DEVELOPMENT OF A FRAMEWORK FOR INTEGRATED SOLID WASTE MANAGEMENT: AN APPLICATION TO KEKIRAWA PRADESHIYA SABHA

Marakkala Manage Mahesh Samanpriya

(169165K)

Degree of Master of Science

Department of Civil Engineering

University of Moratuwa

Sri Lanka

August 2021

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Marakkala Manage Mahesh Samanpriya

(169165K)

Thesis submitted in partial fulfillment of the requirements for the
degree of Master of Science in Environmental Engineering and Management

Department of Civil Engineering

University of Moratuwa

Sri Lanka

August 2021

Declaration

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Abstract

Municipal solid waste management (MSWM) has evolved into a national concern affecting every individual in Sri Lanka. Poorly managed MSW affects to health and wellbeing of people, pollutes the air, soil, and water, causes flooding, spreads diseases, harms flora and fauna, loss of money, and obstructs resource recovery. Therefore, Sri Lanka has been trying to find a long-lasting solution to MSWM, which should be environmentally, socially, and economically acceptable. Integrated Solid Waste Management (ISWM) provides a contemporary and systematic approach to MSWM. In these efforts, the paradigm shift from landfilling to MSW reduction or prevention is thought vital to be embedded. The government's new policy on "Vistas of Prosperity and Splendor" and Draft National Environmental Policy (2021) also mandates the use of ISWM for MSWM in Sri Lanka.

Embedding circular economy perspectives to ISWM further reduces the amount of MSW produced or retained globally by transforming it into resources. Therefore, the quantity of MSW disposed of at landfills is greatly reduced, and natural resources for manufacturing processes are optimized. This study focused on developing an ISWM framework for MSWM in Sri Lanka based on the circular economy perspectives and under the purview of the present administrative framework. The local needs and conditions were carefully analyzed during the study to determine the most suitable options for all aspects of MSWM, including generation, segregation, collection and transport, sorting, recovery, treatment, and final disposal of MSW. The application of the 3R concept for MSW minimization, promoting source-segregation, increasing the efficiency of collection and transport, producing value-added compost and liquid fertilizer, selling reuse and recyclable materials, pre-processing and reusing of construction and demolition waste, landfilling, and generating electricity through waste incineration were proposed under the ISWM framework developed. The value-addition to the final compost product and liquid fertilizer was considered mandatory, as the government has given priority to organic fertilizer production efforts. The proposed ISWM framework was applied to Kekirawa Pradeshiya Sabha to evaluate the long-term sustenance of the framework developed.

The present status of MSWM practices carried out by Kekirawa Pradeshiya Sabha was evaluated through a questionnaire survey, field visits, meetings with officials involved in existing MSWM practices, and a comprehensive literature survey. Based on the deficiencies identified in the current MSWM practices carried out by Kekirawa Pradeshiya Sabha, the proposed ISWM framework developed was tailor-made to overcome the deficiencies identified and improve revenue generation to Kekirawa Pradeshiya Sabha. The current collection of MSW (17%) was increased up to 50% with the provision of two garbage compactors (6-8 m^3 each). The open dumping of mixed waste currently being practiced will completely be halted, and an ISWM facility was designed with a compost plant, resource center, construction and demolition waste collection yard, and controlled landfill. The expected output of value-added compost and liquid fertilizers was 3.5 MT/day and 500 L/day, respectively. The electricity generation was 0.2 MW. Only 0.3 MT/day of fly ash will be disposed of in a secure landfill out of 13.8 MT/day of total MSW collected, which accounts for 1.3% of the total MSW generation. An economic analysis was carried out to evaluate the economic feasibility of the proposed ISMW framework for Kekirawa Pradeshiya Sabha.

The results of economic analysis manifested that the Net Present Value (NPV) was SLR 66.52 million at an interest rate of 10%. The Internal Rate of Return (IRR) was 12%. Further, reduction of greenhouse gas emissions (GHG), land value appreciation, city beautification, improving health and wellbeing of people, promoting tourist attraction, and employment opportunities are other benefits to be gained from the proposed ISWM framework. Therefore, the proposed ISWM framework appears viable from a national economic viewpoint and can be used as a role model for the MSWM by other local authorities, particularly covering agriculture-based cities of Sri Lanka.

Keywords: Municipal Solid Waste Management, Integrated Solid Waste Management, Circular Economy, Greenhouse Gases, Net Present Value, Internal Rate of Return

Acknowledgement

First of all, I would like to extend my heartfelt gratitude to my supervisor Prof. Mahesh Jayaweera, for allowing me to complete the research. Your guidance and encouragement, given at every step of the research, helped me achieve the goals. Your support was immense, and I am very fortunate to have you as my supervisor. I extremely appreciate the advice given while carrying out the research, writings, and moral assistance given to complete the research.

I am very grateful to Prof. Jagath Manatunge and Prof. Buddhika Gunawardana for providing guidance and support for the research. Your advice and assistance given are very much appreciated.

I wish to express my sincere thanks to the Chairman, Secretary, Technical Officer, Development Officer, and other staff of Kekirawa Pradeshiya Sabha for the support given for me to collect data and information regarding MSWM practices carried out by Kekirawa Pradeshiya Sabha.

I would like to thank other staff of the Environmental Engineering Laboratory, Environmental Engineering Division, Department of Civil Engineering of the University of Moratuwa for the support given to me to carry out the research.

I am grateful to my family for being there for me, giving their unconditional love and support to fulfill my aims.

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List of abbreviations

$	United States Dollar
3R	Reduce, Reuse, and Recycle
ABC	Aggregate Base Course
BC	British Columbia
BCR	Benefit-Cost Ratio
BOD	Biological Oxygen Demand
BOQ	Bill of Quantities
C:N	Carbon:Nitrogen ratio
Ca	Calcium
CBA	Cost-Benefit Analysis
CCTV	Closed-Circuit Television
CEA	Central Environmental Authority
CMC	Colombo Municipal Council
CO_2	Carbon dioxide gas
COD	Chemical Oxygen Demand
DEWAT	Decentralized Wastewater Treatment Plant
ECBA	Extended Cost-Benefit Analysis
EIRR	Economic Internal Rate of Return
EM	Effective Microorganisms
ENPV	Economic Net Present Value
EOCC	Economic Opportunity Cost of Capital
EPL	Environmental Protection License
FAO	Food and Agriculture Organization of the United Nations

FCA	Financial Capability Assessment
FOD	First Order Decay
FV	Future Value
GHG	Green House Gases
GPS	Global Positioning System
GSM	Global System for Mobile
GWP	Global Warming Potential
H_2S	Hydrogen Sulfide
HDPE	High Density Polyethylene
IPCC	Intergovernmental Panel on Climate Change
ISWM	Integrated Solid Waste Management
K_2O	Potassium Oxide
LDPE	Low Density Polyethylene
LPG	Liquefied Petroleum Gas
MEPA	Marine Environment Protection Authority
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
MT	Metric Tonnes
N	Nitrogen
NGO	Non-Governmental Organization
NH_3	Ammonia
NH_4NO_3	Ammonium Nitrate
NPV	Net Present Value
NSWMSC	National Solid Waste Management Support Center
NTU	Nephelometric Turbidity Units

O&M	Operation and Maintenance
OECD	Organization for Economic Co-operation and Development
P	Phosphorus
P_2O_5	Phosphorus Pentoxide
PET	Polyethylene Terephthalate
PPP	Public-Private Partnerships
PTA	Policy Thematic Areas
PV	Present Value
PVC	Polyvinyl Chloride
SAR	Sodium Adsorption Ratio
SIM	Subscriber Identity Module
SLLDC	Sri Lanka Land Development Corporation
SLR	Sri Lankan Rupee
SLSI	Sri Lanka Standards Institute
SO_2	Sulfur Dioxide
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TSS	Total Suspended Solids
UDA	Urban Development Authority
UNEP	United Nations Environment Programme
US AID	United States Agency for International Development
US EPA	United States Environmental Protection Agency
VAT	Value-added Tax
WMA-WP	Waste Management Authority of the Western Province

1. INTRODUCTION

1.1 Background of the study

Municipal solid waste management (MSWM) is a critical issue in almost all areas of the world (Sharma and Jain, 2020). The world produced 2.01 billion MT of municipal solid waste (MSW) in 2016 (World Bank, 2018). The generation of MSW in the world has expanded dramatically due to urbanization, rapid growth of population, enhancement of living standards, and the development of the socio-economy (Chen et al., 2015). The average amount of MSW generated per person per day is 0.74 kilograms; however, it varies from 0.11 to 4.54 kilograms (World Bank, 2018). Globally, the generation of MSW is predicted to reach 3.4 billion MT in 2050 (World Bank, 2018). The MSW generated by low-income countries will be tripled by 2050 compared to the annual generation of MSW by low-income countries in 2016 (World Bank, 2018).

The composition of MSW varies significantly from one municipality to another and from country to country (Abdel-Shafy and Mansour, 2018). The high-income countries generate 32% of food and green waste and 51% of dry waste that could be recycled (plastic, paper, cardboard, metal, and glass) from the total MSW generated (World Bank, 2018). The middle-income and low-income countries generate 53% and 56% of food and green waste, respectively (World Bank, 2018).

Considering the collection of MSW, upper-middle- and high-income countries practice a universal collection of MSW. Europe, Central Asia, and North America collect at least 90% of the total MSW generated. Furthermore, the low-income countries collect over 48% of MSW generated in cities, but only 26% of MSW generated outside the urban areas (World Bank, 2018). Today, a sizable quantity of unsorted MSW is collected. Recyclable materials such as plastic, glass, metal, and paper are collected as a whole and discarded as residual waste instead of segregated into different types of recyclables (Sorme et al., 2019).

Open dumping, open burning, landfilling, incineration, composting, recycling, and treatment are final disposal methods of MSW commonly practiced worldwide (Abdel-

Shafy and Mansour, 2018). Landfilling is one of the oldest and most widely used methods for disposing of MSW (Saja et al., 2021). Globally, 37% of the MSW is disposed of in the form of a landfill, 33% of MSW is sent to open dumps, 19% of MSW undergoes recycling and composting, while the rest of MSW is sent for incineration (World Bank, 2018). 39% of the MSW is disposed of in landfills, 35% of MSW is sent for recycling and composting, and 22% of MSW undergoes incineration by high-income countries, but 93% of MSW in low-income countries is sent to open dumps as the prime final disposal practice (World Bank, 2018).

In most countries, MSWM operations are carried out by local authorities. Considering the financial allocations for MSWM by local authorities in low-income-, middle-income-, and high-income countries are about 20, 10, and 4%, respectively. Furthermore, operating costs incurred for the MSWM, including collection, transport, treatment, and disposal, generally exceed $100 per MT in high-income countries, while about $35 per MT in low-income countries (World Bank, 2018). Because of the increased generation of MSW, difficulties in allocating higher costs for the operations of MSWM within the municipal budget, lack of understanding of technicalities associated with the operations of MSWM, and the level of support from the public, MSWM in an urban context have become a major concern for local governments in developing countries (Saja et al., 2021).

The generation of MSW worldwide creates a variety of environmental consequences, including higher rates of GHG emissions, accumulation of plastics in oceans, and nitrogen pollution (Chen et al., 2020). In 2016, the greenhouse gas emissions from MSWM were estimated as 1.6 billion MT of carbon dioxide-equivalent (CO_2-equivalent), excluding transportation (World Bank, 2018). Plastic waste is becoming a growing global concern because it persists for long periods and is consumed by species, creating health problems (Thompson et al., 2009; Wagner, 2017). Depending on the disposal technique, different forms of MSW might have different environmental and health effects (Eriksson et al., 2005). Due to the formation of leachate, gas, odor, dust, and a possible fire hazard, open dumping sites can cause air pollution, water contamination, and soil contamination (Ahsan et al., 2014).

Managing MSW in an environmentally, socially, and economically sustainable manner is still a challenge for most developing countries. Despite the fact that vast amounts of money have been spent on MSWM studies over the last two decades, limited solutions have emerged (Muller, 2002). The majority of the research findings were either not economically viable or unacceptable to some lower socio-economic groups. Therefore, there is a need to formulate and implement an integrated solid waste management (ISWM) plan addressing all aspects of MSWM, including generation, source-segregation, collection and transport, sorting, recovery, treatment, and final disposal. An effective ISWM plan will help overcome many financial, demographic, and other challenges associated with the MSWM, resulting in numerous human health, environmental, economic, and social benefits.

The new concept on “Circular Economy” has rapidly expanded around the world over the last decade, aiming to provide a better solution to the current economic development paradigm, the so-called “Take, Make, and Dispose” model (Ness, 2008). When MSW is considered, the circular economy strives to reduce the amount of MSW produced globally by transforming it into resources. The three fundamental “activities” of the circular economy, referred to as the 3R principle: Reduction, Reuse, and Recycling, are mostly discussed in the literature (Lett, 2014; Reh, 2013; Su et al., 2013; Preston, 2012; Sakai et al., 2011; Feng and Yan, 2007; Ren, 2007). Reduction refers to lowering the amount of basic energy and raw materials used, which can be accomplished through increasing manufacturing efficiency. Reuse refers to the practice of repurposing solid waste from one stage of production to another. Finally, recycling existing materials reduces the need for new materials (Zhu and Qiu, 2008; Zhu et al., 2010).

The circular economy concept is considered as the elimination or mitigation of solid waste and subproducts, and if this is not possible, solid waste and subproducts are integrated into the same or similar production processes with the objective of avoiding negative impacts and conserving the environment. Therefore, the circular economy concept is linked to sustainability, with the goal of preserving the value of resources as long as possible by reducing solid waste output, converting it into resources, and reusing these resources into manufacturing processes. The circular economy attempts to increase the efficiency of the use of resources, with a special focus on MSW, by adopting closing-the-loop production patterns, in order to ensure harmony and balance among the environment, economy, and society (Ghisellini et al., 2016).

Therefore, it is prudent that ISWM, with the incorporation of the circular economy concept, will provide suitable options to manage the MSW in an economically, socially, and environmentally acceptable manner.

1.2 Justification of the study

Sri Lanka is a lower-middle-income country, and the current population is 21.8 million (World Bank, 2020). MSWM has become a severe issue to be addressed in many parts of Sri Lanka. The National Action Plan of Sri Lanka has highlighted that the haphazard disposal of MSW is one of the main reasons for environmental degradation (Bandara, 2011). The local authorities, statutorily responsible for MSW collection, sorting, applying the 3R (Reduce, Reuse, and Recycle) principle, and final disposal within their jurisdiction. In general, final disposal becomes the main issue be faced by many local authorities, and practice open dumping as the common final disposal technique irrespective of health and environmental drawbacks (Gunaruwan and Gunasekara, 2016). In 2019, Sri Lanka produced more than 260 open dumps of various magnitudes in the country (Jayaweera et al., 2019).

The generation of MSW in Sri Lanka increased from approximately 6,400 MT/day in 1999 (UNEP, 2001) to 8,141 MT/day in 2020 (Pariatamby et al., 2020). Based on the report on National Program for the Solid Waste Management in Sri Lanka prepared in 2020, the average per capita MSW generation is 0.47 kg per person per day, ranging from 0.2 kg per person per day in rural villages to 0.85 kg per person per day in highly urbanized cities.

The local authorities collect MSW from door to door in certain areas of their jurisdiction, but the entire area of concern is yet to be covered. The total generation of MSW in Sri Lanka is anticipated to be 8,141 MT per day, but local authorities currently collect 3,854 MT of MSW per day. The country’s MSW collection rate is around 47%, which is below the accepted norms. Based on the report on National Program for the Solid Waste Management in Sri Lanka prepared in 2020, the details of the generation and collection of MSW in each province are depicted in Table 1.1.

Table 1.1: Generation and composition of MSW in each province of Sri Lanka

Province	**Generation of MSW (MT/day)**	**Collection of MSW (MT/day)**	**Collection rate of MSW (%)**
Western	3,368	1,952	58
Northern	374	195	52
Eastern	838	431	52
Central	871	362	41
North Western	596	235	39
Uva	323	123	38
Sabaragamuwa	525	182	35
Southern	838	272	33
North Central	409	103	25
Total	**8,141**	**3,854**	**-**

In some local authorities, fractions of MSW (biodegradable, recyclables, and non-biodegradables) are collected on pre-notified days and time intervals. Further, the collection of unsorted MSW is done by many local authorities. However, roadside unsorted MSW heaps are common sights in many areas, especially in townships, and the same is evident in abandoned lands. These cases are apparent in many towns due to the lack of a good vehicular fleet. Given the old fleet of vehicles, with frequent maintenance issues, many local authorities are faced with the dilemma of operating a sound system of collection and transport of MSW. Garbage compactors of different sizes are not provided to every local authority; hence efficient handling of MSW is markedly reduced. Bad odor emanation, leachate trickling onto the road, and portions of MSW being dropped while on the move are intriguing and inevitable experiences observed during transportation of MSW collected by local authorities. Irregularities in the collection teams and non-implementation of proper health and safety procedures for employees involved in the collection and transport of MSW are often envisaged in many local authorities. Optimization of the collection routes seems to be lacking mostly. In many local authorities, no plan has been established to collect recyclables, and no resource collection centers are established for the public to hand over the different recyclables.

Although Sri Lanka has 136 compost facilities maintained by local authorities, only a few of them meet environmental criteria due to various reasons, the most common of which is poor management. The compost methods preferably adopted by many local authorities, such as the windrow technique and in-vessel technique, are passive aerated methods where composting efficiency seems to be poor, and the final quality of compost would not be guaranteed.

The National Solid Waste Management Support Center (NSWMSC) is in collaboration with the University of Moratuwa, carried out a situational analysis of MSWM in Sri Lanka in 2012 and published the same in 2015. Based on the findings, the quantity of MSW that ended up in open dumps was estimated to be 2,695 MT/day in 2012. The issue of open dumping has been pronounced in the Western Province (93% of MSW collected in the Western Province is disposed of directly in open dumps) in comparison to all the other provinces (75% of the MSW collected is disposed of directly in open dumps). In the recent past, health hazards associated with improper MSWM have profoundly escalated, especially with mounting episodes of the dengue epidemic in the country.

Handling dumpsites in an environmentally safe manner becomes totally neglected by the respective local authorities because of many reasons such as lack of technical know-how and capacities, lack of financial allocations, lethargy on stakeholders, and lack of legal enforcement. Further, in many instances, the decision-makers reached no consensus on the integrated and sustainable approach; hence, aggravated the issue of open dumping with a couple of devastations, including losses of human lives. The collapse of the Meethotamulla open dump in 2017 buried 32 people while destroying 60 houses completely and 27 houses partly (Chathumani et al., 2019). There have been many such open dumps located in residential areas that are at risk of being collapsed.

No investigations are carried out for such vulnerable locations, but some are yet subject to open dumping. The non-availability of suitable locations for sanitary landfills in many regions of the country prevents the establishment of sanitary landfills. Even though there have been suitable locations found, neighboring people and other pressure groups have vehement resistance to such projects from materializing in the country.

The national policy on MSWM was developed in 2007 to ensure that the MSWM practices carried out are integrated, economically viable, and environmentally sound at the national and local levels. Further, the government's new policy on "Vistas of Prosperity and Splendor" mandates that MSW be handled in an integrated manner. The National Physical Plan prepared by the Department of Physical Planning also recommends integrated management when dealing with MSWM projects. The Draft National Environmental Policy, 2021 insisted that the integrated system of waste management covering all local government areas in the country will be in place for effective management of MSW, agricultural and industrial waste, wastewater, and all forms of hazardous waste. Other than that, the ISWM principle has been highly promoted by the Ministry of Environment, Central Environmental Authority (CEA), and various organizations in the country (Bandara, 2011). Despite the fact that all of the national policies, laws, and regulations are in place to promote the ISWM principle, implementing an ISWM concept is still a question.

In general, local authorities do not have a full-fledged system inbuilt with state-of-the-art technology in managing MSW generated within their territory. Therefore, it is obvious that the integrated approach is a prerequisite for the MSWM socially and environmentally acceptable while ensuring economic sustainability. The unavailability of a framework for ISWM in Sri Lanka has led the MSWM in the country to a national concern. Further, in the local context, the circular economy concept has not yet been embedded in the MSWM practices, though the concept has been vastly practiced by other countries. Therefore, this is high time for Sri Lanka to develop an ISWM framework with the incorporation of the circular economy concept to be used for improving the efficiency and effectiveness of MSWM practices.

The ISWM framework to be developed under this study will be implemented for MSWM in Kekirawa. Kekirawa is located in the North Central Province of Sri Lanka. In terms of the collection of MSW, North Central province recorded the lowest collection of MSW with respect to the total generation of MSW among nine provinces in Sri Lanka. There has been no proper MSWM system practiced by the Kekirawa Pradeshiya Sabha (being the governing authority of Kekirawa) since 2003. The mixed waste collected is disposed of in the open dump located at Embulgaswewa, Kekirawa. The open dumping area is a part of the Embulgaswewa natural forest, which was declared as a natural forest by the Gazette Extraordinary No. 1589/09 dated 2009.02.17. Therefore, there is a great risk on the forest due to the haphazard dumping of MSW.

Further, Kekirawa is a small-scale agricultural-based city. Therefore, there is a great potential to sell the value-added solid and liquid fertilizers as the main products of the proposed ISWM framework to be developed for the farmers in the Kekirawa Pradeshiya Sabha area. Other than that, there is a high demand for low-cost building materials to be used for constructing temporary structures inside the agricultural lands.

Therefore, under this study, it is proposed an implementable ISWM framework taking a small-scale agriculture-based city in Sri Lanka (Kekirawa) as a model, incorporating the CE concepts and sustainable principles. It is expected that the proposed framework is replicable in many cities, having a multitude of smallholder agricultural farms, and are currently faced with the dilemma of disposing of MSW in a productive manner.

1.3 Objectives of the study

The main objective of the study is to develop a framework for ISWM with economic drivers.

Following specific objectives were set to achieve the main objective.

i. Evaluate the present status of MSWM practices carried out by Kekirawa Pradeshiya Sabha

The present status of MSWM practices carried out by Kekirawa Pradeshiya Sabha is evaluated in terms of generation, source-segregation, collection, transport, and final disposal of MSW. The current institutional and policy aspects, as well as deficiencies and gaps identified in the existing MSWM system, are analyzed. Necessary data and information are collected through a questionnaire survey, field visits, meetings with officials involved in existing MSWM practices, and a literature survey.

ii. Development of an ISWM framework based on the circular economy perspectives and under the purview of the present administrative framework

The current regime of Sri Lanka has planned to implement an ISWM system to manage MSW generated. As such, two major policy decisions concerning the MSWM have been taken by the government; the Ministry of Public Services, Provincial Councils and Local Government is responsible for collecting and transporting the sorted MSW within the local authority limits to a designated collection center/transfer station, and the Ministry of Urban Development, Coast Conservation, Waste Disposal and Public Sanitation is responsible for managing the segregated MSW until the final disposal. Two state ministers have been appointed by the current regime to facilitate the MSWM operations in the country. Though the administrative framework is in place, an ISWM framework has not yet been developed in Sri Lanka.

Therefore, an ISWM framework is developed based on the Draft National Environmental Policy, 2021 prepared by the Ministry of Environment, the government's new policy on “Vistas of Prosperity and Splendor,” and the National Physical Plan prepared by the Department of Physical Planning. Further, activities proposed under the ISWM framework are defined based on the 3R (Reduce, Reuse, and Recycle) principle, sustainability concepts, nature-based solutions, and disaster-resilient features. The ISWM framework is developed based on the circular economy perspectives, which guarantees that the developed model is economically, environmentally, and socially acceptable and sustainable for the long run.

iii. Development of technology options of the proposed ISWM framework

The technological options of the proposed ISWM framework (composting, anaerobic digestion, landfilling, etc.) will be selected based on the capital cost, operation and maintenance (O&M) cost, availability of funds, social and environmental features, topography, geology, land-use patterns, availability of technical know-how and capacities, and legal enforcement. Further, the best technological options based on the principles of MSWM and policy decisions of the Sri Lankan government will be given priority or promoted.

iv. Economic analysis for the long-term sustenance of the proposed ISWM framework

A detailed economic analysis is carried out to ensure the economic viability of the proposed ISWM framework to be developed for Kekirawa Pradeshiya Sabha for long-term sustenance. Both direct and indirect costs and benefits are considered under the economic analysis.

2. LITERATURE REVIEW

2.1 Legal and regulatory framework applicable to MSWM

2.1.1 Existing policy framework

The National Strategy on Solid Waste Management in 2000 and the National Policy on Solid Waste Management in 2007 were formulated by the Ministry of Environment to promote ISWM perspectives with more emphasis on MSW. The National Strategy and the National Policy focus on waste minimization over recycling, reusing, recycling over the other forms of disposal, maintaining the hazardous contents in waste, and guarantying environmentally sound waste treatment and disposal as a basic requirement for all citizens. Community involvement in solid waste management is an essential driving force for the successful implementation of the solid waste management strategy.

The National Policy for Solid Waste Management was created to ensure that the country's solid waste management methods are integrated, economically viable, and environmentally sound at the National, Provincial, and Local Authority levels.

The main objectives of the policy are:

(a) to ensure that all solid waste generators, managers, and service providers are environmentally accountable and socially responsible,

(b) to ensure the active participation of individuals and all institutions in integrated and environmentally sound solid waste management procedures,

(c) to maximize recovery of resources in order to minimize the amount of solid waste that must be disposed of, and

(d) to safeguard the health and wellbeing of people and ecosystems by minimizing negative environmental impacts caused by solid waste disposal

Accordingly, in the subject of solid waste management, one shall ensure the implementation of the above objectives stipulated in the National Policy on Solid Waste Management.

In 2009, National Action Plan for the Haritha Lanka Program was formulated on the basis of achieving sustainability. Ten mission statements were formulated under the program, and Mission 6 was defined as “doing away with the dumps.” Short-, medium- and long-term targets and performance indicators were formulated from 2009 to 2016 to achieve the objectives of Mission 6.

The National Waste Management Policy prepared by the Ministry of Environment in 2019 was designed to further strengthen the ISWM system by strengthening the management and administration structures of the country. The policy applies to all types of waste, not only MSW. In addition to MSW, other main waste categories such as electrical and electronic waste, building and demolition waste, healthcare waste, and other hazardous waste were identified as wastes that require priority attention.

