pakistan

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