The National Waste Management Policy (2019) was reinforced and reiterated in Vistas of Prosperity and Splendor (Saubhagya Dekma, 2019), which recognizes the importance of making people aware that MSW is their own creation and need to take necessary action to minimize MSW generation as the first step of MSWM. It also highlights the importance of continuing proper MSW collection systems as well as designated final disposal sites, such as sanitary landfills shared by multiple Pradeshiya Sabhas. It further emphasizes that innovative techniques and advanced incinerators will be utilized to dispose of hospital waste and industrial scheduled and non-scheduled waste.

National policies and strategies have been formulated to manage other waste streams such as e-waste, industrial waste, healthcare waste, etc. Liquid and air emissions have been addressed too.

The Draft National Environmental Policy, 2021, prepared by the Ministry of Environment, set out “Pollution Control and Waste Management” as one of the seven policy thematic areas (PTA). Further, one of the goals as set out in the Draft National Environmental Policy, 2021 in relation to waste management in the country is as follows.

"An integrated system of waste management covering all local government areas in the country will be in place for effective management of municipal solid waste, agricultural and industrial waste, wastewater, and all forms of hazardous waste."

National strategies and policies have been formulated to promote the ISWM concept in the country by successive governments, and multiple projects have been initiated and implemented on MSWM at national, provincial, and local levels during the past two to three decades by various governments and non-government agencies. Though such initiatives have been taken, the overall MSWM in the country is still unsatisfactory.

2.1.2 Legal framework for solid waste management in Sri Lanka

Legal provisions in relation to different acts, legislations, regulations, and guidelines pertaining to solid waste management in Sri Lanka are discussed herein.

2.1.2.1 National Environmental Act (Act, No. 47 of 1980 amended by Act, No. 56 of 1988 and Act, No. 53 of 2000)

CEA was established as the "regulator" for all environmental-related activities in Sri Lanka possesses the objective of incorporating environmental considerations in the national development. Among the duties that have been entrusted to the CEA, by the National Environmental Act, No. 47 of 1980 amended by Act, No. 56 of 1988 and Act, No. 53 of 2000, pollution control of all aspects in the environment specifies an important element.

Accordingly, any person discharging waste into the environment should conform with the requirements of the relevant sections that have been stipulated by the National Environmental Act.

In the said Act, waste is defined as follows;

"Waste includes any matter prescribed to be waste and any matter, whether liquid, solid, gaseous, or radioactive, which is discharged, emitted, or deposited in the

environment in such volume, constituency, or manner as to cause an alteration of the environment." - ***Section 33*** -

MSW commonly referred to as garbage refuse or trash or rubbish is a waste consisting of routine consumables discarded by people.

Following sections in the National Environmental Act, No. 47 of 1980, amended by Act, No. 56 of 1988 and Act, No. 53 of 2000 are generally applicable for waste management in Sri Lanka prohibiting the discharge, emission, or deposit of waste into the natural environment.

- Section 12*: "Power to give directions to local authorities"*

With the concurrence of the Minister, the CEA can issue directions in writing to any local authority to take necessary action to safeguard the environment. This provision has been used by the CEA to issue directives to local government bodies to take necessary steps to dispose of waste in a manner that would not cause problems and nuisances to the public.

- Section 23A: *"Minister to determine activities in respect of which a license is required under this Act"*

By section 23A (1) of the National Environmental Act, the Minister is empowered to determine by a gazette notification the "prescribed activities" that a license is required to be obtained for discharging, emitting, or depositing of waste into the environment, which causes pollution.

By the Gazette No. 1533/16 of 2008.01.25, the Minister has determined the "prescribed activities" in relation to section 23A of the National Environmental Act.

By Section 23A(2), it is prohibited to carry out any prescribed activity without a valid license. Section 23A(3) specifies carrying out any prescribed activity without a valid license is an offense.

The Environmental Protection Licence is a legal endorsement subjected to certain conditions applicable for industries or activities to deposit wastes, discharge effluents, and emit smoke or excessive noise or vibration or gases or fumes or vapor to the environment.

- Section 23G: *“Restriction regulation and control of pollution of the inland waters”*

By section 23G of the National Environmental Act confines the disposal of waste into inland waters by any person.

- Section 23H: *“Pollution of inland waters of Sri Lanka”*

Section 23H(1) defines the term ‘inland water pollution.’ Section 23H(2) describes in what circumstances that inland water pollution can occur, and section 23H(3) illustrates that inland water pollution is an offense. Therefore, it is understood that given any circumstances where any activity of discharging solid waste into inland waters causing pollution occurs, it is considered to be an offense.

- Section 23J: *“Restriction on pollution of the atmosphere”*

By section 23J of the National Environmental Act restricts the disposal of waste into the atmosphere by any person.

- Section 23K: *“Pollution of atmosphere”*

Section 23K(1) defines the term ‘pollution of atmosphere’. Section 23K(2) describes in what circumstances that pollution of atmosphere can occur, and section 23K(3) illustrates that pollution of the atmosphere is an offense. Therefore, it is understood that given any circumstances where any activity of disposing of waste into the atmosphere causing pollution occurs, it is reckoned to be an offense.

- Section 23M: *“Restriction, regulation, and control of pollution of the soil”*

Section 23M of the National Environmental Act confines the disposal of waste into the soil by any person.

- Section 23N: *“Pollution of soil an offense”*

Section 23N(1) defines the term ‘pollution of Soil’. Section 23N(2) describes in what circumstances that pollution of soil can occur, and section 23N(3) illustrates limited occasions in which the physical, chemical, or biological characterizations of the soil can be conditioned as per the requirements. 23N(4) states that pollution of soil is an office.

2.1.2.2 Western Provincial Council Statue No. 9 of 2009

By this statute, provisions are made for the management of the collection, transportation, transferring, treatment, and final disposal of waste within the Western Province and establishment of the Waste Management Authority of the Western Province with the objective of keeping the environment of urban and rural areas in the Western Province clean.

The objectives of the Council are stated in Section 5 of the Western Provincial Council Statue, and Section 6 has stipulated the powers of the Council which enable to achieve the objectives that have been mentioned.

- Section 5: *“Objectives of the authority”*
- Section 6: *“Powers of the authority”*

2.1.2.3 Municipal Councils Ordinance No. 29 of 1947

Under Municipal Councils Ordinance No. 29 of 1947, among the other duties of the Municipal Councils, they are responsible for waste management within its municipality limits. Sections 129, 130, 131 of the Act illustrate the duty on waste management as follows.

- Section 129: *“Duty of Council as to conservancy scavenging”*
- Section 130: *“All refuse collected to be the property of Council”*
- Section 130: *“Places for disposal of refuse and keeping equipment”*

The Municipal Councils are empowered to enact by-laws that shall be enforceable within the administrative boundaries of the Municipal Councils for their administration purposes. Colombo Municipal Council (CMC) has enacted several by-laws in respect of waste management within Colombo city.

Following by-laws enacted by CMC are relevant to waste management within the municipal limits of the Council.

The CMC is the local authority that operates in Colombo city limits. The Municipal Council provides services for road, sewer, and waste management within the council limits.

2.1.2.4 Urban Council's Ordinance No. 61 of 1939

Sections 118, 119, and 120 of the Ordinance deals with the duties of waste management in Urban Councils.

- Section 118: *"Duty of Council as to conservancy and scavenging"*
- Section 119: *"All refuse collection to be the property of the Council"*
- Section 120: *"Places for disposal of refuse and keeping equipment"*

Sections 118, 119, and 120 of the Ordinance ensure the proper management of waste within the council area by giving necessary measures and directions to sweep and clean the streets, removal of house refuse, proper disposal of all street refuse and house refuse, and prevent public nuisance.

2.1.2.5 Pradeshiya Sabha's Act, No. 15 of 1987

Sections 93, 94, and 95 of the Act deals with the duties of waste management in Pradeshiya Sabhas.

- Section 93: *"Duty of Pradeshiya Sabha as to conservancy and scavenging"*
- Section 94: *"All refuse collected to be the property of Pradeshiya Sabha"*
- Section 95: *"Places for disposal of refuse and keeping equipment"*

Sections 93, 94, and 95 of the Pradeshiya Sabha’s Act, No. 15 of 1987 ensure the proper management of waste within limits by giving necessary measures and directions to sweep and clean the streets, removal of house refuse, disposal of all street refuse and house refuses, and prevents public nuisance.

2.1.2.6 Urban Development Authority

Urban Development Authority (UDA) was formed by Law No. 41 of 1978 with the objectives of promoting social, economic, and physical development of areas as may be declared by the Minister to be urban development areas. By virtue of section 3(1) of the UDA Law No. 41 of 1978, the Minister may, by Order to be published in the Gazette, by declaring those areas as Urban Development Areas.

- Section 3: *“Declaration of areas as Development Areas by Order of the Minister and effect of such Order”*

As per the Gazette No. 386/23 dated 1986.01.30, 1090/3 dated 1999.07.29, and 1535/4 dated 2008.02.06, the CMC municipality area has been declared as an Urban Development Area.

- Section 8 - Powers and Functions of the Authority

Therefore, in carrying out any development work in respect of solid waste management within the Urban Development Area, relevant provisions of the UDA Act and regulations issued by the UDA shall be followed on all occasions.

2.1.2.7 Coast Conservation Act, No. 57 of 1981

Following sections of Coast Conservation Act, No. 57 of 1981 provide necessary measures to safeguard the coastal areas in relation to solid waste by issuing directions to relevant persons cause pollution in coastal areas.

- Section 25: *“Director to give directions for prevention or intrusion of waste or foreign matter the Coastal Zone”*

If a local authority is unable to comply with the request, it may be notified to the Director, who can then take necessary steps to prevent the activity. In instances where the local government does not take necessary action nor respond to a request, it would mean that they are unable to comply with the request, and hence, the Coast Conservation Department can take action on its own.

2.1.2.8 Fisheries and Aquatic Resources Act, No. 2 of 1996

Provisions section 27(1) and (3) are broad enough to cover the release of or the dumping of any waste to aquatic habitats, including the land adjacent to water bodies which may invariably result in harming the aquatic animals and plants.

2.1.2.9 Nuisance Ordinance No. 15 of 1862

The objective of this Ordinance is to safeguard public health and to minimize nuisances. Section 2 of this Ordinance defines 12 instances of offenses, and thereby, Section 2(3) and 2(12) are relevant in solid waste management that required to be compiled.

- Section 2(3): “*Keeping an accumulation of dung, etc.*”

2.1.2.10 Police Ordinance No. 16 of 1865

By Police Ordinance No. 16 of 1865, there are certain duties that have been rested upon police officers in relation to the prevention of obstructions and nuisances on roads.

Section 63 (g) of the Ordinance prevents activities that create an obstruction of roads and public nuisance, which may apply even to solid waste management activities.

- Section 63: *“Certain duties of police officers - Obstructions and nuisances on roads”*

2.1.2.11 Technical Guidelines on Solid Waste Management

The goal of CEA's publication of Technical Guidelines on Solid Waste Management is to ensure that any MSWM project is initiated or operated in an environmentally sound manner while conforming to legal obligations. Various components of MSWM such as collection, transfer, recovery of useful components of MSW, incineration, composting, biogas generation, and landfilling are covered in the guidelines with technical guidance to carry out with minimal impacts to the environment.

The guidelines are focused on covering only the MSW, and therefore, sewage, hazardous waste: medical and hazardous industrial waste, are not addressed under this Guideline.

Anyone who does MSWM may comply with the requirements applicable in the technical guidelines on solid waste management published by CEA, but this is not a requirement by law.

Target solid waste falling under guidelines

By this set of guidelines, it is targeted to provide guidance of management of waste under as following categories;

1. MSW
    - Domestic waste
    - Commercial waste
    - Institutional wastes
    - Street sweeping waste and beach cleansing waste
    - Garden waste
    - Wastes from drains and watercourses in urban areas
2. Construction wastes
3. Industrial wastes (accepted in municipal landfills)

2.1.2.12 Regulations for Hazardous Waste Management

Hazardous Waste or Scheduled Waste is waste that causes substantial or potential threats to public health or the environment.

Gazette Extraordinary No. 924/13 dated 1996.05.23, the waste categorization and requirements in managing hazardous waste were specified.

The number of categories has been identified as hazardous waste as per Schedule-1 of the Gazette Extraordinary No. 924/13 dated 1996.05.23. The guidelines required for the scheduled waste management in Sri Lanka as per the National Environmental (Protection & Quality) Regulation No. 01 of 2008 have been provided. Elements of hazardous waste generation, collection, transportation, storing, recovering, recycling, or disposal are discussed in the Guideline.

Section 1 of the Guideline provides the legal requirements in managing hazardous waste.

In this clause, it is motioned that the applicable industries are to be obtained a license to manage hazardous waste covering all aspects of waste management.

2.1.3 Institutional framework

The following institutions exist at the provincial and national levels to facilitate MSWM practices in the country.

1. Local Authorities
2. Central Environment Authority
3. Waste Management Authority - Western Province
4. National Solid Waste Management Support Centre
5. Urban Development Authority
6. Sri Lanka Land Development Corporation
7. Ministry of Environment and Natural Resources
8. Ministry of Urban Development, Coast Conservation, Waste Disposal, and Community Cleanliness

9. Marine Environment Protection Authority
10. Department of Coast Conservation & Coastal Resource Management
11. Provincial Councils

2.1.3.1 Local Authorities

Sri Lanka is divided into 341 local authorities, including 24 Municipal Councils, 41 Urban Councils, and 276 Pradeshiya Sabhas. Local authorities are responsible for managing MSW within their jurisdiction by taking necessary measures and directions to sweep and clean the streets, removal of house refuse, suitable disposal of street refuse and house refuses, and prevent public nuisance. Local authorities are responsible for taking all necessary measures and precautions to ensure that MSW collected is disposed of properly without causing environmental pollution and public nuisance. Sri Lanka by 2019 has produced more than 260 open dumps of various magnitudes in the country (Jayaweera et al., 2019). At present, Sri Lanka has 136 functioning compost facilities managed by respective local authorities; however, only a handful of them meet environmental standards due to various reasons, mostly due to proper management. Despite multiple initiatives taken by local authorities, the overall MSWM practices carried out by local authorities are unsatisfactory and need to be improved.

2.1.3.2 Central Environment Authority

CEA was established as the “regulator” for all environmental-related activities within the country. With the concurrence of the Minister, the CEA can issue directions in writing to any local authority to take necessary action to safeguard the environment. This provision has been used by the CEA to issue directives to local government bodies to take necessary steps to dispose of solid waste without causing problems and nuisances to the public.

The role of the CEA in MSWM is to enforce legal provisions established for MSWM in the National Environmental Act, No. 47 of 1981 and its subsequent amendments. This includes granting environmental clearance for projects, granting environmental protection licenses for controlling emissions and discharges to the environment and schedule waste management licenses for controlling the scheduled hazardous waste, formulating national policies of waste management and setting environmental standards, norms, and criteria, implementing multilateral environmental agreements on waste management, promoting awareness of public and stakeholders, etc.

2.1.3.3 Waste Management Authority - Western Province

Waste Management Authority of the Western Province (WMA-WP) was formally established to provide technical expertise and facilitate local authorities in managing waste in an environmentally friendly manner. At the provincial level, this was the first and only specialized authority constituted. WMA-WP is entrusted with the management of collection, segregation, transportation, transfer, treatment, and disposal of waste in the Western Province. WMA-WP delivers its services for the enhancement of regulatory mechanisms of waste management, community-based waste management, local authority-based waste management, and cluster-based mass scale waste management with Public and Public-Private Partnerships (PPP).

2.1.3.4 National Solid Waste Management Support Center

The National Solid Waste Management Support Center (NSWMSC) was formed in 2007 attached to the Ministry of Provincial Councils and Local Government Affairs. The NSWMSC was established to manage the MSW in administrative areas of local authorities. The NSWMSC facilitates local authorities by providing technical support for the MSWM and coordinates government and other organizations to guarantee financial support and assistance to upgrade MSWM services.

2.1.3.5 Urban Development Authority

As per the Gazette Extraordinary No. 386/23 dated 1986.01.30, 1090/3 dated 1999.07.29, and 1535/4 dated 2008.02.06, the CMC municipality area has been declared as an Urban Development Area. Therefore, in carrying out any development work in respect of waste management within the Urban Development Area, relevant provisions of the UDA Act and regulations issued by the UDA shall be followed on all occasions.

A processing facility for MSW was initiated by UDA in 2015, and two Waste-to-Energy plants were approved to be implemented. The management of the Aruwakkalu Sanitary Landfill project and Waste-to-Energy Projects in Kerawalapitiya and Karadiyana are being carried out by the UDA.

2.1.3.6 Sri Lanka Land Development Corporation

In terms of solid waste management, Sri Lanka Land Development Corporation (SLLDC) is responsible for protecting wetlands and preventing pollution in wetlands. After the collapse of the Meethotamulla open dump in 2017, SLLDC initiated a composting project at Kerawalapitiya.

2.1.3.7 Ministry of Environment and Natural Resources

The Ministry of Environment assists CEA in carrying out its function in solid waste management by facilitating the establishment and implementation of national policies for solid waste management within the country.

2.1.3.8 Ministry of Urban Development, Coast Conservation, Waste Disposal, and Community Cleanliness

The Ministry of Urban Development, Coast Conservation, Waste Disposal, and Community Cleanliness assists the formulation of policies in relation to urban development, coast conservation, waste disposal, and community cleanliness for the creation of modern cities and a clean country. The overall supervision of the Aruwakkalu Sanitary Landfill Project and Waste-to-Energy Projects in Kerawalapitiya and Karadiyana are also entrusted with the Ministry.

2.1.3.9 Marine Environment Protection Authority

The Marine Environment Protection Authority (MEPA) was established by the Government of Sri Lanka, under the Marine Pollution Prevention Act, No. 35 of 2008, with the sole responsibility to prevent, control, and manage the pollution of the marine environment of Sri Lanka.

The MEPA is in charge of preventing marine pollution; hence, its role and mandate cover waste management along the coast and in coastal waterways across the country. The MEPA is not responsible for waste collection or disposal.

2.1.3.10 Department of Coast Conservation & Coastal Resource Management

The Department of Coast Conservation & Coastal Resource Management under the Coast Conservation Act, No. 57 of 1981 mandates the protection of the coast from pollution, including waste.

2.2 ISWM concept, options, and challenges

2.2.1 ISWM concept

ISWM entails formulating suitable and reasonable options for different aspects of waste management, including waste generation, source-segregation, collection and transport, sorting, recovery, treatment, and final disposal by carefully examining local needs and conditions (UNEP, 2009). The ISWM concept is used for waste management to improve operational efficiency, community wellbeing, and environmental risk mitigation (Asefi et al., 2020). ISWM is a branch of MSWM that adopts a holistic approach and covers all aspects of MSWM. It formulates a complete solution for MSWM that takes into account all three criteria: environmental effectiveness, societal acceptability, and economic viability (Marshall and Farahbakhsh, 2013). It has been proven that an integrated and holistic approach leads to better decision-making as well as achieving environmental and socio-economic benefits. The proper ISWM plan follows a hierarchical approach, as shown in Figure 2.1.

The paradigm shift from landfilling to source reduction or prevention is thought vital to be embedded in the whole efforts of ISWM. This shift is of paramount importance to be inbuilt for which mindsets of all stakeholders need to be inquired positively.

With the implementation of the ISWM plan for MSWM, the following features will be incorporated.

- Reduced MSW generation through education
- Improved collection of source-segregated MSW
- Enhanced reuse and recycle potential of source-segregated MSW
- Improved composting and anaerobic digestion for biodegradables
- Improved facility for collection of construction and demolition waste
- Improved facility for final disposal of residues (sanitary landfilling, Waste-to-Energy)

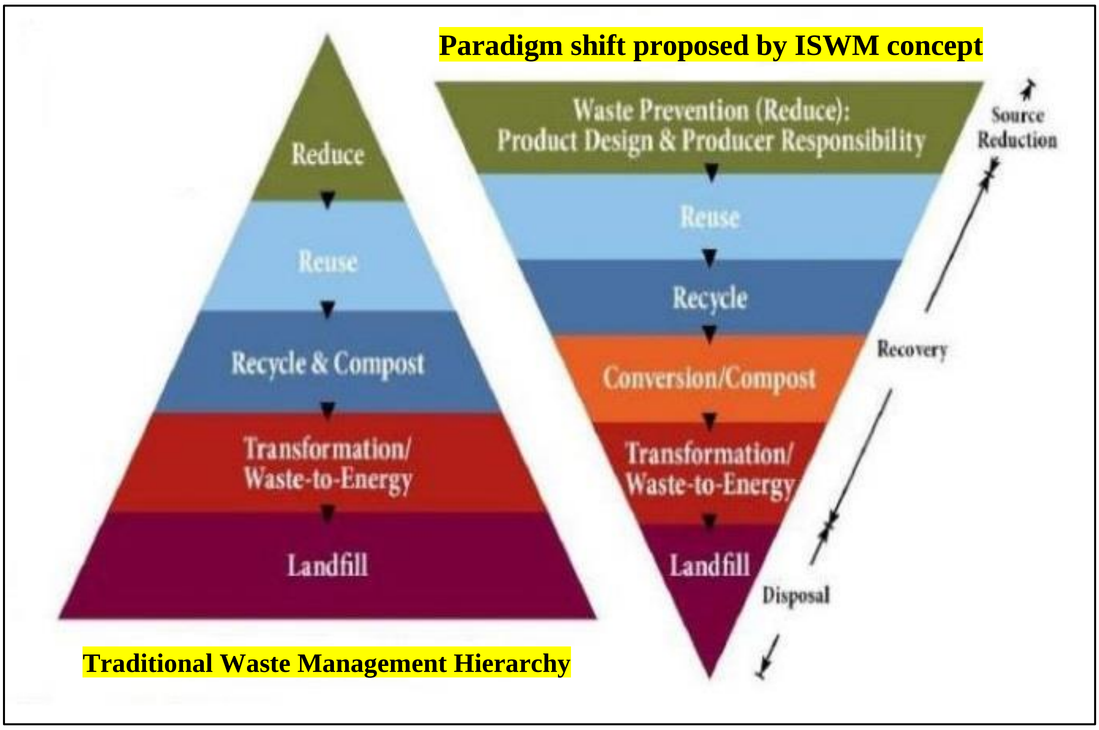


Figure 2.1: Paradigm shift proposed by ISWM concept
(Source: Fagariba and Song, 2016)

ISWM, based on the 3R principle (reduce, reuse, and recycle), aims to improve overall solid waste management operations from all the waste-generating sectors, including MSW, and involve all the stakeholders in the waste sector (Memon, 2010). Thereby, reduction at source is given priority, and every effort is taken to reduce the amount and harmfulness of waste generated during the design, manufacture, purchase, or use of materials. The reuse and recycle waste are done to minimize the use of natural resources and conserve energy through sorting, collection and transport, and reprocessing (UNEP, 2009). Therefore, ISWM requires the adoption of appropriate methods, technologies, and management systems to reduce waste generation and increase the reuse and recycle rate (Malakahmad et al., 2010).

In ISWM planning, it is a prerequisite to identifying types of waste generated, quantities, composition, and present status of MSWM practices. These details are essential for the development of key strategies and components of the ISWM plan (Starovoytova, 2018). Direct waste audits are the most effective way of collecting data to be required to develop an ISWM plan over different quantitative methodologies (Smyth et al., 2010). ISWM focuses on incorporating the perspectives of stakeholders so that the developed ISWM plan addresses the specific needs of the community (McDougall et al., 2001).

The ISWM approach provides significant economic, environmental, and social benefits. Since the 3R concept is highly promoted under the ISWM approach, the cost incurred for collection, treatment, and final disposal is reduced. Additional financial benefits could be gained by applying the ISWM approach include greater revenues from selling final products, increased sales due to “green” and specialty marketing, and more competitive manufacturing practices, and the minimization of regulatory penalties incurred in the past due to waste discharges.

The ISWM approach could have a number of environmental benefits, such as preserving natural resources, reducing quantities of waste generated, and reducing the pressure on local landfills. By shifting from open dumping, air pollution due to unregulated gas emissions and water and soil pollution due to leachate mismanagement could mainly be avoided.

The ISWM approach could have a number of social benefits, such as increased public awareness through capacity-building programs and better public health through the reduction of wastes. This approach can develop collaboration among different stakeholders who are involved in waste management, thereby enhancing community interactions.

2.2.2 ISWM options

ISWM can be viewed as an entity to optimize all possible waste management options, reducing the need for landfills in the long run. The paradigm shift proposed by ISWM assigns landfilling as the least preferred option, which is opposite to the traditional waste management hierarchy. When developing suitable options under ISWM, both short-term and long-term actions and management strategies incorporating the aspects of health and wellbeing, economic, engineering, conservation, aesthetics, and environmental protection (badgie et al., 2011).

The options pertaining to the ISWM are proposed under the following key areas of MSWM, and details of each option available under the following key areas are explained below.

- Source-segregation
- Reduce, reuse, and recycle
- Collection and transport
- Final disposal

Developed countries implement Waste-to-Energy projects for recovery of energy, composting for biodegradables, and recycling and reuse, and searching for better options to treat and dispose of waste (badgie et al., 2011)

2.2.3 Challenges for implementing ISWM

Major challenges associated with the implementation of the ISWM plan are explained below.

1. Urbanization, inequality, and economic growth

In recent years, urbanization has shattered at a higher rate (Tacoli, 2012). Though only 16 cities had populations of at least a million people in the twentieth century, 400 cities had populations of at least a million people in the twenty-first century. Around three-quarters of these cities reported in the twenty-first century were located in low- and middle-income nations (Cohen, 2004). This unplanned growth of population has created extreme land-use planning and infrastructure issues, lowered the ability of national and municipal governments to provide MSWM services at the rate they are demanded. The extremely slow and inefficient institutional systems cause to worsen the provision of MSWM facilities in many regions of the world.

Many people will be forced into slums, where facilities for living and sanitary conditions are deplorable, and MSWM facilities are non-existent (UNFPA, 2011). The needs of MSWM of these densely packed, low-income settlements are underserved or ignored entirely, despite the fact that such areas have the utmost need for these services due to the unavailability of alternative arrangements for MSWM operations (Coffey and Coad, 2010).

Due to the lack of common spaces made available for keeping waste collection bins and the existence of narrow roads and unsurfaced roads which create difficulties to handle regular waste collection vehicles, collection of MSW may not be possible in certain unplanned settlements (Coffey and Coad, 2010; Henry et al., 2006). As a result, garbage is deposited in open areas, access roads, and waterways, where disease vectors thrive (Coffey and Coad, 2010; Konteh, 2009).

Mismanagement of MSW affects to spread of diseases such as dengue and malaria. During rain, leachate generation from open dumps will be accelerated, and it percolates through the soil and enters the waterways, resulting in contaminating food, water, and soil (Marshall and Farahbakhsh, 2013). The environmental degradation caused due to mismanagement of MSW can have a significant influence on the economies of tourism-dependent countries (Henry et al., 2006).

It is prudent that MSWM operations are severely affected by urbanization, inequality, and economic growth. Since ISWM develops a comprehensive approach in managing all aspects of MSWM, urbanization, inequality, and economic growth affect the implementation of the ISWM system as well.

2. Cultural and socio-economic aspects

The MSWM operations carried out are based on the attitudes and behavior patterns of the people, which are influenced by cultural and social aspects (Schubeler, 1996). Even within particular residential communities, the diversity of ethnic and social groups has a significant impact on the implementation of MSWM initiatives. Public awareness and attitudes for MSW reduction, source-segregation, demand for collection and transport, willingness to pay a charge for MSWM services, and unauthorized disposal in public places determine the success or failure of the MSWM operations (Yousif and Scott, 2007; Zurbruegg, 2003).

The composition of MSW is influenced by the socio-economic and cultural context. In many countries, people mainly consume pre-prepared or pre-cooked foods. But people in some countries mainly rely on fresh meat or significant quantities of fresh vegetables and fruit. These changes are found even within the same countries, which affects significant changes in MSW composition.

The composition of MSW is affected by socio-economic aspects at the household level: increased literacy increases the paper content, and wealthier populations are more likely to discard durable objects rather than repair them (Coffey and Coad, 2010). Scavengers informally collect reuse and recyclable materials because they value otherwise end up as waste (Coffey and Coad, 2010; Schubeler, 1996; UN-HABITAT, 2010; Wilson, 2007).

Social expectations on the collection and disposal of MSW are also influenced by waste composition. Some social groups dispose of sorted MSW into designated containers, while others consider the street to be a waste dumping site. Food, shelter, security, and livelihoods remain the top priorities in some metropolitan areas; MSW will only become a priority if these more basic requirements have been satisfied (Konteh, 2009), or public health and environmental damage influence these priorities (Wilson, 2007). Cultural and socio-economic aspects create difficulties in MSWM operations.

3. Policy, governance, and institutional issues

Politics play a significant role in the MSWM sector. The overall MSWM operations are influenced by the association between central and local governments, political influence, and the extent to which people participate in policy-making processes in a democratic manner (Schubeler, 1996).

The major challenge in low-income countries is to balance the policy, governance, institutional systems, and provision and allocation of resources (Konteh, 2009). MSWM isn’t always a top priority for policymakers and planners at the municipal and national levels (Marshall and Farahbakhsh, 2013). Further, social and political priorities may take precedence, leaving limited budgets for MSWM operations (Memon, 2010; Yousif and Scott, 2007). Due to the lack of long-term commitment, work performed in prior administrations is abandoned (Zarate et al., 2008). The misconceptions and disputes among political parties and municipal governments can also cause projects to be shelved (Henry et al., 2006).

The effective MSWM system involves the delineation of defined roles and legal obligations of government and institutional bodies. Even when regulatory and legislative frameworks are in place, governments with poor institutional bodies are frequently overwhelmed by rising MSWM demands (Hardoy et al., 2001).

It is obvious that improper or inappropriate policy, governance, and institutional frameworks create detrimental effects on MSWM practices. Therefore, the ISWM approach addresses such difficulties in MSWM operations to be overcome.

4. International influences

In recent years, several bilateral and multilateral development agencies have focused their attention on the MSWM sector due to the increasing severity of urban environmental challenges and the requirement of capacity-building at the municipality level (Zarate et al., 2008). Many foreign aid projects on MSWM in developing countries aim to acquire markets for delivering sophisticated vehicles, machinery, and equipment, though they are wholly unsuited for local conditions (Coffey and Coad, 2010). Further, it is observed that a lack of expertise in implementing and operating such projects creates severe O&M issues. In many developing nations, such difficulties have a negative impact on the evolution of MSWM practices. Grants/loans for constructing sanitary landfills do not always result in the adoption of this type of final disposal method; well-trained employees and adequate financial support are also required to ensure trouble-free operation (Zurbruegg, 2003). Therefore, the ISWM approach shall carefully evaluate local needs and conditions to determine the most suitable options for all aspects of MSWM operations rather than entirely depending on foreign involvements.

5. Lack of public awareness and participation

Public awareness and participation are key factors in MSWM practices (Shukor et al., 2011). It is crucial that everyone involved in the MSWM system need to work together because greater improvement equals more accountability and awareness (Bortoleto and Hanaki, 2007). Further, it is necessary to convey that MSWM is everyone’s responsibility. In this regard, it’s critical to underline that environmental education is, in essence, a long-term effort that requires a commitment from current and future governments, with the goal of imparting strong environmental awareness among citizens (Bortoleto and Hanaki, 2007). Therefore, the ISWM approach requires more public awareness and participation.

2.3 Development of technology options

2.3.1 Waste prevention

Waste prevention, often known as “Waste reduction,” aims to reduce waste generation. Many local authorities face a difficult task in establishing initiatives to reduce MSW generation as the principal approach of ISWM. Using fewer packaging, utilizing engineering items to last longer, and reusing products and materials are all examples of waste prevention measures. Waste prevention minimizes the expenses of waste processing, treatment, and disposal, as well as the generation of methane. The purchasing behavior of consumers is a significant input that tremendously promotes the avoidance of waste generation and stimulates green product design. Some of the practices which can be practiced to prevent waste generation are conducting awareness campaigns, educating smart shopping practices, promoting the 3R concept, and adopting behavioral changes.

Face-to-face interviews are carried out with women positively affected by waste reduction and recycling. Municipalities and decision-makers could significantly enhance MSWM practices in underdeveloped countries by conducting training programs and motivating women to improve waste reduction, reuse, and recycling (Zand et al., 2020).

2.3.2 Source-segregation

The MSW is subjected to sorting at source into categories such as biodegradables, recyclables, construction and demolition waste, street sweeping waste, and non-biodegradables. Source-segregation is highly promoted by the ISWM approach, and the 3R concept also promotes source-segregation.

Recycling is one of the three key aspects of the 3R concept. Recycling is the process of altering waste into reusable materials. The ability of a material to reclaim the properties originally had determined its recyclability. It is an alternative to the conventional linear process of 'production-consumption and disposal' and expands the life of used material following a circular system that can reduce the usage of additional raw material, help lower greenhouse gas emissions, reduce air, water, and land pollution. Recycling is a key scenario of present waste reduction. Thus, recycling focuses on environmental sustainability by replacing raw material inputs and redirecting waste outputs away from the economic system.

Under ISWM, it is a prerequisite for implementing the sorting or separation of MSW at the source. Further, the collection must be carried out only if the separation or sorting of MSW to biodegradables, recyclables, and non-biodegradables will be practiced by the households. In the case where mixed MSW is kept for collection, such waste should not be collected.

Some of the practices used by local authorities to strengthen separation efforts at the source include promoting the 3R principle, distributing compost bins, conducting awareness campaigns, and strengthening the legal framework. Making people aware of the source-segregation efforts should be done in the form of leaflets distributed by visiting door-to-door. In this effort, the assistance of NGOs, societies, and popular personalities could be looked for. Propaganda work for reduction, reuse, and recycling of waste among people through media, newspapers, NGO involvement for door-to-door campaigns, etc., are necessary to be conducted.

2.3.3 Collection and transport

Adequate quantities of collection and transport of MSW are to be carried out by local authorities is essential for the ISWM approach. The vehicular fleet and employees shall be capable enough to collect and transport source-segregated MSW to processing sites or final disposal sites on a regular basis. Thus, the efficient and effective collection and transport of MSW is another challenge faced by local authorities.

Many local authorities face the difficulty of maintaining a reliable MSW collection and transportation system due to an aging fleet of vehicles with frequent maintenance issues. Garbage compactors of various sizes are not provided to all local authorities, resulting in a significant reduction in MSW handling efficiency. Besides, local authorities provide their vehicular fleet comprising tractors coupled with trailers fabricated with different sizes, and such arrangements are not good practices on a long-term basis. Bad odor emanation, leachate trickling onto the road, and portions of MSW being dropped while on the move are intriguing and inevitable experiences observed by many. Irregularities in the collection teams and non-implementation of proper measures for the health and safety of those involved in the MSW collection and transport are often envisaged in many local authorities.

Under the ISWM approach, an optimized plan for the collection route needs to be worked out depending on the vehicular fleet, and accordingly, prioritization on collection efforts will be done. The GPS-assisted system will be made available for every vehicle for an effective and efficient collection plan to be mobilized.

2.3.4 Final disposal

2.3.4.1 Composting

2.3.4.1.1 Aerobic composting

In a static aerated pile of composting, forced aeration is used to spread the air through the windrows. The composting piles are oriented over a network of perforated pipes. The entire network of pipes is connected to a blower, and the air is supplied to the network under positive or negative pressure (Figure 2.2). The windrow piles are not necessary to be turned unlike, aerobic windrow composting, in which aeration is accomplished by turning the windrows. When the composting process is finished, the piles are broken up for the first time.

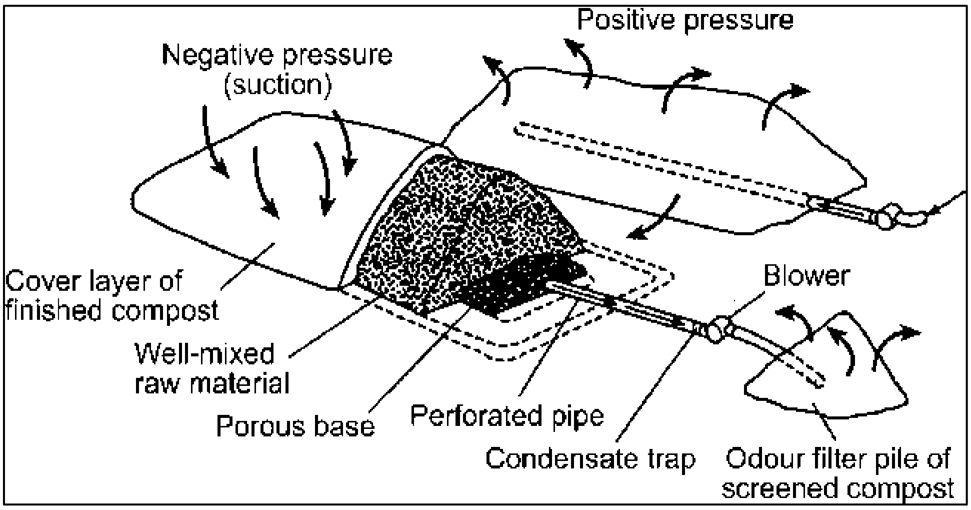


Figure 2.2: Supply of air under negative or positive pressure
(Source: NRAES-114, 1999)

The supply of air to the windrow pile through forced aeration will accelerate the composting process; hence, less time is required for composting (generally, 3–5 weeks). The initial mixing of raw materials is crucial in aerated static pile composting. During mixing, bulking agents (e.g., wood chips) will be added to maintain the air circulation inside the pile. The base of the pile is prepared with wood chips, chopped straw, or any other porous material (Figure 2.2). The base materials are placed on the perforated pile network connected to a blower, which either pulls or pushes air through the pile.

In the aerated static pile composting method, the air is supplied to the network under positive (pushing the air into the pile) or negative (air is withdrawn from the pile) pressure. The negative pressure (suction) sucks air into the pile from the outer surface of the pile to the perforated pipes. The air extracted from the pipes can easily be filtered to control the odor emanating during composting. The positive pressure pushed air out of the pile over the entire pile surface. Therefore, odor control is difficult. Positive pressure provides better airflow than negative aeration.

Maintaining moisture content in a pile during composting is important. This method will require high cost and expert commitments together with continuous monitoring, unlike aerobic windrow composting. But the footprint required is less since this method does not require additional spaces for turning.

2.3.4.1.2 In-vessel composting

In-vessel composting includes feeding organic (biodegradable) waste into a drum, concrete-lined trench, or related equipment (Figure 2.3). This method relies on different forced aeration and mechanical turning to accelerate the process of composting. Many deficiencies (space, composting duration, etc.) encountered in both windrow composting and aerated static pile composting methods are addressed by this method. In-vessel composting can process substantial quantities of waste without utilizing much space, unlike the windrow composting method. Further, this method is capable of controlling environmental conditions: temperature, moisture, and airflow effectively. The size of the vessel can vary in size and capacity. There are different in-vessel methods composed of different combinations of vessels, aeration devices, and turning mechanisms.

Figure 2.3: In-vessel composting

(Source: info@xactsystemscomposting.com)

The organic waste to the vessel can be processed as a batch or can be moved progressively by the pressure of incoming new waste. The advantages of this method are less odor, faster, lower labor cost, less leachate generated, and small area requirements. The vessels can also be fixed inside apartments, schools, restaurants, etc. Some of the disadvantages are high cost and requiring expert knowledge to design and operate.

The detention time within the vessel differs from 1–2 weeks, but practically, it takes 4–12 weeks as a curing period followed by the active composting period inside the vessel because of the requirement of balancing microbial activity and cooling of the pile.

2.3.4.1.3 Windrow composting

Windrow composting is the widespread composting method used in many parts of Sri Lanka because of its appropriateness for a wide range of feedstocks and easy facility management. The operating cost of windrow composting is relatively low when compared to other composting methods. This method involves the feedstocks being formed into long, low piles known as windrows. To re-establish porosity, break up, and blend material, the windrows are moved or turned on a regular basis. The windrow is also reintroduced to oxygen during the turning process. Aeration of windrows is still primarily passive due to the quick consumption of oxygen, and keeping good free air space inside the materials is essential. The time required for active composting can be as low as three months for this approach if it is done properly, and the site is aggressively managed but could be even more than four months if not managed well. The time required for curing using this approach is 4–8 weeks. The time required for composting depends on factors such as the degree of feedstock preparation, the type of feedstock, the type of composting technology used, climatic conditions, and the level of operator control.

The size, shape, and spacing of windrows depend on the space available and equipment used for turning. The turning of piles can be done through a skid steer loader, front-end loader, or compost turning machine. Freshwater or leachate stored in the leachate tank should be sprinkled during the turning process to maintain the moisture content of the waste.

When windrow composting is done outside, the pile is exposed to precipitation, which might cause runoff issues. Any runoff must be collected and treated or supplied to an incoming feedstock batch to increase moisture content. To avoid runoff difficulties, piles can be placed beneath a roof or inside a building; however, this increases the facility’s capital expenses. Heat, water vapor, and gases trapped in the pore spaces are released into the atmosphere every time a windrow is turned. Because there is nothing that can be done to trap water vapor and gases if the facility is outside, this composting method has the capability to affect nearby neighboring properties; as a result, always turn windrows when the impact from odors is at their lowest.

2.3.4.1.4 Composting through Kawashima machine

A screw-type composting machine developed by KAWASHIMA Co., Ltd. (KAWASHIMA), Japan, is used to produce compost within 30–45 days. The organic (biodegradable) materials will be fed to the machine as the main raw material. The agricultural waste can be used as a material for water content adjustment, and livestock excreta can also be utilized as a raw material.

This method will reduce a large amount of garbage at dumping sites; hence, the serviceability period of the dumpsites will be increased. Further, this method improves water environment issues and human health issues. It also contributes to reducing methane emissions to the environment.

The screw-type agitating equipment agitates waste only along the upward and downward direction; thereby, the air is spread evenly throughout the waste (Figure 2.4). Due to the aerobic nature, the anaerobic bacteria cannot survive; hence, fermentation occurs by aerobic bacteria under high temperatures. Since the top portion of the garbage contacts with air, a slight decrease in temperature is expected (approximately 5 ºC drop after churn). The high temperature maintained allows early maturing of the compost. It also removes noxious insects and germs and reduces the emission of odorous gases by anaerobic fermentation. This system discharges no effluent because the moisture content in the organic waste is evaporated by the high temperature. Therefore, both solid waste (organic fraction), as well as liquid filth can be treated simultaneously.

Figure 2.4: Kawashima composting machine
(Source: info@envir.lk)

2.3.4.2 Waste-to-Energy technologies

Waste-to-Energy facilities comprise different types, which include Incineration, Gasification, Pyrolysis, and Anaerobic Digestion.

2.3.4.2.1 Incineration

The most common technology for treating waste is incineration. It is a thermo-chemical process. In this method, the combustible content of a solid waste stream is subjected to oxidation to generate heat energy. This process can be used to generate electrical power using a steam turbine, industrial processes, or district heating. The combustion of waste using an excess of oxygen (air) to ensure complete combustion at a temperature above 850 °C is known as incineration. The huge advantage of Waste-to-Energy incinerating plants is the production of electricity which in the long run can help to reduce costs.

Bottom ash, fly ash, and flue gas are other products of incineration in which are found several regulated pollutants (e.g., mercury, lead, cadmium, etc.). The common gaseous pollutants in the flue gas are carbon dioxide, nitrogen oxides, sulphur oxides. Combustion of waste is a major source of furans and dioxins, which are highly toxic and carcinogenic pollutants. Dioxins are cancer-forming chemicals, and a very efficient flue gas treatment unit is a must for an incinerator. Even though the quantity of ash that remains from the process is small, it contains several heavy metals and poisons which require further treatment before being disposed of to avoid serious harm to the public and the environment.

Although the focus should be on reducing waste and recycling, incineration does not follow recycling and waste reduction strategies. Burning most of the waste without considering the strategy of recycling will only cause environmental damage, and it may promote more waste production.

Unlike landfills, where garbage is left to deteriorate, releasing unpleasant odors and causing air pollution, incineration can give less unwanted odors because waste is burned. Incineration also has the advantage of being able to operate in all weather, and the ash produced by waste combustion can be used in construction, exported, or even landfilled. Incineration systems take up a small amount of area. As a result, there are convenient and practical trash management options.

The construction of an incinerator facility is a costly undertaking. The costs of building the infrastructure and operating the incinerator plants, in particular, are extremely high. Aside from that, operating an incinerator plant necessitates highly skilled professionals and a dedicated workforce. Regular maintenance is also required for incinerator plants, which adds to the already high running expenses.

The high capital and O&M cost of incineration plants have been a negative factor in establishing incinerator plants in middle-income countries. A high proportion of biodegradable waste in developing countries and higher moisture content are negative factors.

2.3.4.2.2 Gasification

Gasification is a technique that converts a carbon-based material, like MSW or biomass, into different types of energy without burning them. Instead, gasification transforms the solid and liquid waste materials into syngas which is also called synthesis gas, through a chemical reaction. Usually, the gasification is performed at a temperature above 700 °C. Around the world, there are various solid waste gasification facilities that are either operational or under construction. For MSW treatment, gasification has significant advantages over typical combustion techniques. It takes place in a low-oxygen environment, which prevents dioxins and huge amounts of SOx and NOx from forming. Furthermore, only a portion of the stoichiometric amount of oxygen is required for burning.

Tars, heavy metals, halogens, and alkaline compounds are released into the product gas during gasification, which can pose environmental and operational issues. Tars are high molecular weight organic gases that can damage reforming catalysts, sulfur removal systems, and ceramic filters and cause slagging in boilers and other metal and refractory surfaces. The high capital and O&M cost of gasification plants have been a negative factor in establishing such plants in middle-income countries.

2.3.4.2.3 Pyrolysis

Another Waste-to-Energy technology is pyrolysis. Pyrolysis is the thermal decomposition of trash at 540–1000 °C in the absence of oxygen, creating gas, solid, and liquid residues, followed by a secondary chamber that often combusts the resultant synthetic gases or oils, often providing power or usable heat.

The major disadvantages of this method include the potential for toxic residues such as inert mineral ash, inorganic compounds, and unreformed carbon, as well as the potential for a variety of toxic air emissions such as acid gases, dioxins and furans, nitrogen oxides, sulphur dioxide, particulates, and pyrolysis plants, require a certain quantity of materials to work effectively. The high capital and O&M cost of pyrolysis plants have been a negative factor in establishing such plants in middle-income countries.

2.3.4.2.4 Anaerobic digestion

Organic materials, such as animal or food waste, is broken down in anaerobic digestion to produce biogas and biofertilizer. An anaerobic digester is a sealed, oxygen-free tank where this process takes place in the absence of oxygen.

The anaerobic digestion technology is best suited to the treatment of wet organic feedstocks, like high moisture food waste, agricultural biomass, and animal wastes, including manure, domestic sewage, and biodegradable components of MSW. The biogas can be used as a source of renewable energy as a fuel in combined heat and power gas engines or upgraded to Bio-Compressed Natural Gas to replace LPG. Anaerobic digestion has advantages like low biological solids yield, which means less wasting than seen in aerobic treatment, tolerant of heavy loadings. The produced digestate can be used as a fertilizer if contaminants are not above the application specification limits. The high capital and O&M cost of anaerobic digestion plants have been a negative factor in establishing such plants in middle-income countries.

2.3.4.3 Landfilling

2.3.4.3.1 Controlling landfilling

A controlled landfill is categorized as a non-engineered type landfill. It developed due to the necessity to halt open waste dumpsites and establish improved facilities, including technical control procedures (leachate, stormwater, and gas) since open dumping creates severe environmental and socio-economic implications.

The characteristics of the controlled landfills are given below.

- The area of the controlled landfill is fenced to avoid stray animals (elephants, dogs, cows, cranes, goats, etc.) entering the site. The entering of straw animals will lead to creating health and safety issues, disturbance to the daily operations, etc.
- The waste disposed of is covered with soil at the end of each day to prevent the waste disposed of from being blown around and avoid flies from breeding on the waste. Further, this facilitates less accessibility to scavenging animals and prevents the waste from catching fire.
- The controlled landfill site is staffed, and some of the machinery and equipment is available for operations such as spread, compact, and covering the waste with a layer of soil at the end of each day.
- The leachate collection and treatment techniques are addressed during the design of the controlled landfill (not as comprehensive as sanitary landfills).
- Necessary infrastructure facilities (internal roads, tipping pad, etc.) are available in the controlled landfill site.
- Some of the waste types (clinical, toxic, and hazardous wastes) are not accepted to be disposed of in the controlled landfill.
- There are limitations on accepting the quantity of waste to the controlled landfill.
- A detailed assessment will be carried out to ensure that the land selected to establish the facility meets the minimum siting criteria.

2.3.4.3.2 Sanitary landfilling

A sanitary landfill is categorized as an engineered landfill. It should be designed and operated to minimize impacts on human and the environment. The sanitary landfills follow comprehensive planning right from the beginning (selection of the site up to final closure of the landfill) as opposed to open dumpsites and controlled landfills. Therefore, it requires substantial financial resources and expert involvement. Sanitary landfilling is the most desirable and suitable method of final waste disposal compared with open dumping and controlled landfilling.

The design norms for site selection, development of infrastructure and utility facilities at the site, selection of liner materials, leachate, stormwater, and gas collection and treatment, specifications for landfilling operations and closure after completing the operations of landfilling, water quality monitoring, air quality monitoring, plantation at the landfill site, post-care of the landfill site, etc. are necessary to follow when designing a sanitary landfill. A typical layout of the sanitary landfill is depicted in Figure 2.5.

The following items must be provided in the layout.

- Active cells where waste to be disposed of
- Tipping pad
- Liner system
- External and internal access roads
- Machinery and equipment parking and repair
- Weighbridge
- Office premises
- Location of the waste inspection point and transfer station (if necessary)
- Temporary storage for special waste which is not permitted to be disposed of in the landfill
- Demarcation of the sanitary landfill areas and areas for stockpiling
- Cover materials
- Leachate and groundwater collection and treatment facilities,

- Gas collection and treatment facilities
- Monitoring wells (water, air, etc.)
- Wheel washing facility

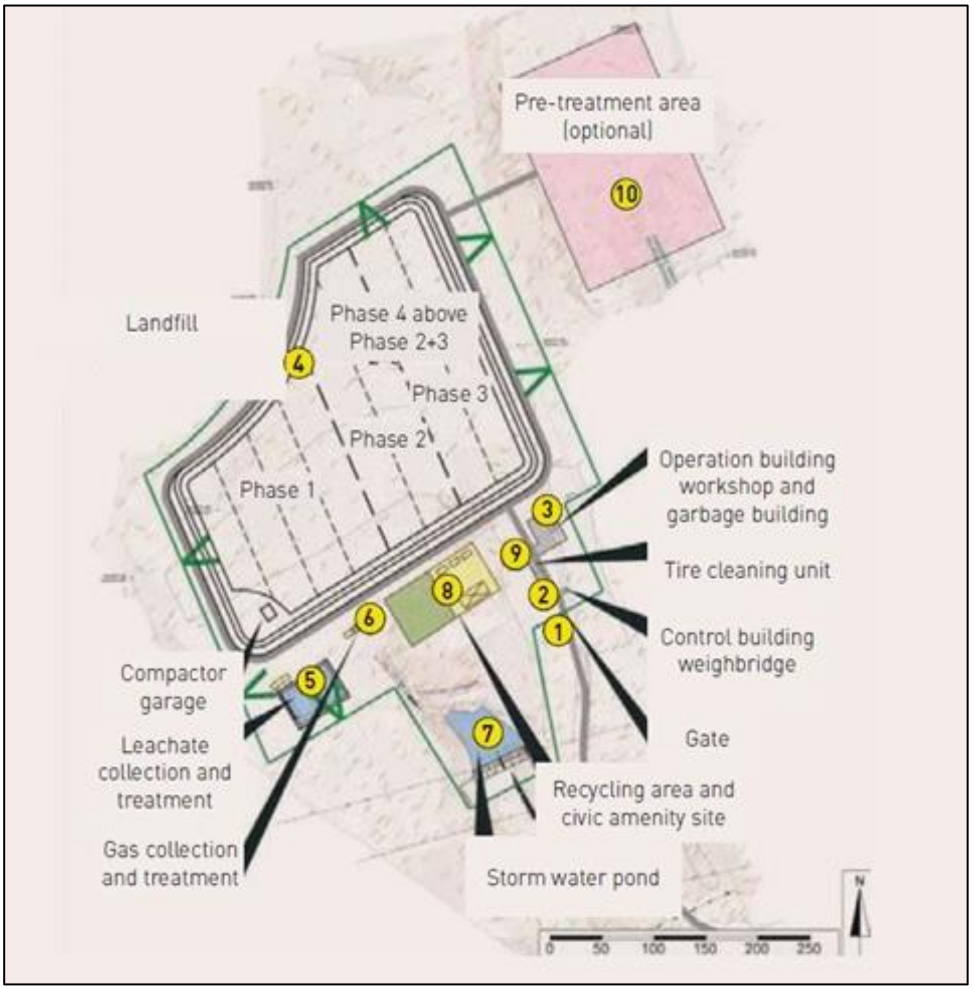


Figure 2.5: Typical layout of the sanitary landfill

The site selection for establishing a sanitary landfill is based on the availability of an adequate area of land, hauling distance from the point of waste generation or transfer station to the landfill, availability of suitable access roads, availability of soil for covering, existing groundwater level, traffic conditions, drainage channels, geologic and hydrologic condition, surface water hydrology, climatic conditions, and environmental condition.

The lining system protects the soil, groundwater, and surface water from landfill leachate by reducing groundwater infiltration and assisting in the management of landfill gas migration. For the design life of the facility, the chosen liner system must achieve constant performance and be compatible with the projected leachate. The liner prevents leachate and its harmful contents from migrating into underlying aquifers or neighboring rivers until it deteriorates, causing spoliation of the local water supply.

The liner system ensures environmental protection through frequent checks and balances. Once the liner system is constructed and approved, the first layer of waste is placed in the cell. The first layer of waste is placed carefully to avoid the puncture of the liner. A leachate collection system shall be provided on top of the liner system to remove leachate accumulated on the liner, which may cause damage to the liner system. Further groundwater collection system shall be provided below the liner system to remove groundwater, which may cause damage to the liner system by uplift force. The components of the liner system are depicted in Figure 2.6.

Leachate management is an important part of the sanitary landfill. A proper leachate management system cut off a sufficient amount of collected leachate from the landfill to avoid the formation of pressurized such that reduce the risk of liner failure and leaks.

Further improper management of leachate will lead groundwater to contaminate if leaked. In such cases, high concentrations of leachate are often found in nearby springs and flushes, which would create adverse impacts on flora and fauna.

A proper leachate management system consists of:

- Liners

  Liners have the ability to stretch and distort without tearing. It should be resistant to puncture, abrasion, chemical damage, ultraviolet light, and temperature variations.

- Leachate collection and drainage system

  The leachate collection and drainage system shall be capable of collecting and discharging the leachate to be generated in the landfill. The system can be installed beneath the waste mass, in trenches beneath the mass, or above the grade of the landfill site base.

- Filters

  The layer of filter (granular or geotextile) is used on top of the drainage network to avoid entering solid matter.

- Leachate treatment system

  The leachate treatment system shall be capable of treating the leachate collected up to the levels as stipulated in the relevant guidelines prior to sending it to the natural environment. Since leachate generated during the decomposition of waste is significantly high with different wastewater characteristics (BOD, COD, TSS, TN, etc.), priority shall be given to design a suitable leachate treatment plant and sludge management shall also be looked into.

Landfill gas is the main product of waste degradation, and its composition changes with the stabilization process of waste, the composition of waste, hydrogeology of the landfill site, and landfill method.

The landfill gas mainly consists of methane and carbon dioxide, including a number of minor constituents in low concentrations. Landfill gas is likely to be produced in large quantities and gathered in the field. As a result, the pressure will be increased, and landfill gas will be diffused anywhere. This uncontrolled diffusion can not only cause air pollution but may cause a fire, even an explosion. Therefore, landfill gases need to be managed for the proper operation of the landfill.

Objectives of a landfill gas management system are to minimize the risk of migration of landfill gases beyond the boundary of the site, minimize the risk of migration of landfill gases into services and building on-site, and avoid the unnecessary entry of air into the landfill and thereby minimize the risk of landfill-oriented fires.

Groundwater and surface water management is of paramount importance when designing a sanitary landfill. Because landfill leachate can pollute groundwater and surface water if it is not properly collected, treated, and safely disposed of, it can percolate through the soil and reach water aquifers. Therefore, landfill design provides provisions for the management and protection of these entities and should ensure that the ingress of groundwater and surface water is minimized and controlled. The accumulation of groundwater under the liner system will result in damage to the liner. Therefore, the groundwater pipes will be laid below the liner system to drain the groundwater accumulated in the landfill area. No raw leachate is permitted to be discharged to surface water sources without treatment.

2.4 Financial and economic perspectives in relation to ISWM

2.4.1 Financial and economic perspectives

MSWM operations consume a large amount of the recurring municipal budget in low- and middle-income cities (Scheinberg et al., 2010). The World Bank and USAID depicted that municipalities in developing countries typically spend 20–50% of their available municipal budget on MSWM operations, which can only reach less than half of their population.

Inefficiencies in the public sector and rising costs have prompted local authorities to consider whether this function could be better delivered by the private sector (Massoud and El-Fadel, 2002). As a result, public-private partnerships (PPP) are becoming increasingly popular as a way to improve the performance of MSWM operations while lowering costs (Abdrabo, 2008). However, financial and economic aspects are to be taken into account more severely to ensure the long-term sustainability of PPP models. However, before making any strategic decisions on how to proceed, it is critical to first gain a thorough grasp of the present costs of providing services and the corresponding revenues (Hoornweg et al., 2005). Both short- and long-term financial costs must be considered, as well as mechanisms for getting consistent revenues to meet these expenditures to ensure financial viability. One of the major barriers in sustaining any MSWM system is the lack of specialized financial monitoring and data analysis (Parthan et al., 2012).

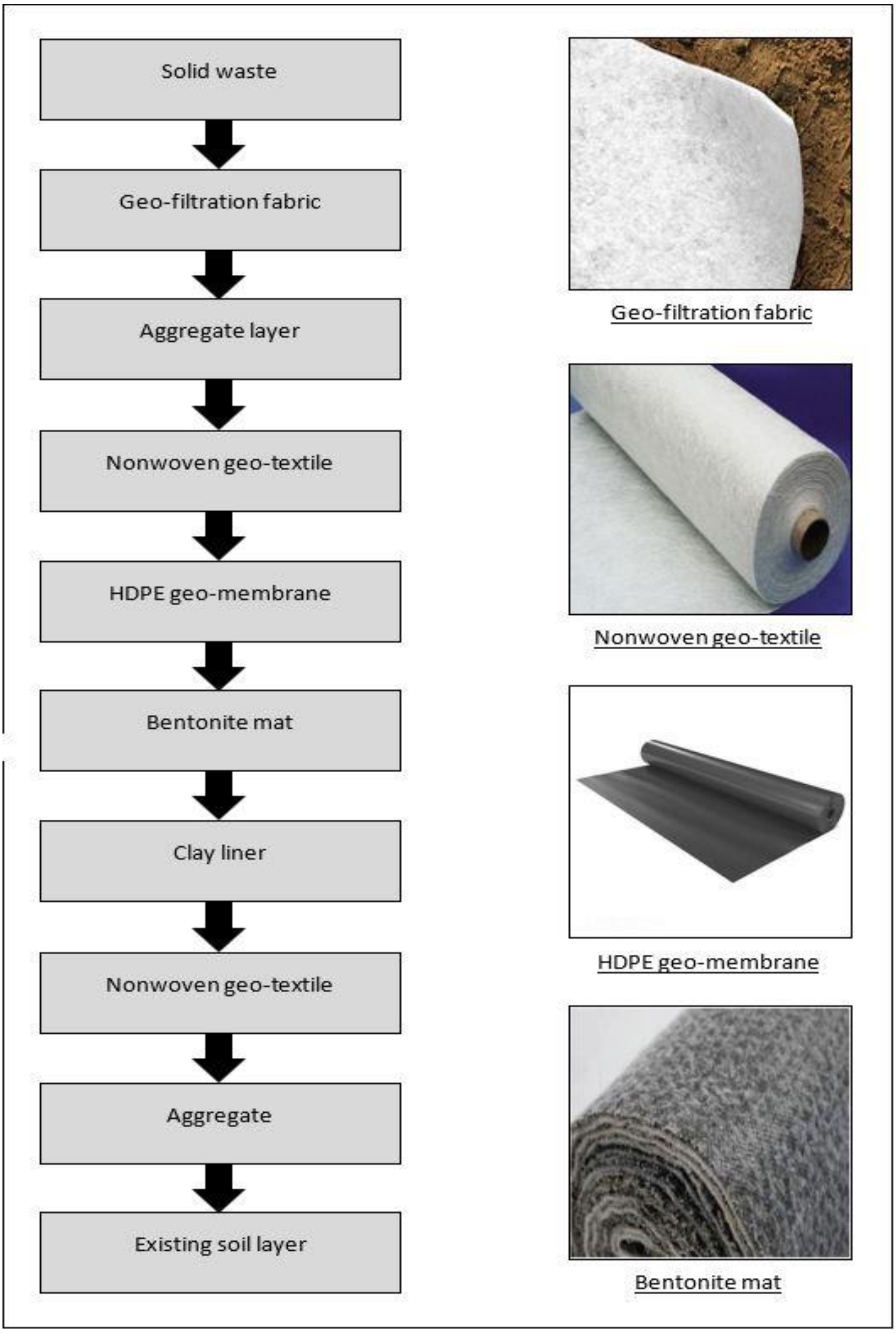
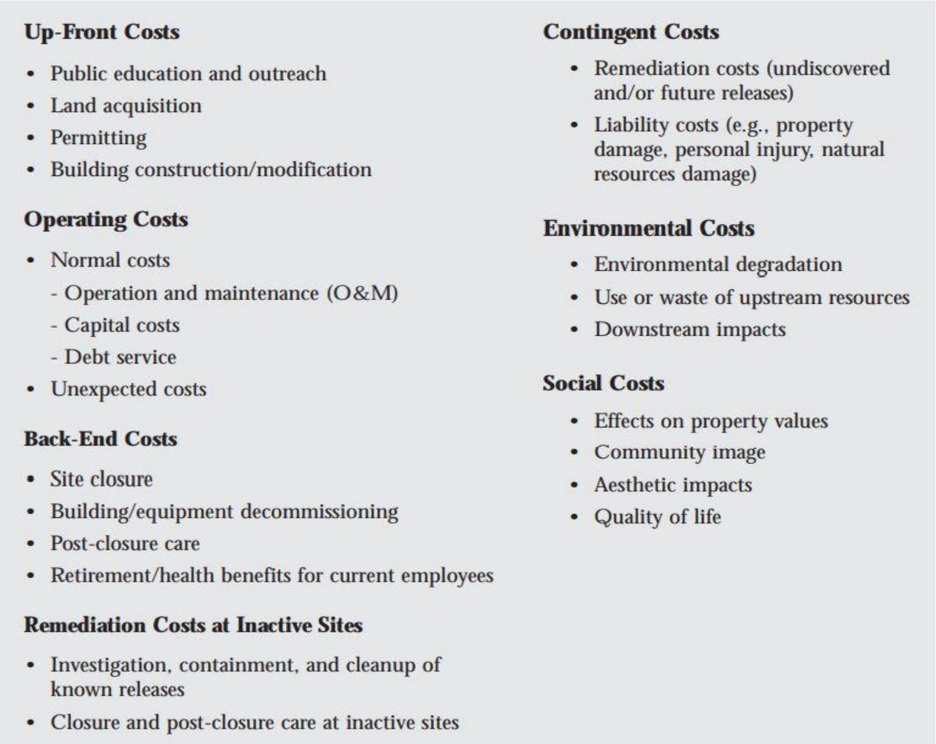


Figure 2.6: Components of the liner system (From top to bottom)

ISWM addresses all aspects of MSWM, including generation, segregation, collection and transport, sorting, recovery, treatment, and final disposal, and each aspect includes various costs and benefits. The cost and benefits are categorized as direct and indirect. Therefore, direct and indirect costs and benefits are to be taken into account to evaluate the life cycle assessment of the ISWM framework developed with the incorporation of circular economy perspectives.

The handbook on "Full Cost Accounting for Municipal Solid Waste Management" published by US EPA summarizes types and examples of costs incurred for MSWM operations (Figure 2.7).

Local taxes or fees for MSWM services (user charges and tariffs), revenue from the sale of compost, liquid fertilizer, recycled materials, energy recovered, gate fees at final disposal sites, and transfers from local or national budgets are all possible sources of revenue. Further, income from permits, rental of assets, profit-sharing deals, and littering fines are all minor sources of revenue (Soos, 2017).



Up-Front Costs

- Public education and outreach
- Land acquisition
- Permitting
- Building construction/modification

Operating Costs

- Normal costs
  - Operation and maintenance (O&M)
  - Capital costs
  - Debt service
- Unexpected costs

Back-End Costs

- Site closure
- Building/equipment decommissioning
- Post-closure care
- Retirement/health benefits for current employees

Remediation Costs at Inactive Sites

- Investigation, containment, and cleanup of known releases
- Closure and post-closure care at inactive sites

Contingent Costs

- Remediation costs (undiscovered and/or future releases)
- Liability costs (e.g., property damage, personal injury, natural resources damage)

Environmental Costs

- Environmental degradation
- Use or waste of upstream resources
- Downstream impacts

Social Costs

- Effects on property values
- Community image
- Aesthetic impacts
- Quality of life

Figure 2.7: Types and examples of costs incurred for MSWM operations

Source: FCA concept (US EPA, 1997)

When environmental and social implications are taken into account, an extended cost-benefit analysis (ECBA) is performed to determine whether a project is economically justifiable. It is carried out by broadening the scope of normal CBA, which assesses the project's planned benefits against estimated costs, to include environmental/social implications as either costs or benefits assessed in monetary terms. It is based on a cost-benefit analysis of the discounted expenses and benefits. The economic analysis entails a cost-benefit analysis of the project in terms of the "with" and "without" project scenarios. It involves the following steps: Identification and evaluation of costs and benefits at economical prices; Comparing of annual streams of costs with benefits and estimation of Net Present Value (NPV), Benefit-Cost Ratio (BCR) and Extended Internal Rate of Return (EIRR) and carrying a sensitivity analysis to assess the effects of changes in the key variables such as costs and benefit on the base criteria.

2.4.2 Circular economy

ISWM is focused on applying the 3R concept based on eco-design, 'closing the loop,' the usage of 'circular economy' principles, and the recyclability of new products (Wilson et al., 2013). The circular economy strives to reduce the quantity of waste produced globally by repurposing it into resources (Salguero-Puerta et al., 2019). According to Winkler (2011), "studies suggested that closing process chains can boost the share of reused or recycled materials up to 80% (instead of 1% with unclosed process chains)." In the long run, a circular economy fulfills both environmental and economic goals because the loops are closed and stirred by the life cycle analysis of products (Erses Yay, 2015). Therefore, the circular economy is a major alternative to the currently dominant linear take-make-consume-dispose economic model (European Environment Agency, 2016). The transition from the take-make-consume-dispose economic model to the circular economy model, which will protect the environment, produce new economic growth, and increase public awareness, is the most adaptable option to improve current MSWM operations (Diaz and Otoma, 2013).

A case study was done in Ho Chi Minh City, Vietnam, in 2017 manifested that there is a greater potential for the circular economy in Ho Chi Minh City because recyclables account for the majority of MSW collected. The study highlighted that the following two options are made available for implementing circular economy approaches in Ho Chi Minh City: recycling the recyclable components of the MSW generated at the household level and recycling of land already utilized for landfilling. Further, the findings show that several reuse options are made available: use landfill materials to a Waste-to-Energy plant for producing energy after landfill mining, reuse reclaimed land after landfill mining, and use the remaining landfill for gasification process in a biogas plant (Schneider et al., 2017).

A study was carried at the University of Lome, Togo, to assess the level of efficiency achieved in terms of the indicators such as waste reduction, reuse, and recycling by introducing the circular economy concept. According to these indications, 59.5% of the MSW generated at the University in 2018 could be composted, and 27.0% of the energy utilized could be replaced by biogas. The entire plastic content was subjected to reuse and sell the rest in the port of the city. The old tyres accumulated within the University premises were used to pave the entire campus roadway, which accounts for 1.5% of the rubber required to pave the entire roadway within the University. As a result of these indications, MSWM within the University could be controlled, and the study recommended that the circular economy concept is appropriate to be applied for the MSWM for the rest of the country (Salguero-Puerta et al., 2019).

A study on “Municipal solid waste in a circular economy perspective” was carried out in Lusaka City in Zambia in 2016. The goal of the study was to see how likely it was to get local businesses involved in solving the problem of MSW by using closed-loop or circular economy production approaches. The study manifested that the circular economy concept has the potential to develop and contribute to the reduction of MSW. Government policies, institutions, and processes, on the other hand, must be adjusted to encourage the development of a circular economy that maximizes waste valorization. Further, the study envisaged that there is an urgent need to change away from the present paradigm currently being practiced in Lusaka City in Zambia, which focuses on large capital costs for landfills and accompanying equipment for the primary purpose of resolving garbage-related public health issues (Chibinda, 2016).

A case study on “Drivers for development of the circular economy” was carried out in Serbia in 2016. This study focused on the drivers, which have a greater impact on MSWM in Serbia, as well as ways to enhance the system by altering the impacts of drivers. The objective is related to the drivers of MSWM in the context of the circular economy. The study highlighted that the majority of MSW (in a mixed form) in 12 Serbian municipalities disposed of at landfills. Slovenian Municipality Ljubljana developed a Zero Waste Concept that resulted in a successful separate collection system, which was aided by the installation of pay-as-you-throw. Europe recommends that resource efficiency be achieved through the Zero Waste Concept to progress towards the circular economy concept. Reduce, reuse, and recycling activities should be promoted to implement the circular economy, which would result in less MSW on landfills and the creation of green jobs at the same time. This study proposes an innovative strategy for integrating the best Zero Waste initiatives in municipalities using the circular economy concept. The findings of the study manifested that the results will provide a solid foundation for waste managers to make future decisions and establish MSWM strategies through the circular economy concept (Ilic and Nikolic, 2016).

A study on “Circular economy of composting in Sri Lanka: Opportunities and challenges for reducing waste-related pollution and improving soil health” was carried out in Sri Lanka in 2016. The findings of the study manifested that composting organic waste minimizes pollution costs associated with open dumping and reduces the amount of land needed for sanitary landfilling. The inter-provincial trade of compost would bring additional income to compost users and also deliver low-priced organic fertilizers to the agricultural zones of the country. The study highlighted that further investments are needed to strengthen the waste management system in Sri Lanka. Compost quality monitoring and certification should be developed to eliminate information asymmetry, increase confidence between producers and end-users, and promote sales. Finally, the government should play an important role by setting suitable institutional legislation, supporting environmental awareness training programs, and providing financial incentives through recycling subsidies (Bekchanov and Mirzabaev, 2018).

A study on “Evaluation of the circular economy potential of plastic waste in Sri Lanka” was carried out in Sri Lanka in 2021. The study manifested that the use of plastic in Sri Lanka is increasing at a rate of 16% per year, with a current consumption of 265,000 megagrams each year. In 2017, the efficiency of the collection and recycling of plastic was determined to be 33% and 33%, respectively. Various scenarios for the year 2025 were explored with the incorporation of plastic waste into Sri Lanka’s Renewable Energy Development Plan (2019–2025). The three main recommendations made by the study to transform to a circular economy for plastic waste are sorting of plastic waste at the source, mining of landfills to collect non-recyclable plastics for producing energy, and incorporation of different sectors (Samarasinghe et al., 2021).

Many barriers remain for developing the circular economy for MSWM operations in developing countries. Some of the barriers are lack of financial sustainability, existence of informal enterprises, and requirement of technological infrastructure (Alam et al., 2008; Ragazzi et al., 2014). Due to environmental, social, economic, and political differences, no circular economy model developed for MSWM practices can be considered similar in every context. Furthermore, there are many differences between MSWM practices carried out by megacities and small communities due to the financial commitments, quantities, composition, social behaviors, and some other factors. Therefore, it is of utmost importance to develop an ISWM model for MSWM with the incorporation of the circular economy concept, which is specific to the local authority, state, or country.

3. METHODOLOGY

This chapter explains the methodologies adopted to achieve the specific objectives as set out under Chapter 1.

3.1 Methodology to evaluate the present status of MSWM practices carried out by Kekirawa Pradeshiya Sabha

The present status of MSWM practices carried out by Kekirawa Pradeshiya Sabha was evaluated in terms of generation, source-segregation, collection and transport, and final disposal of MSW through a questionnaire survey, field visits, meetings with officials involved in existing MSWM practices, and literature survey. The current institutional and policy aspects applicable to the MSWM in Kekirawa Pradeshiya Sabha were also addressed.

A questionnaire was developed to collect details required to assess the present status of MSWM practices carried out by Kekirawa Pradeshiya Sabha. The questionnaire survey was formulated under six sub-sections covering all aspects of MSWM, and each sub-section addressed the following:

1. General

   Sub-section 1 was aimed to collect background details such as Grama Niladhari Divisions, demography, and zoning plan of Kekirawa Pradeshiya Sabha. The details on personnel engaged in MSWM practices and budget allocations on MSWM in the last three consecutive years by Kekirawa Pradeshiya Sabha were also requested under sub-section 1.

2. Generation and source-segregation of MSW

   Sub-section 2 was aimed to collect details on the generation and source-segregation of MSW within the territory of Kekirawa Pradeshiya Sabha. Under MSW generation, the details on quantities, sources, and composition of MSW generated within the territory of Kekirawa Pradeshiya Sabha were collected. Under source-segregation, whether source-segregation is practiced by residents or not, categories of MSW segregated, current practices on managing MSW by residents, and details of the activities carried out to encourage source-segregation by Kekirawa Pradeshiya Sabha were collected.

3. Collection and transport of MSW

   Sub-section 3 was aimed to collect details on the collection and transport of MSW carried out by Kekirawa Pradeshiya Sabha. The details on frequency and quantity of MSW collection, parties involved in MSW collection, methods deployed for MSW collection, schedule of MSW collection, vehicular fleet used for MSW collection and transport, and the details of trips completed by each garbage-collecting vehicle.

4. Transfer station

   Sub-section 4 was aimed to collect details on a transfer station, if available in Kekirawa Pradeshiya Sabha. Accordingly, the details on the type of the transfer station, location, area, years of operation, quantities of MSW receiving and discharging per day, whether sorting operations are carried out at the transfer station or not, major categories and quantities of MSW sorted, and transport MSW from the transfer station to final disposal sites were collected. Further, details on the transport of MSW from the transfer station to the final disposal site were discussed in this section.

5. Pre-treatment and final disposal of MSW

   Sub-section 5 was aimed to collect details on pre-treatment and final disposal techniques currently being practiced by Kekirawa Pradeshiya Sabha. The details on methods deployed to pre-treat and dispose of different types of MSW, quantities, frequencies, and details of the final disposal site, including vehicular fleet used at the final disposal site, were collected. Any complaints received from the public and negative impacts recorded due to such final disposal techniques were collected. The mitigatory measures have been taken by Kekirawa Pradeshiya Sabha to minimize such impacts, and progress of such measures was also collected.

6. Institutional and managerial aspects

   Sub-section 6 was aimed to collect details on institutional and managerial aspects related to the MSWM in Kekirawa Pradeshiya Sabha. The issues identified during generation, source-segregation, collection and transport, and final disposal of MSW were recorded, and suggestions to mitigate such issues identified were asked. Further, expectations from government/donor agencies/NGO for carrying out smooth MSWM operations, external forces that disturb the smooth MSWM operations, awareness and adequacy of current laws, regulations, and legislation related to MSWM, and economic perspectives at national and local levels to be implemented to improve the current MSWM practices were addressed.

The chairman, technical officer, supervisors, drivers, and laborers who are involved in current MSWM practices of Kekirawa Pradeshiya Sabha were interviewed to complete the questionnaire survey to be required to assess the present status of MSWM practices carried out by Kekirawa Pradeshiya Sabha. The details collected were verified through conducting site visits, discussions had with residents and officials in other government and non-government organizations, and carrying out a comprehensive literature review. Further, the present status of MSWM practices carried out by the Kekirawa Pradeshiya Sabha was evaluated through the discussions had with the public (10 Nos.), who are government-sector employed, private-sector employed, and self-employed.

The questionnaire survey report is attached in Annexure 3.1.

3.2 Methodology for the development of an ISWM framework based on the circular economy perspectives and under the purview of the present administrative framework

The ISWM framework was developed based on the Draft National Environmental Policy, 2021 prepared by the Ministry of Environment, the government’s new policy on “Vistas of Prosperity and Splendor,” the National Physical Plan prepared by the Department of Physical Planning, and other laws, regulations, and legislation applicable to MSWM in Sri Lanka as explained under Chapter 2.

The ISWM framework developed with the incorporation of circular economy perspectives was based on the following key considerations:

1. The generation of MSW is reduced through the application of the 3R concept. Necessary actions are to be taken by respective local authorities to make aware people to minimize the generation of MSW.

2. The source-segregation of MSW is required to be practiced by people. The MSW are sorted into biodegradable waste, recyclable waste, construction and demolition waste, street sweeping and drain cleaning waste, and non-biodegradable waste.

3. The collection and transport of MSW are carried out by respective local authorities effectively and efficiently. The collection is carried out only if MSW are sorted into the above-mentioned categories. The collection routes are optimized, and an adequate vehicular fleet is to be involved in the collection and transport of source-segregated MSW.

4. The biodegradable fraction of the MSW collected undergoes composting. Windrow composting is recommended to be practiced. The compost produced undergoes a value addition process to enhance the final quality of the compost product. The excess leachate generated is used for manufacturing liquid fertilizers. The leachate undergoes a value addition process to enhance the final quality of liquid fertilizer produced.

5. The recyclable fraction of the MSW collected is collected and sold to third-party recyclable waste collectors. Such materials are reused.

6. The construction and demolition waste collected is pre-processed and sold. Such materials are used for filling operations. A part of the materials is reused. Residues are disposed of at a controlled landfill.

7. The non-biodegradable fraction of the MSW, together with street sweeping and drain cleaning waste and a part of the residues from composting, are disposed of at the controlled landfill. A part of the materials disposed of at the controlled landfill is decayed, and the residues are mined and sent to a Waste-to-Energy project to produce electricity. Thereby, the operations of the controlled landfill can be continued.

8. The legal and administrative framework needs to be strengthened to ensure the smooth operation of the proposed ISWM framework.

The suitability of the proposed ISWM framework explained above was analyzed for Kekirawa Pradeshiya Sabha in terms of MSW generation, source-segregation, collection and transport, pre-treatment, and final disposal, and the details are explained below.

1. MSW generation

The design period of the proposed ISWM framework to be implemented in the Kekirawa Pradeshiya Sabha was ten years. The selection of the 10-year design period was made due to the availability of a limited area to develop the proposed ISWM facility. However, all the structures were designed for 30 years.

If greater design periods are considered, phase-wise developments will be carried out to utilize spaces allocated for different unit processes effectively. Since the land area available to develop the proposed ISWM facility in Kekirawa Pradeshiya Sabha is limited, phase-wise developments were not encouraged.

It was assumed that the rate of increase of MSW generation is proportional to the rate of increase of population within the territory of Kekirawa Pradeshiya Sabha, and it was 1.1% per year as per the statistics by the Department of Census and Statistics, Sri Lanka for the period of 2013–2019. The MSW generation within the territory of Kekirawa Pradeshiya Sabha at the end of the design period (ten years) was calculated using Equation 1.

$$\mathrm{Y} = 365 \times \mathrm{W} \times (1 + 0.01\mathrm{X})^{\mathrm{n}} \tag{1}$$

where Y is the MSW generation within the territory of Kekirawa Pradeshiya Sabha at the end of the design period (ten years), W is the current MSW generation within the territory of Kekirawa Pradeshiya Sabha, X is the rate of increase of MSW generation per year, and n is the design period of ten years.

2. Source-segregation of MSW

The proposed ISWM framework highly promoted source-segregation as it is a mandatory requirement to be satisfied to ensure the smooth operation of the proposed ISWM framework with optimal use of employees and resources. The MSW generated is sorted into the following categories:

- Biodegradable waste
- Recyclable waste
- Construction and demolition waste
- Street sweeping and drain cleaning waste
- Non-biodegradable waste.

The composition of MSW generated within the territory of Kekirawa Pradeshiya Sabha is depicted in Table 3.1.

Table 3.1: Composition of MSW generated

Category of MSW	**Composition**
Biodegradable waste	60%
Recyclable waste	10%
Construction and demolition waste	< 0.5 MT/day
Street sweeping and drain cleaning waste	< 0.1 MT/day
Non-biodegradable waste	30%

Source: Data available at Kekirawa Pradeshiya Sabha

It was assumed that no significant changes are expected to the composition of MSW within the territory of Kekirawa Pradeshiya Sabha during the design period of ten years.

3. Collection and transport of source-segregated MSW

It was planned to increase the collection of the source-segregated MSW up to 50% from the 17% of the current collection of mixed waste by Kekirawa Pradeshiya Sabha. The collection of the source-segregated MSW is not carried out in areas within the territory of Kekirawa Pradeshiya Sabha, where population density is less than 100 persons/km^2. Because the collection in those areas where the population density is 100 persons/km^2 is not feasible due to the higher cost incurred for the collection and transport of minor quantities of source-segregated MSW.

Since it was planned to increase the quantity of source-segregated MSW up to 50%, the current vehicular fleet is required to be strengthened to manage the expected quantity. The present status of the current vehicular fleet was evaluated, and additional vehicles were proposed. Further, the routes where the collection of mixed waste is carried out by Kekirawa Pradeshiya Sabha was evaluated, and a new collection network was proposed to optimize the average time taken per trip, the average distance traveled per trip, and cost incurred per trip.

4. Final disposal of MSW

A compost plant, resource center, and controlled landfill were proposed to be established by the proposed ISWM framework to manage the biodegradable, recyclable, and non-biodegradable fractions of the source-segregated MSW collected within the territory of Kekirawa Pradeshiya Sabha, respectively. The selection of a controlled landfill rather than a sanitary landfill is mainly based on the unavailability of a 150 m buffer zone around the landfill, which is a mandatory requirement to be satisfied for constructing a sanitary landfill as stipulated under the “Technical Guidelines on Solid Waste Management in Sri Lanka” prepared by CEA and due to the higher capital cost. The non-biodegradable fraction of the source-segregated MSW together with a part of the residues from the compost plant and street sweeping and drain cleaning waste are disposed of at the controlled landfill. A part of the waste materials disposed of at the controlled landfill is degraded with time, and thereafter, the landfill is mined, and waste materials will be sent to a Waste-to-Energy project.

Thereby, the landfill operations can be extended. The government expects a Waste-to-Energy project by involving the private sector under the PPP model to be established in the North-Central region to permanently address non-perishable MSW generated in the region.

A conceptual design of the proposed ISWM facility to be implemented in Kekirawa Pradeshiya Sabha was carried out to obtain costs and revenues incurred during the construction and operation stages. The costs and revenues were used to evaluate the financial and economic feasibility of the proposed ISWM framework for Kekirawa Pradeshiya Sabha. The conceptual design of the proposed ISWM facility for Kekirawa Pradeshiya Sabha was carried out based on the following data, information, assumptions, etc., and the details are depicted in Table 3.2.

Table 3.2: Data, information, assumptions, etc., used for the conceptual design

Component	**Data/information/Assumptions/etc.**	**Reference**
Compost plant	Density of the MSW in unconsolidated form is 300 to 400 kg/m^3	Katiyar et al., 2013
	Density of the MSW in consolidated form is 600 to 700 kg/m^3	Kavazanjian, 2001
	Operational capacity of the shredding machine is 4 MT/day	Manufacturer’s details
	Operational capacity of the sieving machine is 2 MT/day	Manufacturer’s details
	Volume reduction during composting is 20–60%	BC Agricultural Composting Handbook, 1998
	Moisture content of the final compost product is less than 40%	
	Weight reduction during composting is up to 50%	
Controlled landfill	Density of the MSW in consolidated form is 600 to 700 kg/m^3	Kavazanjian, 2001

The following codes of practice, guidelines, standards, etc., were referred to for carrying out the conceptual design of the proposed ISWM facility for Kekirawa Pradeshiya Sabha.

- Technical Guidelines on Solid Waste Management in Sri Lanka by CEA
- SLS 1246:2003 - Specification for Compost from Municipal Solid Waste and Agricultural Waste
- SLS 544 - Code of Practice for Handling and Storage of Bagged Fertilizers
- Planning and Building Regulations by UDA
- Building Regulations by Kekirawa Pradeshiya Sabha
- Discharge Standards of Treated Effluent for Irrigation Purposes as stipulated in the Gazette Extraordinary No. 1534/18 of 01.02.2008
- Draft Specification for Liquid Organic Fertilizers by Sri Lanka Standard Institution

Further, the following concepts/aspects/facilities were also embedded in the proposed ISWM framework developed, and the key features to be provided under each concept/aspect/facility to the proposed ISWM facility in Kekirawa Pradeshiya Sabha are explained in sub-sections 4.2 and 4.3.

1. Circular economy concept

The circular economy perspectives were embedded in the proposed ISWM framework with the aim of reducing the quantities of residues to be disposed of at landfills. The non-biodegradable and non-recyclable fractions of the source-segregated MSW together with a part of the residues from the compost plant and street sweeping and drain cleaning waste are disposed of at controlled landfill. A part of the waste materials disposed of at the controlled landfill is degraded with time, and thereafter, the landfill is mined, and waste materials will be sent to a Waste-to-Energy project. Thereby, the landfill operations can be extended. Further, the details of the MSWM techniques to be adopted together with options for reusing by-products are explained under sub-section 3.3.

2. 3R concept

The 3R concept was embedded in the proposed ISWM framework with the aim of reducing the quantities of residues to be disposed of at landfills by promoting “Reduce,” “Reuse,” and “Recycle.” The proposed ISWM framework highly recommended the 3R concept to be applied from the source of generation until the final disposal. The public awareness and capacity-building aspects were promoted by the proposed ISWM framework to promote the 3R concept.

3. Sustainability concepts

The sustainability concepts were embedded in the proposed ISWM framework with the aim of reducing mainly the environmental pollution due to MSWM operations. Under environmental sustainability, the quantities of the emission of greenhouse gases from different final disposal techniques were carefully evaluated, and the techniques, which emanate fewer quantities of greenhouse gases were given priority. The 3R concept and circular economy concepts also comply with sustainability concepts. The management of leachate was carefully considered; hence, pollution of groundwater, surface water, air, and soil will be minimized. Further, disturbances to the natural and manmade ecosystems are minimized.

Sustainability in terms of social and economic perspectives is considered under sub-section 3.4. The different types of MSW sorted were proposed to be treated based on the closed-loop approach to reduce the overall environmental, social, and economic impacts of the proposed ISWM framework.

4. Green infrastructure

The green infrastructure aspects were embedded in the proposed ISWM framework, as green infrastructure is reckoned to be building blocks providing ingredients for improving urban and climate change resilience by mimicking nature, reducing carbon, water, and energy footprints.

Rainwater harvesting, leachate reticulation, use of solar energy, natural lighting, and natural ventilation, use of permeable paving blocks, plant canopy trees around final disposal sites, and use of renewable materials or materials with low embodied energy for construction works were taken into consideration for the proposed ISWM framework.

5. Inclusive infrastructure

The inclusive infrastructure aspects were embedded in the proposed ISWM framework to ensure gender inclusiveness within the workforce to be involved in the operation stage of the proposed ISWM framework effectively and efficiently. It was planned to involve the female workforce also in the operation of the proposed ISWM framework; hence, gender-inclusive features were taken into account.

Some of the gender-inclusive features considered were the provision of sanitary facilities, changing rooms, lockers for private belongings, restrooms with first-aid facilities, and separate areas for having meals. Security-related infrastructure would be made available to reinforce a fearless working environment. The proposed ISWM framework addressed the list of activities that can be handled through the female workforce.

6. Competitive infrastructure

The competitive infrastructure aspects were embedded in the proposed ISWM framework to ensure the smooth operation of the proposed ISWM framework. Provision of 3-phase electricity, pipe-borne potable water, lightning arrestors, internal and external access roads, lighting, safety, security, stormwater drainage, and wastewater treatment and disposal were embedded in the proposed ISWM framework. Improved IT facilities are incorporated into the proposed ISM framework to improve the efficiency of the collection and transport of MSW.

7. Climate change and disaster risk resilience features

The climate change and disaster risk resilience features were embedded in the proposed ISWM framework to ensure the smooth operation of the proposed ISWM framework. Flood, fire, explosion, and asphyxiation hazards, extreme climate conditions such as gusty weather, extreme droughts were taken into consideration during the development of the proposed ISWM framework.

3.3 Methodology for the development of technology options of the proposed ISWM framework

The technology options of the proposed ISWM framework were selected based on the capital cost, O&M cost, availability of funds, social and environmental concerns, topography, geology, land-use patterns, availability of technical know-how and capacities, and legal enforcement.

The details of technology options proposed for Kekirawa Pradeshiya Sabha under the proposed ISWM framework are explained below. The technology options made available for carrying out non-engineering MSWM practices such as open dumping, open burning, plowing in fields, hog feeding, grinding, and discharging into sewers were not considered for the study.

1. Value addition to final compost product

The characteristics of the final compost product generated from the compost plant to be established in Kekirawa Pradeshiya Sabha under the proposed ISWM framework was evaluated in terms of the characteristics such as pH, nitrogen, phosphorous, potassium, magnesium, calcium, and organic carbon levels, and measured values were compared with the SLS 1246:2003 - Specification for Compost from Municipal Solid Waste and Agricultural Waste. The quantities of additives added to enhance the quality of the final compost are based on the existing levels of the parameters mentioned above.

This study focused only on enhancing nitrogen content in the final compost product up to 1% as stipulated in SLS 1246:2003 - Specification for Compost from Municipal Solid Waste and Agricultural Waste. Therefore, a powdered form of Calcium Nitrate was added to enhance the existing level of nitrogen to 1%. The only water-soluble source of calcium available to plants is calcium nitrate fertilizer. It can be used as a fertilizer as well as a disease control agent (Bonnie, 2021). The Sodium Adsorption

Ratio (SAR) was measured once a year to verify whether no excess Calcium is made available in the soil where value-added final compost product is applied.

2. Value addition to leachate

The typical quantities of leachate generation during composting are 75–100 L/MT (Hashemi et al., 2017; Liu et al., 2015, 2010). The recirculation of leachate reduces the total quantity of leachate production by 47.1% (Bilgili et al., 2007). The density of leachate is 1,010 kg/m^3 (Cardoso et al., 2019). The characteristics of the leachate generated from the compost plant to be established in Kekirawa Pradeshiya Sabha under the proposed ISWM framework were evaluated in terms of the characteristics such as pH, electrical conductivity, total nitrogen, total potassium, total phosphorus, and organic carbon. The measured values were compared with the Draft Specification for Liquid Organic Fertilizers by Sri Lanka Standard Institution. The quantities of additives added to enhance the quality of leachate are based on the existing levels of the parameters mentioned above. This study focused only on enhancing nitrogen content up to the level as stipulated in the Draft Specification for Liquid Organic Fertilizers by Sri Lanka Standard Institution. Therefore, Calcium Nitrate was added to enhance the existing level of nitrogen in leachate to the minimum level as stipulated in the Draft Specification for Liquid Organic Fertilizers by Sri Lanka Standard Institution. The only water-soluble source of calcium available to plants is calcium nitrate fertilizer. It can be used as a fertilizer as well as a disease control agent (Bonnie, 2021). The SAR was measured once a year to verify whether no excess Calcium is made available in the soil where value-added liquid fertilizer product is applied.

3. Deodorization system

A deodorization system was designed to control the pungent odor that emanates from the following areas.

- Unloading area
- Waste disposal area of the controlled landfill
- Leachate collection tank and network
- Garbage-collecting vehicles

Effective microorganisms (EM) were used to remove bad odor emanates in compost plants (Higa, 2000). The EM bacterial solution has currently been used in several large-scale final disposal sites: Karadiyana dumping site, Kerawalapitiya compost plant, and Aruwakkalu sanitary landfill. Therefore, EM bacterial solution was planned to be used for the odor control in the proposed ISWM facility to be implemented in Kekirawa Pradeshiya Sabha.

4. GPS tracking system

GPS tracking system for garbage-collecting vehicles and other mobile machinery is important to improve the efficiency of the proposed ISWM system to be implemented in Kekirawa Pradeshiya Sabha. Garbage-collecting vehicles from the source of generation of MSW to the final disposal sites are often in operation every day. However, the routes through which they travel may not be the same every day. Hence, the efficiency of such vehicles could not be assessed without a GPS tracking system. Further, the other machinery at work in the compost plant and controlled landfill needs to work for a dedicated number of hours before service. Such data may not be possible to gather without the GPS tracking system. The GPS tracking devices are mounted or fitted in a secured location of vehicles and machinery. With the system being ready, one can track the vehicle easily utilizing a mobile phone by dialing the portable number of the SIM joined to the GSM modem. In such a case, the information could be retrieved as a short message on the mobile phone. This framework permits tracking the vehicle easily.

3.4 Methodology for carrying out economic analysis for the long-term sustenance of the proposed ISWM framework

A detailed economic analysis was carried out to ensure the economic viability of the proposed ISWM framework to be applied to Kekirawa Pradeshiya Sabha for long-term sustenance. A financial analysis was carried out at first, and then an economic analysis was carried out.

3.4.1 Financial analysis

The total income and expenditure of the proposed ISWM facility to be implemented in Kekirawa Pradeshiya Sabha was estimated during the analysis, and a separate project cash flow was prepared.

The details of the capital cost incurred during the construction phase and O&M cost incurred during the operation phase are depicted in Table 3.3.

Table 3.3: Details of the cost incurred during construction and operation phases

Construction phase	**Operation phase**
Preliminary investigations • Survey works • Baseline monitoring • Hydrological study • Design of proposed features (compost plant, controlled landfill, etc.) • Soil investigations Promoting source-segregation • Distribution of leaflets • Propaganda campaign through public announcements • Conducting awareness sessions with the help of Public Health Inspectors Collection and transport • Distribution of leaflets, Propaganda campaign through public announcements	Environmental monitoring • Environmental monitoring aspects, including gas emissions in the controlled landfill, water quality in the nearby canal network, groundwater quality Promoting source-segregation • Distribution of leaflets • Propaganda campaign through public announcements from time to time during operations • Conducting awareness sessions Collection and transport • Preventive maintenance of all vehicles involved in the collection • Corrective maintenance of all vehicles involved in the collection • Major repair for vehicular fleet

• Procurement of garbage compactor of 6–8 m^3 • GPS-assisted garbage-carrying vehicular tracking system for tracking vehicles Compost plant • Construction of compost plant • Construction of main office/ administration space/dining, resting, and washrooms for workers • Construction of stormwater drainage system • Construction of leachate collection, storage, reticulation, treatment, and disposal system • Construction of wastewater collection, treatment, and disposal system • Construction and water supply system • Construction of infrastructure facilities • Construction of wheel washing facility • Construction of deodorization system • Purchasing of vehicles, machinery, and equipment • Purchasing of office equipment	• Management of GPS-assisted garbage-carrying vehicular tracking system • Fueling for the vehicular fleet (Assuming eight vehicles running 40 km on average for a day) Compost plant • Training for employees • Machinery and equipment maintenance • Fuel cost for machinery • Electricity, water, telecommunication • Cost of bacterial solutions for odor control (bacterial solution will be sprayed to the landfill and compost plant, if necessary) • Packaging of finished compost (Two workers for packaging finished compost product - 3 MT/day) • Packaging of finished liquid fertilizer (Two workers for packaging finished liquid fertilizer product – 500 L/day) • Value addition to the compost and testing of final quality • Value addition to the liquid fertilizer and testing of final quality

• Supply and installation of CCTV system • Purchasing of personnel protective gears • Obtaining approvals <u>Recycling and reusing waste</u> • Distribution of leaflets, propaganda campaign through public announcements <u>Controlled landfill</u> • Construction of controlled landfill, including liner system, tipping pad, leachate collection network, etc. • Construction of infrastructure facilities • Construction of the construction and demolition waste yard • Construction of the constructed wetland	• Main office/administration cost, including stationery • Building maintenance cost • CCTV network maintenance • Approval renewals (EPL) • Cost for personal protective equipment for employees • Welfare and medical expenses for employees (for 57 employees) • Cost of maintaining the security <u>Recycling and reusing waste</u> • All costs related to the resource center are mentioned under composting section <u>Controlled landfill</u> • Supply of soil for daily cover, temporary roads, bunds, etc. • All the other costs related to the landfill site is allocated under composting • Tipping fee of SLR 3,000 to the Waste-to-Energy plant by Kekirawa Pradeshiya Sabha <u>Salaries and wages</u> • Salaries and wages (including new recruitments) - 57 personnel, both permanent and temporary

A detailed bill of quantities (BOQ) prepared for the proposed ISWM facility to be implemented in Kekirawa Pradeshiya Sabha is attached in Annexure 3.2.

With the proposed ISWM facility to be implemented in Kekirawa Pradeshiya Sabha, there will be more income-generation streams from which a part of O&M cost could be recovered. The details of the revenues during the operation phase are depicted in Table 3.4.

Table 3.4: Details of the revenues during the operation phase

Source of revenue	**Details**
Collection tariff from commercial establishments	A tariff from 200 commercial establishments that have the capability to pay tariff under the "Polluter Pays Principle" are expected to be collected. It was planned to collect SLR 1000 per entity.
Selling of recyclables	Based on the previous records available at Kekirawa Pradeshiya Sabha, it was planned to earn SLR 12,000 per month by selling recyclable waste.
Selling of construction and demolition waste for filling	It was planned to earn SLR 10,000 per month by selling processed construction and demolition waste.
Selling of final compost product	The expected quantity of value-added final compost product was 3,000 kg/day. The 1 kg of the final product was planned to be sold at the cost of SLR 25. The price increase of fertilizer is 10% (Pandyaswargo, 2014).
Selling of liquid fertilizers	The expected quantity of value-added liquid fertilizer was 400 L/day. The 1 liter of the final product was planned to be sold at the cost of SLR 40. The price increase of fertilizer is 10% (Pandyaswargo, 2014).
Accepting MSW under emergency case	It was planned to accept MSW from other local authorities under emergency conditions at the cost of SLR 1,500/MT.

Once expenditures and revenues were calculated, the financial analysis was carried out based on the following assumptions.

- All values are presented in SLR.
- The physical contingencies are calculated at 5% from the base cost estimates.
- The analysis period is 24 years, of which 23 years are operational.
- The construction, operation, and maintenance cost have been calculated based on the current market rates.
- The revenues are calculated based on the existing market conditions, including demand and supply factors.
- The major repairs in the vehicular fleet are first assumed to have occurred in five years from the base year and then once in three years.
- The discount rate is considered as 5%.
- The general increase in O&M cost and revenue is considered as the mean inflation rate for the past ten years, which is 5.62%.
- The estimated price increment in liquid and solid fertilizers is 10%.

The capital cost is spent from the first year onwards, and the O&M cost is spent from the second year onwards. From the third year, the general increase in price was considered. The average Sri Lankan inflation rate (Pandyaswargo, 2014) of 5.62 (Central bank of Sri Lanka, 2019) was incorporated for the annual cost increase, and the interest rate of 10% was employed as the discount rate for the Net Present Value (NPV) calculation. The general increase in price was calculated by using Equation 2.

$$\text{O\&M cost in 2022} = \text{O\&M cost in 2021} \times 1.05626 \tag{2}$$

where O&M cost is O&M cost. Equation 2 was used to calculate O&M cost in other years as well.

Based on the cash flow, the financial viability of the project was assessed by developing the financial indicators; NPV and Internal Rate of Return (IRR). NPV was calculated using Equations (3) and (4).

$$\text{PV}\ (Costs\ or\ Revenues) = \frac{FV\ (Costs\ or\ Revenues)}{(1+r)^t} \tag{3}$$

where FV is the future value, PV is the present value, r is the discount rate, and t is the time period.

$$\text{NPV} = \text{PV (Revenues)} - \text{PV (Costs)} \qquad (4)$$

3.4.2 Economic analysis

Since the financial analysis carried out for the proposed ISWM facility to be implemented in Kekirawa Pradeshiya Sabha was not feasible, an extended cost-benefit analysis was done. Under the extended cost-benefit analysis, indirect costs and benefits were taken into consideration other than the aspects considered during financial analysis.

Economic benefits can be direct and indirect. Direct benefits are encountered in financial analysis. Indirect benefits are not encountered in financial analysis and are not represented by cash flows. Some of the indirect benefits considered for the economic analysis are explained below.

Reduction of the emission of GHG

The estimation of the emission of GHG was done based on the First Order Decay (FOD) method developed by the Intergovernmental Panel on Climate Change (IPCC). The FOD method assumes that the biodegradable fraction of the waste decays slowly for a few decades, and during which carbon dioxide, methane, and nitrous oxide are formed.

The methane generation was calculated using Equation 5 (IPCC, 2006).

$$\text{Methane generation} = \left(\mathrm{W} \times \mathrm{MCF} \times \mathrm{DOC} \times \mathrm{DOC_F} \times \mathrm{F} \times \frac{16}{12}\right) \times (1 - \mathrm{R}) \times (1 - \mathrm{OX}) \qquad (5)$$

where W is the total quantity of MSW disposed of at a waste disposal site (Gg/year), MCF is the methane correction factor, DOC is the degradable organic carbon fraction, $\mathrm{DOC_f}$ is the fraction of DOC dissimilated, F is the fraction of methane in landfill gas, 16/12 is the conversion of carbon to methane, R is the recovered methane (Gg/year), and OX is the oxidation factor.

The DOC was calculated using Equation 6.

$$DOC = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D) \quad (6)$$

where A is the weight percentage of paper and textile, B is the weight percentage of the garden, park waste, and other non-food organic perishables, C is the weight percentage of food waste, and D is the weight percentage of wood and straw waste in the MSW (wet basis) collected.

Once methane generation was calculated, the equivalence CO_2 value was calculated by multiplying the methane generation by 36, which was taken as the Global Warming Potential (GWP) of methane (Vallero, 2019). The monetary value of global warming impact was calculated by multiplying the calculated carbon equivalence value by $13.2 (Johari et al., 2012). This value was converted to Sri Lankan rupees by multiplying it by the current exchange rate of Sri Lanka.

The methane generation was calculated before and after implementing the proposed ISWM framework in Kekirawa Pradeshiya Sabha. Thereby, the reduction of methane generation was calculated. The indirect benefit gained through the reduction of the emission of GHG were taken into account for economic analysis.

Methodology for carrying out economic analysis

A separate cash flow was prepared, including the capital cost, O&M cost, direct revenues, and indirect benefits. The following assumptions were made for the economic analysis.

- All costs are based on the current exchange rates.
- The economic costs of capital works and annual O&M costs are calculated based on the financial cost estimates.
- The economic opportunity cost of capital (EOCC) is assumed at 9% in real terms. If each component's Economic Internal Rate of Return (EIRR) exceeds the EOCC, it can be concluded to be economically viable.

- The analysis was conducted from 2020 to 2044, including 1-year of construction with 23 years of operation period upon completion of construction.
- The economic analysis assessed the economic viability in terms of EIRR and economic net present value (ENPV).

4. RESULTS

This chapter explains the results obtained under each specific objective as set out under Chapter 1.

4.1 Present status of MSWM practices carried out by Kekirawa Pradeshiya Sabha

The data and information presented in this sub-section were extracted from the questionnaire survey prepared with the consultation of personnel involved in the MSWM practices carried out by Kekirawa Pradeshiya Sabha.

4.1.1 MSW generation and composition

The MSW generation at present in Kekirawa Pradeshiya Sabha is approximately 41 MT/day. The major source of MSW generated is residential. The commercial developments located in the Kekirawa Pradeshiya Sabha area contribute to the total MSW generated on a moderate scale. The contribution from different sources to the total MSW collected are given in Table 4.1.

Table 4.1: Contribution from different sources to the total MSW collected and its predominant types

Sources of MSW	Predominant type of waste
Household	Organics
Commercial (hotels, markets, etc.)	Organic/polythene/plastic
Institutional (police station, schools, etc.)	Organics
Street sweepings, dirt from canals	Grit/soil/grass
Construction and demolition	Inert materials
Industrial (factories)	Polythene/plastic/cardboard/paper
Sanitation residues or `night-soil’	Sludge/sanitary towels

The composition of the MSW collected by Kekirawa Pradeshiya Sabha is given in Table 4.2. Based on the data as depicted in Table 4.2, it can be seen that the percentage of the organic fraction in the MSW collected is 60%, which can be sufficient for composting on a commercial scale. Both short-term biodegradables (e.g., food waste) and long-term biodegradables (e.g., coconut shells, tree leaves, and branches) are encountered for the organic fraction. Hence, long-term biodegradables are to be cut into small pieces to speed up biodegradation for composting to be practiced.

Table 4.2: Composition of the MSW collected
(Source: Data available at Kekirawa Pradeshiya Sabha)

Type	**Composition**	
	MT/day	**%**
Short-term biodegradables (e.g., food, food waste)	3.59	51.3
Long-term biodegradable (e.g., cardboard, coconut shell, branches of trees)	0.61	8.7
Paper	0.18	2.5
Wood/Timber	0.35	5.0
Sawdust/Paddy husk	Very little	-
Textiles	0.33	4.7
Polythene/Plastic/Polymer	0.37	5.3
Building waste (Construction and demolition)	0.49	7.0
Metal (Iron)/non-metal (Aluminum, etc.)	0.09	1.3
Slaughterhouse waste	Very little	-
Glass	0.39	5.6
Street sweeping	Very little	-
Other	0.41	5.9
Porcelain	0.19	2.7
Total	7.00	100
Moisture content of the total waste (%)	No data	-
Calorific value of the total waste (MJ/kg)	No data	-

The calorific value and moisture content of the MSW collected were not available at Kekirawa Pradeshiya Sabha. Based on the literature, the moisture content of MSW on a wet weight basis is relatively high, ranging from 70 to 80%. Bandara (2008) reported that the average calorific value of MSW ranges between 600–1000 kcal/kg (2.51–4.18 MJ/kg).

4.1.2 Source-segregation of MSW

Based on the data collected through the questionnaire survey, the source-segregation of MSW is not popular among people in Kekirawa Pradeshiya Sabha. The mixed waste is handed over to the garbage-collecting vehicles. Further, Kekirawa Pradeshiya Sabha has not practiced proper mechanisms to use source-segregated MSW for different applications (e.g., biodegradable waste for composting, construction and demolition waste for land reclamation, non-biodegradable and non-recyclable waste for landfilling, etc.) except collecting some of the recyclable waste for selling. Thus, people in Kekirawa Pradeshiya Sabha are not encouraged to do source-segregation because of the non-availability of sound final disposal options available for the Kekirawa Pradeshiya Sabha limits, and no financial benefit is received by handing over recyclable waste to garbage-collecting vehicles. Burning MSW in the open air, street-side dumping, and managing MSW in a pit at their residences are some of the options currently being practiced, but such numbers are small.

The Kekirawa Pradeshiya Sabha operates a resource center to collect recyclable waste. Few citizens hand over recyclable waste (paper/cardboard, plastic, metal, glass, PET bottles, etc.) to the garbage-collecting vehicles. The recyclable waste generated within the Kekirawa Pradeshiya Sabha area is collected on pre-determined days at different routes; hence, people can hand over recyclable waste to the garbage-collecting vehicles. The recyclable waste collected is stored in the resource center. Once bulk quantities are collected in the resource center, the recyclables will be sold to the third party at nominal prices.

4.1.3 Collection and transport of MSW

The details as depicted in Table 4.3 manifested that the current collection of MSW by Kekirawa Pradeshiya Sabha is 17% of the total MSW generated within the territory of Kekirawa Pradeshiya Sabha.

Table 4.3: Details of the generation and collection of MSW in Kekirawa Pradeshiya Sabha

Item	**2020 (Current)**
Total MSW generation	41 MT/day
Percentage of the total MSW collection with respect to the total MSW generation	17%
Total MSW collection	7 MT/day
Percentage of the biodegradable waste in the total MSW collected	60%
Total biodegradable waste in the total MSW collected	4.2 MT/day
Percentage of the non-biodegradable waste in the total MSW collected	30%
Total non-biodegradable waste in the total MSW collected	2.1 MT/day
Percentage of the recyclable/reuse materials in the total MSW collected	10%
Total recyclables/reuse materials in the total MSW collected	0.7 MT/day
Total construction and demolition waste in the total MSW collected	< 0.5 MT/day
Total street sweeping and drain cleaning waste in the total MSW collected	< 0.1 MT/day

Source: Data available at Kekirawa Pradeshiya Sabha

The MSW generated from main roads and by-roads are collected by Kekirawa Pradeshiya Sabha on a daily basis. A compactor (6–8 m^3 capacity) and five tractors with modified trailers (5 m^3 each) are used to collect the MSW. However, two tractors with modified trailers are often out of operation at any given time; hence, three are available for the collection of MSW. Further, two gully bowsers owned and operated by the Kekirawa Pradeshiya Sabha are used for wastewater operations.

The collection of MSW by the compactor is done one time per day, and the compactor travels on average 70 km/day. It takes approximately 8 hours to complete a trip by the compactor. The collection by tractors is done one time per day, and one tractor travels on average 25 km/day. It takes approximately 8 hours to complete a trip by one tractor.

The workers involved in the collection of MSW do not sort the mixed waste during collection, but some of the recyclable materials coming with the other waste are sorted and collected into separate bags by the workers. The recyclable materials collected are sold to a third party at a cost or handed over to the resource center operated by Kekirawa Pradeshiya Sabha.

The details of the vehicular fleet used for MSWM practices by Kekirawa Pradeshiya Sabha are given in Table 4.4.

Table 4.4: Details of the vehicular fleet used MSWM practices

Vehicle type	**Number of vehicles**	**Average capacity per vehicle**	**Number of trips per day**	**Average distance traveled per trip (both up and down)**	**Average time taken per trip (both up and down)**
Compactor truck	1	6–8 m^3	1	70 km	8 hours
Tractor with a modified trailer	5	5 m^3 (1–1.3 MT)	1	25 km	8 hours
Gully bowser	2	3,000 L	-	-	-

4.1.4 Transfer stations

There is no waste transfer station; hence, mixed waste collected is directly sent to the open dump located at Embulgaswewa, Kekirawa. Some of the recyclable materials collected are sold to a third party at a cost or handed over to the resource center.

4.1.5 Final disposal system

4.1.5.1 Open dumping

The mixed waste, except for some of the recyclable materials, is disposed of in the open dump located at Embulgaswewa, Kekirawa. The operations of the open dump have been carried out since 2003, and the total area of the land is 3 acres. The location of the open dump marked on the google map is depicted in Figure 4.3. The open dump is located 5 km away from the Kekirawa town, and the land faces the Kekirawa-Ganewalpola road.

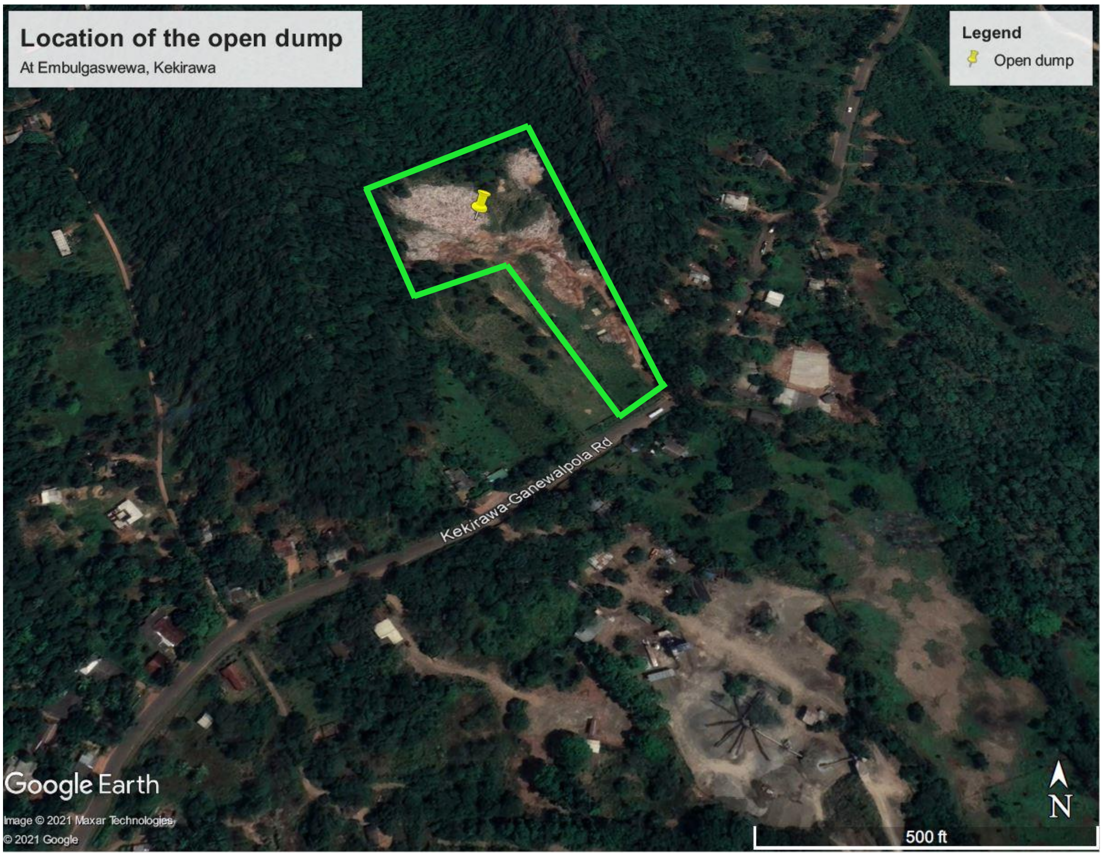


Figure 4.1: Open dump located at Embulgaswewa, Kekirawa

The ownership of the land belongs to the Forest Conservation Department. The open dumping area is a part of the Embulgaswewa natural forest, which was declared as a natural forest by the Gazette Extraordinary No. 1589/09 dated 2009.02.17. The Forest Conservation Department is in the process of transferring the ownership of the land to the Kekirawa Divisional Secretariat, and thereafter, the land will be transferred to the Kekirawa Pradeshiya Sabha.

The photographic observations of the open dump are depicted in Figures 4.2 to 4.6. Earlier, the mixed waste collected was dumped into the pits excavated within the land. Once each pit was filled with mixed waste, a new pit was excavated, and the dumping of mixed waste to the new pit was continued. The pits, which were fully filled with mixed waste, were covered by a layer of soil. Recently, the dumping of mixed waste into the pits was stopped, and the mixed waste is directly dumped on the ground.

A backhoe loader owned by Kekirawa Pradeshiya Sabha is used for the operations of the open dump. Once the mixed waste is unloaded from the garbage-collecting vehicles, the backhoe loader is used to level the mixed waste evenly on the ground (Figure 4.7). Such activities minimize the nuisance caused in the surrounding area by wind blowing and stray animals. No residential developments are observed within, or close proximity to the open dump, and no complaints have been received to Kekirawa Pradeshiya Sabha from the public regarding the operations of the open dump.

Temporary or permanent staff officers, workers, and security officers are not employed at the open dump. A biogas generation project was implemented in the open dumpsite in 2006. The underground tanks and other structures were constructed by the project. Currently, the entire project was abandoned (Figure 4.8).

Figure 4.2: Current status of the periphery of the open dump

Figure 4.3: Access to the open dump from the Kekirawa-Ganewalpola road

Figure 4.4: Current status of the open dump

Figure 4.5: Different types of waste being disposed of at the open dump

Figure 4.6: Undisturbed area of the open dumpsite

Figure 4.7: Backhoe loader operations in the open dumpsite

Figure 4.8: Underground tanks and other structures used for biogas generation

The biogas plant (Figure 4.8) has been abandoned since 2008. All the infrastructure developed for the biogas production was broken-down and unserviceable. The reasons for the failure of the biogas production project are unavailability of technical know-how, operational difficulties, poor yield of biogas generated, unavailability of a suitable mechanism of managing liquid waste generated, difficulties in rehabilitating the biogas plant in case of any failure, and lack of financial commitments. With the proposed ISWM framework to be implemented in the Kekirawa Pradeshiya Sabha, the rehabilitation of the biogas plant was completely given up since it costs more and difficulties in operation and maintenance. Further, windrow composting was proposed for the short-term and long-term biodegradable components of the MSW collected; hence, there is no need to invest for the biogas plant.

The unavailability of a leachate collection and treatment system at the open dump causes soil pollution, spreading of odorous gases, breeding of mosquitos and other insects, etc. The unavailability of a stormwater drainage network causes water stagnation, spreading of disease vectors, operational issues during rain, etc.

4.1.5.2 Resource center

A resource center in Kekirawa is operated by the Kekirawa Pradeshiya Sabha to collect the recyclable waste generated within the Kekirawa Pradeshiya Sabha area. Kekirawa Pradeshiya Sabha owns the land where the resource center is located. Recyclable waste is collected by workers engaged in MSWM operations by Kekirawa Pradeshiya Sabha by carrying out the door-to-door collection at pre-determined days at different routes; hence, people can hand over recyclable waste directly to the garbage-collecting vehicles. Once bulk quantities are collected, the recyclable waste will be sold to third-party recyclable waste collectors at nominal prices. The selling rates for the different types of recyclable waste are given in Annexure 3.1. The collection of different types of recyclable waste is depicted in Figures 4.9 to 4.12.

A baling machine and an electronic scale are available in the resource center (Figures 4.13 to 4.14). Therefore, the baling and weighing operations are carried out by a laborer employed in the resource center during the daytime.

Figure 4.9: Collection of plastics

Figure 4.10: Collection of polythene

Figure 4.11: Collection of cardboard

Figure 4.12: Collection of PET bottles

Figure 4.13: Baling machine

Figure 4.14: Electronic scale

4.1.5.3 Current institutional arrangement for MSWM by Kekirawa Pradeshiya Sabha

A separate team has been formulated by Kekirawa Pradeshiya Sabha to carry out MSWM practices. The Chairman of Kekirawa Pradeshiya Sabha heads the team. The current institutional arrangement for MSWM is given in Figure 4.15. The team has looked into the entire MSWM activities from MSW generation (household level) until the final disposal. However, due to the lack of human resources, there are many lapses in the current MSWM practices. At present, the MSWM team comprises a technical officer, two supervisors, four drivers, and 26 laborers.

One supervisor is assigned to work on a full-time basis in the field, while the other supervisor will work in both office and field. The supervisor who works on a full-time basis in the field maintains records on daily work done by the workers, progress of work, attendance of the workers, etc. Both supervisors are required to report to the technical officer at the end of each day. The technical officer attends to any issue on MSWM within the territory of the Kekirawa Pradeshiya Sabha area, if necessary. Special cases (purchasing of machinery, equipment, and vehicles, etc.) that are beyond the capacity of the technical officer will be informed to the Chairman. The Chairman discusses such issues with the council and makes decisions. The Chairman also looks after daily MSWM operations carried out by Kekirawa Pradeshiya Sabha from time to time. The decisions on improvements in the MSWM system are often taken by him to improve the efficiency of the overall MSWM system. If such issues are beyond his preview, matters are taken up with the respective provincial council.

However, the institutional setup needs further strengthening to ensure the smooth operation of the MSWM system in Kekirawa Pradeshiya Sabha. The present carder positions may be inadequate to continue a sound system; hence, many drawbacks of the existing system were observed. It appears that no formal training has been given to the technical staff so that the correct protocols in relation to the MSWM system are not practiced in the whole system.

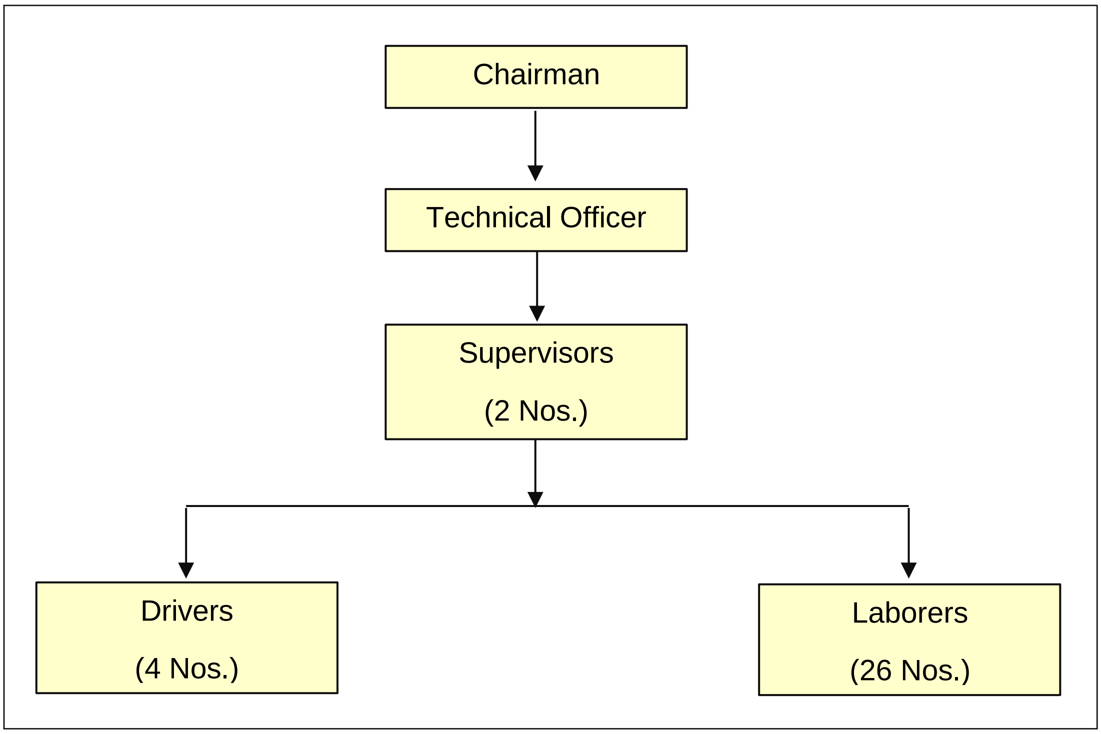


Figure 4.15: Current institutional arrangement for MSWM by Kekirawa Pradeshiya Sabha

4.1.5.4 Deficiencies and gaps identified in the existing MSWM system

The deficiencies and gaps identified in the existing MSWM system in Kekirawa Pradeshiya Sabha are summarized below.

1. Lack of the collection of MSW

Though the quantity of MSW generated within the territory of Kekirawa Pradeshiya Sabha is 41 MT/day, the quantity of MSW collected is 7 MT/day. Therefore, the percentage of MSW collected is 17% of the total MSW generated. Such a drawback is due to the non-availability of a sufficient number of garbage-collecting vehicles and a lack of workforce for MSWM practices. The lack of the collection of MSW will lead to roadside dumping and open burning. Though some of the residents manage a pit within their premises to dispose of the MSW, it will become a hazard during heavy rain. Because the pits are overflown, and leachate-rich stormwater will be flown to nearby canals or wells, leading to water pollution.

2. Unavailability of source-segregation

The residents within the territory of Kekirawa Pradeshiya Sabha do not engage in source-segregation of MSW. The mixed waste is handed over to the garbage-collecting vehicles. Due to the unavailability of proper methods for the final disposal (e.g., biodegradable waste for composting, non-biodegradable and non-recyclable for landfilling, etc.), except collecting some of the recyclable waste for selling, the mixed waste is collected and disposed of in the open dump located at Embulgaswewa as a whole.

3. Non-availability of a place for collecting construction and demolition waste

The construction and demolition waste collected by Kekirawa Pradeshiya Sabha is directly disposed of in the open dump located at Embulgaswewa. Due to the presence of foreign materials (e.g., steel parts, concrete, etc.), injuries may be very likely to the workers involved in MSWM practices. Though construction and demolition waste can be used for filling lands or any other purpose, Kekirawa Pradeshiya Sabha does not tap the potential for reusing such waste rather than open dumping.

4. Lack of garbage-collecting vehicles

The percentage of the current collection of MSW compared with the total MSW generated in Kekirawa Pradeshiya Sabha is 17%. The percentage of the collection is less due to the lack of garbage-collecting vehicles. If enough vehicles are available, more waste will be collected by Kekirawa Pradeshiya Sabha.

5. Odor emanates from the open dump

No proper odor control mechanism or covering the MSW disposed of by a layer of soil at the end of the day is practiced by Kekirawa Pradeshiya Sabha in the open dump. Therefore, during the degradation of biodegradable waste, especially slaughterhouse waste, odorous gases such as H_2S, SO_2, NH_3 emanate to the surrounding environment and create a nuisance to the public. This issue becomes severe during wet weather conditions.

6. Spreading of flies, rodents, and other insects

During rain, leachate-rich stormwater pockets are formed in the open dump; hence, flies, rodents, mosquitoes, and other insects are easily grown and flee in the surrounding area. Therefore, there is a high risk of spreading diseases such as dengue, malaria, etc.

7. Unavailability of a mechanism to collect and treat leachate accumulated in the open dump

Due to the unavailability of a mechanism to collect and treat the leachate accumulated in the open dump, the raw leachate will directly mix with the stormwater during rain and be flown to the surface/groundwater sources. Due to the presence of high nitrogen and phosphorous compounds in the leachate, the phenomena called “eutrophication” took place. The mixing of leachate-rich stormwater with drinking water sources will lead to deteriorating the quality of water; hence, health issues will arise. Further, due to the unavailability of a liner below the open dump area, leachate can be able to percolate into the ground, which affects the deterioration of groundwater quality.

8. Spreading of windblown litter in the surrounding environment

Due to the unavailability of a fence covering the boundary of the open dump, lightweight materials (polythene, plastic, etc.) are windblown and spread in the surrounding area. Further, water puddles are collected on such material, and mosquito breeding on such materials may take place with a high risk of dengue episodes.

9. Ownership of the land

Though the MSW has been disposed of in the open dump area of 3-acre land since 2003, the land ownership belongs to the Forest Conservation Department. The open dumping area is a part of the Embulgaswewa natural forest, which was declared as a natural forest by the Gazette Extraordinary No. 1589/09 dated 2009.02.17. The Forest Conservation Department is in the process of transferring the ownership of the land to the Kekirawa Divisional Secretariat, and thereafter, the land will be transferred to the Kekirawa Pradeshiya Sabha.

10. Poor bearing capacity of the soil underneath the dump

Earlier, the mixed waste collected was dumped into the pits excavated within the land. Once each pit was filled with mixed waste, a new pit was excavated, and the dumping of mixed waste to the new pit was continued. The pits, which were fully filled with mixed waste, were covered by a layer of soil. Therefore, the bearing capacity of the soil in the pit areas was poor and needed ground improvement techniques if proposed interventions are built in those areas.

11. Poor aesthetic appearance

The open dump area is not maintained properly. Many stray animals can be observed in the open dump, and windblown litter has spread in the surrounding environment.

4.2 Proposed ISWM framework based on the circular economy perspectives and under the purview of the present administrative framework

The proposed ISWM framework developed on the circular economy perspectives and under the purview of the present administrative framework is schematically presented in Figure 4.16.

The entire MSW to be collected is subjected to source-segregation into categories such as biodegradable waste, recyclable waste, construction and demolition waste, street sweeping and drain cleaning waste, and non-biodegradable waste. These components are collected separately on pre-determined days and times so that the public is notified of the schedule for a given week. Each component is collected and transported to the designated locations for further treatment. As shown in Figure 4.16, biodegradable waste is transported to a compost plant while the recyclable waste is brought to a resource center. Construction and demolition waste is transported to the construction and demolition waste collection yard. In the meantime, street sweeping and drain cleaning waste and non-biodegradables are sent to a controlled landfill. The collection and transport of source-segregated MSW to the collection center/transfer station/proposed facility are done by respective local authorities.

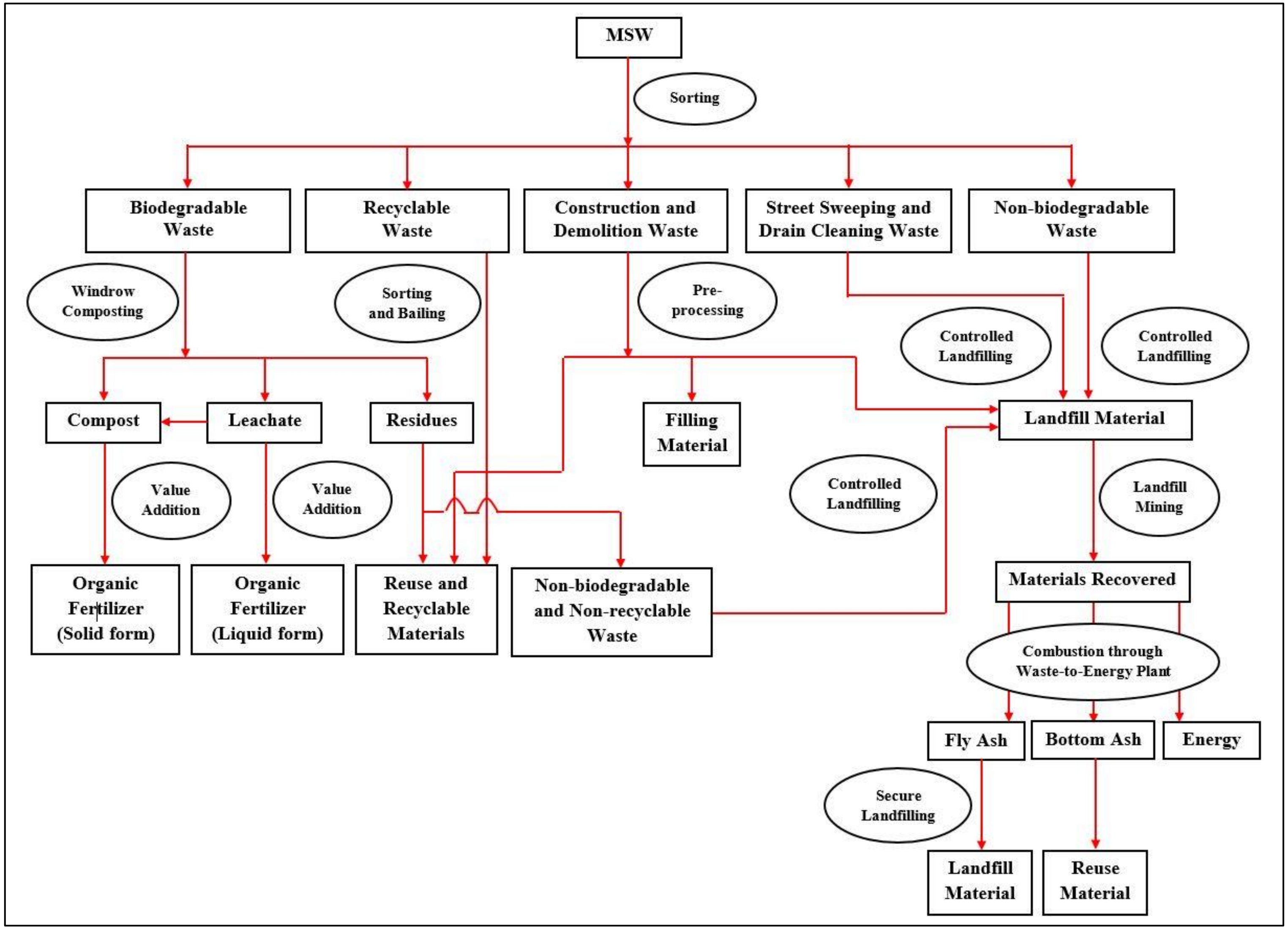


Figure 4.16: Proposed ISWM framework

Biodegradable waste received to the compost plant is subjected to windrow composting so that compost can be produced. The compost undergoes a value addition process to enhance the final quality of compost. A part of the leachate generated during composting is recirculated, while the rest is used for producing liquid fertilizer. A part of residues generated during composting is used as reuse and recyclable materials and used for covering windrow piles formed in active composting and curing areas. The rest of the residues are sent to the controlled landfill.

The recyclable waste collected is unloaded at the resource center. The area dedicated for storing recyclable waste in the resource center is partitioned mainly into six compartments to store plastic, metal, glass, paper, polythene, and PET bottles separately. The recyclable waste received to the resource center is resorted and stored at the designated compartment. Once bulk quantities are collected, the recyclable waste will be sold to third-party recyclable waste collectors at nominal prices.

The construction and demolition waste collected is unloaded at the construction and demolition waste collection yard. The materials like asbestos, wood, and tiles are used as reuse and recyclable materials. The other waste is pre-processed (crushing into small sizes) and used as a filling material.

The non-biodegradable waste, together with a part of the residues from the compost plant and street sweeping and drain cleaning waste, are disposed of at the controlled landfill. A part of the waste materials disposed of at the controlled landfill is degraded with time, and thereafter, the landfill is mined, and waste materials will be sent to a Waste-to-Energy plant for producing energy. The bottom ash generated from the plant is used as a reuse material for manufacturing paving blocks, curbstones, etc. The fly ash generated from the plant is disposed of at a sanitary landfill.

The legal and administrative framework needs to be strengthened to ensure the smooth operation of the proposed ISWM framework from MSW generation until final disposal.

Proposed ISWM framework based on the circular economy perspectives and under the purview of the present administrative framework

The suitability of the proposed ISWM framework explained above was analyzed for Kekirawa Pradeshiya Sabha, and the details are explained below.

4.2.1 MSW generation

The calculation of the generation and collection of MSW in Kekirawa Pradeshiya Sabha area at the end of the design period of 10 years is as follows.

Rate of increase of MSW generation (X) = 1.10% per year

Design period (n) = 10 years

Current generation of MSW per day (W) = 41 MT/day

MSW generated at the end of the design period (Y) = $365 \times \mathrm{W} \times (1 + 0.01\mathrm{X})^{\mathrm{n}}$

= $365 \times 41 \times (1 + 0.011)^{10}$

= 16,695 MT/year

= 46 MT/day

Therefore, the generation of MSW at the end of the design period of 10 years within the territory of Kekirawa Pradeshiya Sabha is 46 MT/day. During the implementation of the proposed ISWM framework for Kekirawa Pradeshiya Sabha, it is highly recommended to conduct public awareness programs on the 3R concept.

4.2.2 Source-segregation of MSW

Based on the proposed ISWM framework, it is a prerequisite to implement source-segregation within the territory of Kekirawa Pradeshiya Sabha into the following main categories:

- Biodegradable waste
- Recyclable waste
- Construction and demolition waste
- Street sweeping and drain cleaning waste
- Non-biodegradable waste.

The collection must be carried out only if MSW is sorted into the above-mentioned categories by people. In the case where mixed MSW is kept for collection, such mixed MSW should not be collected. Making people aware of the source-segregation efforts should be done by Kekirawa Pradeshiya Sabha in the form of leaflets distributed by visiting door-to-door. In this effort, the assistance of NGOs, societies, and popular personalities could be looked for. From time to time, Kekirawa Pradeshiya Sabha needs to promote source-segregation among the general population of the area with the support and guidance of the Ministry of Public Services, Provincial Councils, and Local Government.

Capacity-building programs for all who are involved in MSWM practices in local authorities (both desk-type and hands-on experience) are conducted so that they can impart the knowledge to others. Also, they could practice the correct protocols in MSWM. Propaganda work for the 3R concept among people through media, newspapers, NGO involvement for door-to-door campaigns, etc., are conducted.

It is of utmost importance to keep the road network, especially in town areas within the territory of Kekirawa Pradeshiya Sabha, clean for which street sweeping and drain cleaning are practiced early in the morning. The street sweeping and drain cleaning waste usually comprises heavy soil particles and grit particles with non-degradable waste. Such materials are collected and disposed of at the controlled landfill.

4.2.3 Collection and transport of MSW

At present, a total quantity of 7 MT/day mixed waste is collected by Kekirawa Pradeshiya Sabha daily. The percentage of the current collection of MSW by Kekirawa Pradeshiya Sabha is 17%. Based on the proposed ISWM framework to be applied to Kekirawa Pradeshiya Sabha, it is planned to increase the collection of the source-segregated MSW up to 50%, and the details are as follows.

Current generation of MSW per day (W) = 41 MT/day

Current collection of MSW per day = 7 MT/day

Percentage of the collection of MSW from the total MSW generated per day (Current) = 17%

MSW generated at the end of the design period (Y) = 46 MT/day

Percentage of the collection of MSW from the total MSW generated per day (with the proposed ISWM framework) = 50%

MSW to be collected at the end of the design period = 23 MT/day

Percentage of the biodegradable waste in the total waste collected (Current) = 60%

Percentage of the biodegradable waste in the total waste collected (with the proposed ISWM framework) = 60%

Biodegradable fraction of the MSW to be collected at the end of the design period = 13.8 MT/day

Percentage of the recyclable waste in the total waste collected (with the proposed ISWM framework) = 10%

Recyclable fraction of the MSW to be collected at the end of the design period = 2.3 MT/day

Percentage of the non-biodegradable waste in the total waste collected (with the proposed ISWM framework) = 30%

Non-biodegradable fraction of the MSW to be collected at the end of the design period = 6.9 MT/day

The summary of the collection of different categories of MSW, including composition at the end of the design period compared to the present status, is depicted in Table 4.5.

Table 4.5: Collection of different categories of MSW, including composition

Item	**Year**		
	2020 (Current)	**2022 (At the implementation of the proposed ISWM framework**	**2030 (End of the design period)**
Total MSW generation	41 MT/day	42 MT/day	46 MT/day
Percentage of the collection of MSW from the total MSW generated per day	17%	50%	50%
Total MSW collection	7 MT/day	21 MT/day	23 MT/day
Percentage of the biodegradable waste in the total waste collected	60%	60%	60%
Total biodegradable waste in the total waste collected	4.2 MT/day	12.6 MT/day	13.8 MT/day
Percentage of the non-biodegradable waste in the total waste collected	30%	30%	30%
Total non-biodegradable waste in the total waste collected	2.1 MT/day	6.3 MT/day	6.9 MT/day
Percentage of the recyclable waste in the total waste collected	10%	10%	10%
Total recyclable waste in the total waste collected	0.7 MT/day	2.1 MT/day	2.3 MT/day

Total construction and demolition waste in the total waste collected	<0.5 MT/day	<0.5 MT/day	<0.5 MT/day
Total street sweeping waste in the total waste collected	<0.1 MT/day	<0.1 MT/day	<0.1 MT/day

Since it is planned to increase the quantity of source-segregated MSW collected up to 50%, the current vehicular fleet is required to be strengthened to manage the expected quantity.

The Kekirawa Pradeshiya Sabha, at present, possesses a vehicular fleet of a compactor (6–8 m^3) and five tractors with trailers (5 m^3) for the collection of MSW. However, it has been intimated that, on average, two tractors and trailers undergo repair at any given time so that only three are available for collection. It is estimated that the compactor carries 4 MT of MSW on average for a given occasion with a density of 0.5–0.6 MT/m^3. Similarly, one tractor with a modified trailer carries 1 MT of MSW on average for a given occasion with a density of 0.2–0.3 MT/m^3. Hence, approximately 7 MT could be collected per day with the deployment of the compactor and three tractors. There will be an additional quantity of 14 MT/day to be collected daily to improve the collection of MSW up to 50%. Two compactors with a capacity of 6–8 m^3 each will be provided; hence, on average, a total of 8.0 MT could be collected. The number of trips per day made by the compactor truck currently being used by Kekirawa Pradeshiya Sabha needs to be doubled; hence, an additional 4 MT/day could be collected. The two tractors which have been out of operation need to be rectified and deployed for collection; hence, an additional 2 MT/day could be collected. Thereby, the total MSW collection could be increased up to 21 MT/day. In other words, the total MSW collection could be increased by up to 50% of the total MSW generated within the territory of Kekirawa Pradeshiya Sabha.

The two compactors to be provided will be utilized to collect MSW from the town areas of Habarana and Maradankadawala located within the territory of Kekirawa Pradeshiya Sabha. The supply of two compactors can also be used to dispatch what is collected in the controlled landfill to a Waste-to-Energy project. The compactor currently being used will be utilized to collect the MSW from the Kekirawa town area and suburbs and planned to make two trips per day. All the tractors and trailers will be used to collect MSW from other areas that are not covered by the compactors. Handcarts will be utilized for instances where larger vehicles cannot be used. The present O&M plan will be modified for better service delivery. The workforce involved in the collection needs to be improved with at least employing another two drivers and four workers for two compactors to be provided, and such a carder improvement could be made initially on a temporary basis.

An optimized plan for collection routes needs to be worked out depending on the vehicular fleet, and accordingly, prioritization on collection efforts will be done. The GPS- assisted system will be made available for every vehicle for an effective and efficient collection plan to be mobilized.

The following section enumerates the adequacy of the vehicular fleet to be utilized for the collection of MSW.

Capacity of a tractor-trailer = 5.0 m^3

Density of the un-compacted MSW = 0.2–0.3 MT/m^3

Weight of MSW that can be carried out by a tractor-trailer per trip = 1.0–1.3 MT/trip

Number of trips per tractor per day = 1

Number of tractors with trailers = 5

Total weight of the MSW that can be collected by five tractors with trailers = 5 MT/day

Total number of compactors available in Kekirawa Pradeshiya Sabha = 1

Capacity of the compactor available = 6–8 m^3

Total number of compactor trucks to be provided to Kekirawa Pradeshiya Sabha = 2

Capacities of the compactors to be provided = 6–8 m^3 each

Density of the compacted MSW = 0.5–0.6 MT/m^3

Weight of the MSW that can be carried out by a compactor per trip = 3.0–4.8 MT/trip

Total number of trips made by the compactors = 4

Total weight of the MSW that can be collected by the compactors = 16 MT/day

Total weight of the MSW collected by three compactors and five tractors with trailers = (5 + 16) MT/day

= 21 MT/day

The waste collection at the end of the 10-year horizon is 23 MT/day. The additional capacity (2 MT/day) is planned to be collected through the same fleet by increasing the number of trips made by the tractors. The Kekirawa Pradeshiya Sabha is entirely responsible for collecting and transporting the source-segregated MSW collected to the final disposal site.

4.2.4 Final disposal of MSW

The land currently utilized by Kekirawa Pradeshiya Sabha to dispose of the mixed waste is developed to establish the compost plant, controlled landfill, and office premises under the proposed ISWM framework. The total area of the land (3-acres) will be utilized for proposed development activities. The land is located about 5 km along the Kekirawa-Ganewalpola road from the Kekirawa town, known as Embulgaswewa (Figure 4.1). The land is facing the Kekirawa-Ganewalpola road. The ownership of the land belongs to the Forest Conservation Department. The open dumping area is a part of the Embulgaswewa natural forest, which was declared as a natural forest by the Extraordinary Gazette No. 1589/09 dated 2009.02.17 (Annexure

4.1). The forest conservation Department is in the process of transferring the ownership of the land to the Kekirawa Divisional Secretariat, and thereafter, the land will be transferred to Kekirawa Pradeshiya Sabha.

The master plan of the proposed ISWM facility is depicted in Figure A.1 in Annexure 4.2. The roof coverage area of the facility is shown in Figure A.2 in Annexure 4.2. The proposed facility borders the Kekirawa-Ganewalpola road. There exists a gate and watcher’s hut at the entrance (Figure 4.17). As the vehicles enter, parking for official vehicles is on the right-hand side, and the weighbridge is located in the same direction via de-routing. The office area is located on the right-hand side of the main approach road, and it closes to the Kekirawa-Ganewalpola road. When entered further up along the main approach road, the compost plant is located on the right, while the controlled landfill is located opposite to the compost plant. A 5 m buffer zone will be maintained around the entire land parcel to enhance the greenery and to reduce environmental issues. A fence is erected around the land to keep stray animals away from the facility.

4.2.4.1 Compost plant

The compost plant will be constructed on an area of about 150 perch, as depicted in Figure 4.17. The schematic diagram of the compost plant is depicted in Figure A.3 in Annexure 4.2. Details of the compost plant are elaborated under the detailed design section.

The compost plant consists of key areas such as unloading/receiving area, sorting area, shredding area, active composting area, curing area, sieving area, value addition area, packing area, stores, residue collection and storage area, and unsuitable/hazardous/ reject material storage area.

Further, the proposed ISWM facility includes main office/administration space, tyre washing area, dining area and washrooms for workers, equipment/machinery parking and repair, watcher’s hut, restroom for workers, weighbridge, parking for office vehicles, parking for vehicles of the workers, parking for garbage-collecting vehicles, infrastructure facilities (electricity, water supply, access internal roads and external roads, boundary fence with gate, lighting, lightning arrester, etc.), wastewater collection, treatment, and disposal, leachate collection, storage, reticulation system, and selling, stormwater drainage system, and odor control facility.

Figure 4.17: 3D view of the proposed ISWM facility at Kekirawa Pradeshiya Sabha

4.2.4.1.1 Design philosophy

Once the garbage-collecting vehicles arrive at the ISWM facility, the security officers working in the watcher’s hut adjacent to the gate (Figure A.1 in Annexure 4.2) will first verify the identity of garbage-collecting vehicles. Once access to the ISWM facility is permitted, the garbage-collecting vehicles are first directed to the weighbridge to weigh the quantity of MSW inside each vehicle. The weight of the garbage-collecting vehicles without MSW will be measured once each vehicle is registered with the Kekirawa Pradeshiya Sabha for MSW operations. The data (vehicle number, weight without MSW, etc.) will be entered into the operating system of the weighbridge by the officials of Kekirawa Pradeshiya Sabha once the registration is completed. Therefore, the system itself will display the weight of the MSW inside the vehicle, and such data will be saved in the data logger installed inside the weighing station.

The garbage-collecting vehicles are then directed to the tipping pad (unloading area) to unload the MSW carried by vehicles. Before unloading, the supervisor will inspect whether the vehicles take up the source-segregated MSW or not. If not, such MSW is not permitted to be unloaded to the tipping pad. The number of unloadings will be two times per hour. A perimeter drain will be constructed in the tipping pad to collect the leachate accumulated in the tipping pad and directed to the leachate collection tank through a centralized drain system under gravity.

A skid steer loader is used to push the MSW from the unloaded area to the sorting area. Since the number of unloadings per hour is two, the skid steer loader is capable of handling two unloadings per hour. Each pile is spread to a maximum height of 25 cm in the sorting area by using the skid steer loader.

The MSW spread (thickness of 25 cm) in the sorting area will be sorted by a labor force of at least two workers. Only biodegradable waste (organic fraction only) is sorted for composting, recyclable materials are sorted for recycling, and other categories of MSW will be sent to the residue collection center. Large size biodegradable materials (e.g., coconut shells, grass clippings, etc.) will be sent to the shredding machine fixed at the shredding area for cutting into small pieces. Perimeter drains will be constructed in the sorting area and shredding area to collect the leachate accumulated and directed to the leachate collection tank through a centralized drain system.

Separate bins are kept at the sorting area to store the recyclables found in the MSW spread. At the end of the day, all bins are emptied, and recyclables collected will be sent to the recyclable materials collection area (resource center).

Small-sized biodegradable materials will be directly sent to the active composting area using the skid steer loader. The large-size biodegradables will be loaded into the shredding machine to cut into small pieces. Once shredding operations are finished, the shredded garbage will be sent to the active composting area by using the skid steer loader.

Active composting and curing are the two main steps to be carried out under composting. Passively aerated windrow method is used, and this method involves the feedstock shaped into piles, which are long and low in height, known as windrows. The periods of active composting and curing are, in general, eight weeks and four weeks, respectively. The windrow piles are regularly turned to re-establish mainly porosity. The turning process promotes entering oxygen into the windrow.

The windrows are formulated on a firm concrete foundation, which is constructed to withstand loads acting on the pad (e.g., dead load and live load). A centralized drain system will be constructed to collect the leachate accumulated during active composting and curing, and the concrete pad will be sloped to the drains accordingly. A roof shelters the active composting area and curing area with sufficient height enabling machinery, equipment, and vehicles to operate easily and limit the generation of leachate-rich stormwater during rain.

The moisture content in the windrow pile needs to be maintained; hence, the leachate accumulated in the leachate collection tank is sprinkled into the piles. A leachate reticulation system will be installed for this purpose. The rainwater collection tank and leachate collection tank will be coupled through a gate valve. Therefore, when leachate volume is low, rainwater is diverted to the leachate collection tank.

After the curing period, the mature compost has rather variable sizes of particles. As per the SLS 1246:2003, the particle size of the final compost shall be less than 4 mm. Therefore, the mature compost after curing is sieved through a trommel of sieve size is 4 mm; hence, the size of the particles less than 4 mm will be passed through the sieve while the large size particles remain separated.

The final quality of the compost is verified in terms of pH, nitrogen, phosphorous, potassium, magnesium, and calcium levels present in the compost concerning the levels as stipulated in the SLS 1246:2003. The quality of the final product will be measured regularly. The value addition to improve the final quality can be done accordingly. The compost samples will be collected and tested every six months through a recognized laboratory. Value addition to enhancing the quality of the final product is done based on the test results.

After verifying the quality, the final compost product will be packed in moisture-proof and strong packages or containers. It could be different sizes; 1 kg, 2 kg, 5 kg, 10 kg, 20 kg, or 25 kg. The final compost can also be sold in bulk containers but covered completely, as agreed between the purchaser and the Kekirawa Pradeshiya Sabha. After packing, the packages will be stored. The handling and storage of the packages will be as stipulated in SLS 544.

All the garbage-collecting vehicles after unloading will go through the wheel washing area before leaving the facility. This will prevent dirt and mud, leaving on vehicle tyres from polluting the public roadways. The application of effective bacteria on vehicles will also be made to minimize the bad odor.

The machinery and equipment required for the daily operations of the compost plant will be provided (e.g., shredding machine, sieving machine, cutter pumps, and odor control system).

A part of the residues accumulated at the residue collection area will be loaded to the tractor-trailer and sent to the controlled landfill located adjacent to the compost plant, while the rest will be used for covering windrow piles. This will be done at the end of each day.

The office, resting area, washrooms, and parking for office vehicles and garbage-collecting vehicles are located separately. A perimeter drain will be constructed to collect the stormwater accumulated during rain and directed to the main stormwater drain. A comprehensive drainage management plan will be prepared for the proposed land, including proposed interventions to be done. The infrastructure facilities such as internal roads, lighting, electricity, telephone, lightning protection, etc., will be provided.

The summary of the conceptual design carried out for the compost plant is depicted in Table 4.6. The detailed calculations are given in Annexure 4.3.

Table 4.6: Summary of the conceptual design carried out for compost plant

Facility	Key area	Details
Compost plant	Unloading/ receiving area	• The dimensions of the unloading area are 6.8 m long and 11 m wide. • The number of garbage-collecting vehicles to be handled within the unloading area is two vehicles per hour. • The distance between two piles in the unloading area is 2 m. • The height of a pile, when unloaded from the garbage-collecting vehicles, is 1 m. • A roof with a 6 m clear height is provided.
	Sorting area	• The dimensions of the sorting area are 13.2 m long and 11 m wide.

		• The manual sorting method is proposed, and female employees are engaged in sorting operations. • It takes 30 minutes to sort one pile leveled at the sorting area. • The height of the biodegradable waste spread at the sorting area is 25 mm. • The distance between two piles in the sorting area is 2 m. • A skid steer loader is used for the operations of the sorting area. • The reject materials are collected into separate bins and sent to the residue collection area. If recyclable materials are found, they are collected into separate bins and sent to the resource center. • A roof with a 6 m clear height is provided.
	Shredding area	• The dimensions of the shredding area are 7 m long and 11 m wide. • The capacity of the shredding machine is 4 MT/day. • The shredding machine comprises a feeding hopper, rotatable drum (5 mm mesh size), conveyors, and shredding unit. • A skid steer loader is used for the operations of the shredding area. • The long-term biodegradable waste (coconut shells, banana trunks, twigs,

		etc.) is fed to the feeding hopper by a skid steer loader. • A roof with a 6 m clear height is provided.
	Active composting area	• The dimensions of the active composting area are 45 m long and 32 m wide. • The method of composting is passively aerated windrow composting. • The loss of weight of the biodegradable waste during unloading, sorting, and shredding is 5%. • The number of windrow piles per week is one. • The volume of biodegradable waste in a pile is 133 m^3. • The period of active composting is eight weeks. • Based on the nature of biodegradable waste received, bulking agents are introduced to maintain the favorable C:N ratio as 25:1 to 30:1 as much as possible. • The moisture content of the windrow piles is maintained as 55–65%. • The turning of windrow piles is carried out every 3–5 days using a backhoe loader or a skid steer loader. • The distance between two windrow piles in the active composting area is 2 m.

		• The bottom width of a windrow pile is 4 m, and the top of the windrow pile will be curved in shape. The total length and height of each windrow are 20 m and 2.5 m, respectively. • A roof with a 6 m clear height is provided. • The space required to erect two windrow piles is additionally provided to facilitate the turning of windrow piles.
	Curing area	• The dimensions of the curing area are 23 m long and 32 m wide. • The volume reduction during active composting is 50%. • The number of windrow piles per week is one. • The period of curing is four weeks. • The distance between two windrow piles in the curing area is 2 m. • The bottom width of a windrow pile is 4 m, and the top of the windrow pile will be curved in shape. The total length and height of each windrow are 20 m and 2.5 m, respectively. • The turning of windrow piles is carried out every 5–8 days using a backhoe loader or a skid steer loader. • A roof with a 6 m clear height is provided.

	Sieving area	• The dimensions of the sieving area are 5 m long and 8 m wide. • The capacity of the sieving machine is 2 MT/day. • The sieving machine comprises a feeding hopper, rotatable drum (4 mm mesh size), and conveyors. • The size of the sieves is 4 mm. • The mature compost after the curing period will be loaded to the feeding hopper by using the skid steer loader. • The reject materials are collected and sent to the residue collection area. • A roof with a 6 m clear height is provided.
	Value addition area	• The dimensions of the value addition area are 6 m long and 8 m wide. • The nitrogen-, phosphorous-, and potassium-rich materials are kept inside the area and mixed with the final compost to improve the final quality. • The amounts of nitrogen-, phosphorous-, and potassium-rich materials to be added are determined based on the laboratory test results to be carried out on a quarterly basis through an accredited laboratory. • A roof with a 6 m clear height is provided.

	Packing area	• The final compost product is packed in moisture-proof and strong packages or containers. • Polypropylene or jute bags are suitable for packaging purposes. But the inner lining of bags is required. • It shall be of mass 1 kg, 2 kg, 5 kg, 10 kg, 20 kg, or 25 kg. • The final compost can be sold in bulk containers. • A portable packing machine is used to seal the packages. • A platform weighing scale is used for weighing operations. • A roof with a 6 m clear height is provided.
	Stores	• The dimensions of the stores are 6 m long and 8 m wide. • A lockable door is fixed to ensure the safety of the stores. • The floor of the stores is raised to avoid stormwater entering the floor, and final compost packages are kept on top of the wood pellets to avoid ground moisture from absorbing into the packages. • A roof with a 6 m clear height is provided.
	Main office/ administration space	• The area of the office premises is 43.5 m^2. • An office area, washrooms (male and female) for office staff, and dining and

		resting areas for office staff are provided. • A male washroom, female washroom, and shower cubical are provided. • The necessary infrastructure facilities such as electricity, water, and telephone facilities are provided. • The office area will be air-conditioned. • A roof with a 4 m clear height is provided.
	Tyre washing area	• The dimensions of the bay are 4 m wide and 10 m long. • The angle of the bay shall be maintained as four degrees. • After unloading, garbage-collecting vehicles move through the tyre washing area before leaving the facility. • The water supply will be provided through a 1-inch pipe network. • A deodorization agent (effective bacteria) is sprayed to the tyres and garbage carrier. • A pit is constructed to collect the washed water, and the washed water collected in the pit is recirculated after passing through a filtration process. • The washing system comprises storage tanks, spray guns, and pressure pumps. • The rate of the application of the deodorization agent is 2 L/vehicle.

	Dining area and washrooms for workers	• The dimensions of the dining area are 5 m long and 5 m wide. • A dining area and washrooms (male and female) for workers are provided. • Toilets (2 Nos.) and shower cubicles (3 Nos.) will be constructed for male workers, while a toilet and shower cubicles (2 Nos.) will be constructed for female workers. • The necessary infrastructure facilities such as electricity and water facilities are provided. • A roof with a 4 m clear height is provided.
	Equipment/ machinery parking and repair	• The dimensions of the area are 10 m long and 8 m wide. • The minor repairs and preventive maintenance works are carried out. • A roof with a 6 m clear height is provided.
	Watcher’s hut	• The dimensions of the watcher’s hut are 3 m long and 3 m wide. • Guard pillars are fixed in front of the watcher’s hut for safety. • The necessary infrastructure facilities such as electricity, water, and telephone are provided. • A roof with a 3 m clear height is provided.
	Restroom for workers	• The dimensions of the area are 8 m long and 4 m wide.

		• Two restrooms (one for males and the other for females) are provided. • The necessary infrastructure facilities such as electricity and water are provided. • A roof with a 4 m clear height is provided.
	Weighbridge	• The gross capacity of the weighbridge to be installed is 50 MT. • The operating temperature will be 20 °C to 40 °C. • The platform of the weighbridge should have a skid resistance surface. • Standard software and a display device shall be accompanied by a package, and a data logger for data storage is required.
	Parking for office vehicles	• Parking slots (8 Nos.) with dimensions of 2.5 m wide and 4.9 m long each are provided. • The parking area is sheltered with a roof of 4 m clear height.
	Parking for vehicles of the workers	• The parking area is sheltered with a roof of 4 m clear height. • Facilities are provided to park three-wheelers and motor bicycles.
	Parking for garbage-collecting vehicles	• No construction activities are carried out other than leveling and compaction of existing ground.
	Infrastructure facilities (electricity,	• Three-phase electricity is provided.

	water supply, access internal roads and external roads, boundary fence with gate, lighting, lightning arrester, etc.)	• Water for domestic purposes is obtained from National Water Supply and Drainage Board. • The water demand for the project is estimated at 10 m^3/day. • Five (2,000 L capacity each) water tanks will be used to supply water for domestic purposes. • Two water tanks are installed on an elevated structure while the other three water tanks are installed underground. The water is distributed to the designated outlet points through gravity. Two water pumps (1 duty/1 standby) will be installed to pump the water from the underground tanks to elevated tanks. • The width of external and internal access roads is maintained as 6 m. • External and internal roads are asphalt paved, and drains are provided wherever necessary. • A green PVC-coated galvanized chain link fence is erected around the premises. The height of the fence is 1.5 m. • Solar-driven lighting is provided to illuminate outdoor areas. • Natural lighting is promoted as much as possible.

		- Lightning arresters are provided to ensure safety.
	Wastewater collection, treatment, and disposal	- The domestic wastewater generated during the operation stage will be directed to an underground collection tank (septic tank) with a capacity of 8 m^3. - A compact decentralized wastewater treatment plant (DEWAT system) is installed to treat the domestic wastewater generated. - The DEWAT system comprises aerobic biological treatment, clarifier, and disinfection. - The capacity of the plant will be 4 m^3/day. - The treated effluent will be used for irrigation. - The sludge accumulated at the collection tank will be emptied in a 1-year time interval.
	Leachate collection, storage, reticulation system, and selling	- The leachate generation is 75 L/MT. - The total generation of leachate is 1 m^3/day. - Nearly 500 L/day of leachate accumulated at the leachate collection tank is recirculated, while the rest will be used for manufacturing liquid fertilizer. - A leachate collection network is constructed to collect the leachate

		accumulated in the unloading area, sorting area, shredding area, active composting area, and curing area. • A perimeter drain network with the dimensions of 300 mm wide and 300 mm minimum height will be provided. • The slope of the leachate collection drains is maintained at 1:50. • The drains are covered with gratings of high quality. • The leachate collected is directed to the leachate collection tank under gravity. • The dimensions of the leachate collection tank are 2.5 m wide, 2.5 m long, and 3 m deep. The leachate collection tank is capable is storing leachate for a period of 14 days. • Stormwater collection tank and leachate collection tank will be coupled through a gate valve. Therefore, when leachate volume is low, rainwater is diverted to the leachate collection tank. • The leachate accumulated in the leachate collection tank is recirculated back to the windrows formed in the active composting area and curing area. • Two submersible cutter pumps (1 duty/1 standby) are installed inside the leachate collection tank to pump the leachate, and a pipe network together

		with two outlet points is provided to distribute the leachate to the piles. • A flexible horse (50 m long) can be fixed to any outlet point; hence, the leachate will be sprayed to the designated windrow pile.
	Stormwater drainage system	• A part of the stormwater accumulated in the compost plant area is directed to stormwater collection tanks (2 Nos.) through a silt trap, while the other part is directed to the stormwater drain constructed along the main approach road. • The rainwater stored in the stormwater collection tanks is used for cleaning/washing purposes. Two submersible pumps (1 duty/1 standby) are installed at the bottom of one tank. • The rain that falls on rooftops in the compost plant is directed through gutters and downpipes into roadside drains [1.0 m wide and 1.0 m deep (minimum)] and perimeter drains [0.5 m wide and 0.5 m deep (minimum)]. • The slope of the drains is maintained as 1:150. • The manholes are constructed at all junctions in the stormwater drainage network. The manholes are covered with a water seal lid (cover) made of galvanized iron.

		• The maximum rainfall intensity is taken as 150 mm/hour.
	Odor control facility	• An odor control system is provided to lessen the odor that emanates from the compost plant. • Effective bacteria are used as the deodorizing agent. • The odor control facility consists of storage tanks, spray guns, a piping network, and pressure pumps.
	Residue collection and storage area	• The dimensions of the area are 5 m long and 8 m wide. • A part of the residues accumulated at the residue collection area will be used to cover windrow piles while the rest will be loaded to a trailer and disposed of in the controlled landfill at the end of the operations of the compost plant each day.
	Unsuitable/ hazardous/ reject material storage	• The dimensions of the area are 4 m long and 4 m wide. • Unsuitable/hazardous/reject materials are collected into sealed bins and handed over to the waste collectors who are registered with the CEA. • It is recommended not to accept such waste to the facility.

4.2.4.2 Resource center

The dimensions of the resource center are 8 m long and 8 m wide. The room is partitioned into six compartments to collect plastic, metal, glass, paper, polythene, and PET bottles, respectively. Once bulk quantities are accumulated, those recyclables are sold to the waste collectors registered with the CEA. A selling counter will be constructed, and a cadre position is allocated for the operation of the resource center. A platform weighing scale is purchased and for weighing operations.

4.2.4.3 Controlled landfill

The non-biodegradable and non-recyclable fraction of the source-segregated MSW together with part of the residues from the compost plant and street sweeping and drain cleaning waste are disposed of at controlled landfill. The watcher’s hut located adjacent to the gate will visually inspect the garbage inside the garbage-collecting vehicles and be permitted to enter the controlled landfill if accepted.

The controlled landfill is located opposite the compost plant (Figure 4.17). The area of the landfill (excluding the area required for the infrastructure facilities) is 1,914 m^2, and the total lifespan is approximately 1-year and 9-month. The landfill comprises a tipping pad, waste disposal area, and construction and demolition waste collection yard. A 5-m buffer zone will be maintained around the landfill. The height of the landfill is 8 m.

A concrete drain capable of carrying leachate-rich stormwater will be built along the periphery of the landfill. The leachate-rich stormwater drained via the network will be directed to a constructed wetland where water quality improvement will be expected. The treated water is collected and made use for irrigation purposes for the vegetation in the 5 m buffer zone around the controlled landfill.

According to the design calculations, the lifespan of the landfill is approximately 1-year and 9-month, and during which it could receive a little more than 7,000 MT of waste. The design calculations of the controlled landfill are given in Annexure 4.4. The summary of the design parameters is depicted in Table 4.7.

Table 4.7: Summary of important design parameters of the controlled landfill

No.	**Description**	**Value**
1	Total MSW collection at the end of the design period	23 MT/day
2	Total non-biodegradable waste in the total MSW collected	6.9 MT/day
3	Total residues generated from the compost plant to be sent to controlled landfill	3.0 MT/day
4	Total street sweeping and drain cleaning waste in the total waste collected	<0.1 MT/day
5	Additional waste from other local authorities	1.5 MT/day
6	Total waste to be transferred to the controlled landfill	11.5 MT/day
7	Total waste to be transferred to the controlled landfill each year	3,650 MT/year
8	Estimated rate of increase (or decrease) of MSW generation per year	1.1%
9	Proposed life of the controlled landfill	21 months
10	Total waste disposed of at the end of the proposed life of the controlled landfill	7,067 MT
11	Density of waste	0.6 MT/m^3
12	Height of the controlled landfill	8 m
13	Average estimate of the capacity of the controlled landfill	15,312 m^3
14	Area required for the operations of the controlled landfill	1,914 m^2
15	Area required for infrastructure facilities	383 m^2
16	Total area required for the operations of the controlled landfill, including infrastructural facilities	2,297 m^2

Progressive development of the controlled landfill

The areas, lifespan, and the quantity of the waste to be disposed of are depicted in Table 4.8. The controlled landfill is developed as two layers. Due to the space limitations of the proposed area to be utilized for the controlled landfill, more than two layers were not possible.

Table 4.8: Progressive development of the controlled landfill

Layer	Area	Lifespan (Months - nearly)	Quantity of the waste to be disposed of (MT - nearly)
1	1,914	16	5,344
2	560	5	14,500
Total		**21**	**19,844**

The preparation of the landfill area (clearing, ground improvement, laying of liner system, etc.) suitable for waste disposal is carried out before the commencement of waste filling operations.

The total height of the landfill is 8 m, and the slope of the landfill is 30 degrees. The filling of the garbage in the controlled landfill will be carried out in two layers, and the height of each layer is 4 m. Once the first layer is laid, a 2 m clear gap (berm) is maintained from the perimeter of the top surface of the first layer to start the second layer (Figure 4.18). The introduction of a berm at the end of each layer is imperative for the slope stability of the waste-filled layers.

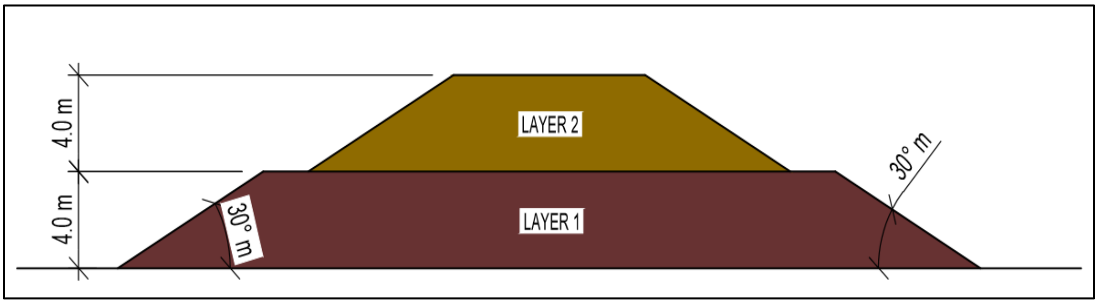


Figure 4.18: Sectional view of the controlled landfill

The landfilling operations are commenced with layer-1. The filling of waste will start from the tipping pad onwards. It will take 16 months to complete layer-1 (Figure A.9 in Annexure 4.5). Once layer-1 is completed, the filling of waste to layer-2 will begin. It will take five months to finish layer-2 (Figure A.10 in Annexure 4.5). Therefore, landfilling operations will take place for 21 months from the date of commencement of the landfilling operations. The progressive development of layer-1 is given in (Figure A.11 in Annexure 4.5).

A backhoe loader will be used to bring the waste from the tipping pad to the working face, spread the waste in the working face, and compact the layer spread with the number of passes over it. The slope at which waste is leveled in the perimeter is 30 degrees. The bottom of the slope towards the edge of each layer is formed to be a horizontal strip of 2 m to act as a berm. Temporary roads (10–20% slope ramp) will be formed when the landfill operations are done in layer 2.

A part of the waste materials disposed of at the controlled landfill is degraded with time, and thereafter, the landfill is mined, and waste materials will be sent to a Waste-to-Energy project. Thereby, the landfill operations can be extended.

The summary of the conceptual design carried out for the controlled landfill is depicted in Table 4.9.

Table 4.9: Summary of the conceptual design carried out for controlled landfill

Facility	**Key area**	**Details**
Controlled landfill	Landfill area	• Total area required for the operations of the controlled landfill, including infrastructural facilities, is 2,297 m^2. • Proposed life of the controlled landfill is 21 months. • The total number of layers is two. • The slope of the controlled landfill is maintained at 30 degrees.

		• The height of each layer is 4 m. • The clear gap of the berm is maintained as 2 m. • The operations of the landfill area are carried out by a backhoe loader. • Temporary roads (10–20% slope ramp) are formed when the landfill operations are done in upper layers.
	Tipping pad	• The tipping pad is 10 m long and 10 m wide. • The edge of the tipping pad is laid with concrete curbs and colored yellow and black to ensure visibility of the edge of the tipping pad for the vehicle drivers.
	Construction and demolition waste collection area	• The construction and demolition waste collection yard is 10 m long and 5 m wide. • A crushing machine is installed inside the area. • A backhoe loader is used to heap the construction and demolition waste in the yard and load the construction and demolition waste to the vehicles on request to be taken away. • The area is laid with the soil of high quality in terms of compaction (not less than 95%), and a thickness of 225 mm ABC (aggregate base course) is laid and compacted (degree of compaction is not less than 95%) on top of the properly compacted soil layer.
	Liner system	• A liner system is provided at the bottom of the landfill area and tipping pad area to avoid groundwater pollution. • The dynamic compaction is carried out to compact and level the existing ground.

		• A clay liner of 300 mm with a coefficient of permeability less than 1 x 10^{-7} cm/sec is laid on top of the prepared ground. • On top of the clay layer, a non-woven geotextile layer having a weight greater than 1 kg/m^2 is laid to prevent puncturing, crushing, and piercing the clay layer. • Odor control is done if necessary.
	Leachate management system	• A drainage network [width and height of the drain are 600 mm (minimum)] is constructed along the perimeter of the landfill area to collect the leachate-rich stormwater accumulated. • The drains are covered with gratings of high quality. • The slope of the drain is maintained at 1:60 to minimize the clogging of particles. • Cascade drains and berm drains are constructed to collect the leachate rich stormwater from layer 2 to the ground • The leachate-rich stormwater is then directed to the constructed wetland located adjacent to the landfill for subsequent treatment. • Refer to Annexure A.6 for leachate collection system of the proposed ISWM facility
	Stormwater drainage system	• The stormwater accumulated at the landfill is directed to the leachate collection network and treated through the constructed wetland. • Refer to Annexure A.7 for stormwater collection system of the proposed ISWM facility

	Constructed wetland	• The area of the constructed wetland is 264 m^2. • The subsurface horizontal bed flow wetland is constructed. • The zigzag configuration is maintained throughout the wetland to avoid the short-circuiting phenomenon. • The operations of the wetland are designed as a continuous flow. • *Phragmites karka* (Sinhala name: Nala gas) is selected as the type of plant to be grown. • Calicut tiles are used as the wetland media. The size of the media is 25–50 mm. • The treated effluent discharged from the constructed wetland is used for irrigation purposes. • Refer to Annexure 4.8 for detailed design

Material balance of the proposed ISWM framework

The material balance of the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha was carried out to evaluate the quantities of final products and by-products to be generated (Figure 4.19). The quantities of final products expected to be obtained are depicted in Table 4.10.

Table 4.10: Quantities of the final products obtained from the proposed ISWM facility

Final product	Quantity
Organic fertilizer (Solid form)	3.5 MT/day
Organic fertilizer (Liquid form)	500 L/day
Reuse and recyclable materials	5.1 MT/day
Filling material	0.4 MT/day
Energy	0.2 MW

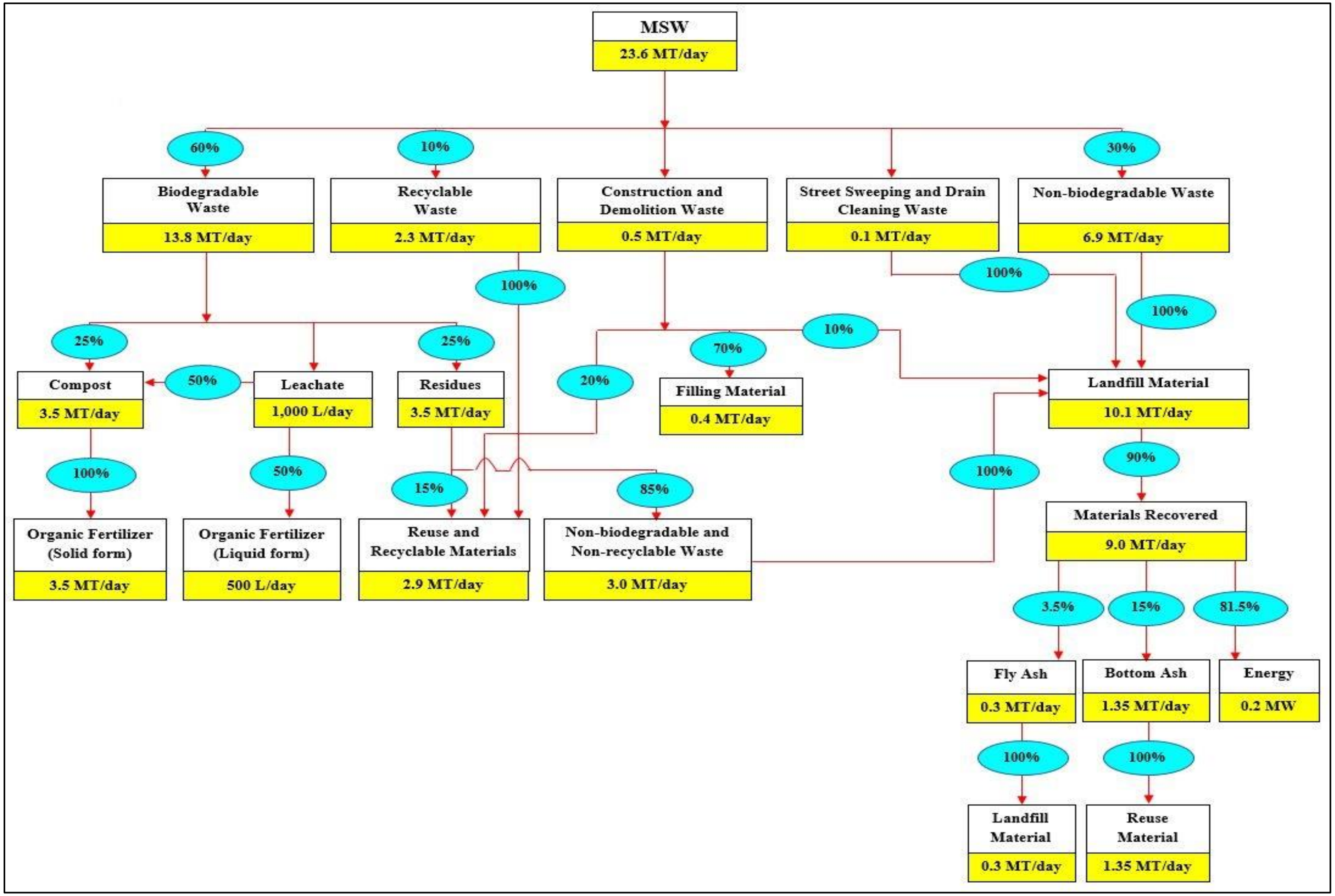


Figure 4.19: Material balance of the proposed ISWM framework

The electricity output expected to be gained from the proposed ISWM facility is calculated as follows.

Electricity output = 8.7 x 9,000 x 0.22

= 17,226 MJ/day

= 17,226 x 1.16 x 10^{-5}

= 0.2 MW

The fly ash generated from the Waste-to-Energy plant (0.3 MT/day) will be disposed of in the secure landfill in Aruwakkalu Sanitary Landfill. The bottom ash generated during energy production (1.35 MT/day) will be used for manufacturing paving blocks and the similar nature of construction materials.

The large pieces of construction and demolition waste undergoes pre-processing to break such materials into small pieces. The construction and demolition waste is used in the following manner:

1. Materials such as bricks, timber, conduits, pipes, railing, roofing tiles, asbestos sheets, etc., will be reused.
2. Materials such as plastics, broken glass, scrap metal, aluminum cans, etc., will be used recycled.
3. Materials such as rubble, concrete pieces, brickbats, etc., will be used as filling materials.
4. Fine materials such as sand will be used as a cover material over the controlled landfill.
5. The rest of the materials will be sent to the controlled landfill.

Due to the space limitations, the MSW disposed of at the controlled landfill will be kept within the controlled landfill for a minimum of 1-year. Thereafter, such MSW will be mined and sent to the Waste-to-Energy plant for producing energy.

4.2.5 Institutional arrangement

It is imperative that a proper institutional arrangement will be worked out for efficient service delivery to the people of the Kekirawa Pradeshiya Sabha. Failure to provide a sustainable institutional arrangement for the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha, the expected outcomes of the proposed ISWM framework cannot be achieved.

For proper ISWM, there needs an improved workforce in the form of an organizational structure, as suggested below (Figure 4.20).

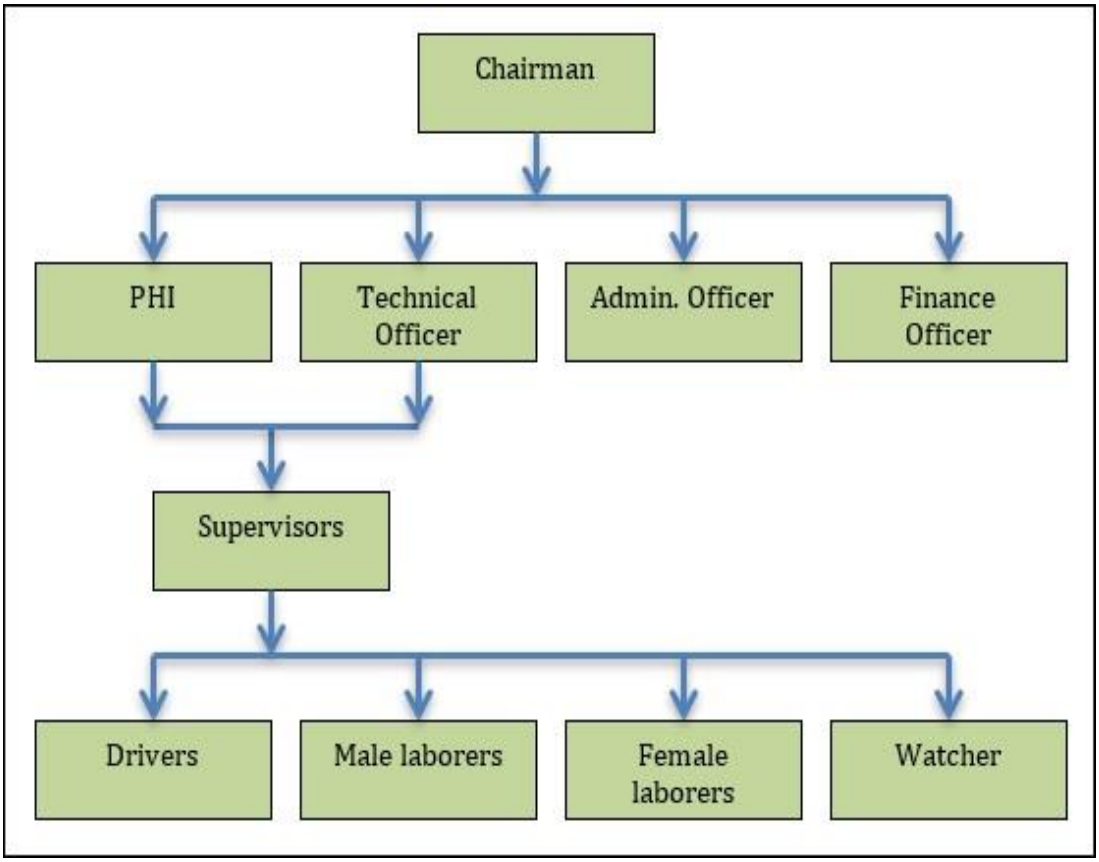


Figure 4.20: Proposed institutional arrangement for efficient ISWM

It is mandatory to have an adequate workforce for an effective and efficient ISWM within Kekirawa Pradeshiya Sabha. Table 4.11 elucidates the proposed workforce required for the operation of the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha.

Table 4.11: Summary of the conceptual design carried out for controlled landfill

Type	Existing cadre	Proposed additions	Reason for requirement
Chairman	01	00	To lead the proposed ISWM framework
PHI	00	01	To manage the implementation of the proposed ISWM framework and attend to issues cropping up
Technical Officer	01	01	To manage the newly proposed compost plant and the controlled landfill (person to be recruited needs to station at the proposed compost plant). The one who is already at work needs to look into the work related to the collection and O&M of the vehicular fleet.
Administration Officer	01	00	To manage all administrative work related to the proposed ISWM framework
Finance Officer	01	00	To manage all finances related to the proposed ISWM framework
Supervisors	02	00	One supervisor needs to station at the proposed compost plant so that he can look after the activities of the compost plant and the controlled landfill. The other person can get involved in the collection, vehicular fleet management, etc.
Drivers	04	05	Four drivers are involved in the collection work. For two garbage compactors, rectified two tractors, and a

			skid-steer loader, five new drivers are required.
Laborers (male)	22	08	At present, 22 male laborers are at work. With the supply of two garbage compactors, four male laborers will be required for the vehicular fleet. Further, four male laborers are required to be absorbed to operate the compost plant and the controlled landfill.
Laborers (female)	04	09	At present, four female laborers are at work. Further, nine female laborers are required to be absorbed to operate the compost plant, preferably for manual sorting operations, packaging, storekeeping, and street sweeping.

4.3 Development of technology options of the proposed ISWM framework

The key technology options proposed for Kekirawa Pradeshiya Sabha under the proposed ISWM framework are explained below.

4.3.1 Final disposal of MSW

A deodorization system is provided for the odor control of the following:

- Unloading area
- Waste disposal area of the controlled landfill
- Leachate collection tank
- Leachate collection network
- Garbage-collecting vehicles.

Effective microorganisms (EM) are used to remove bad odor emanates in compost plants (Higa, 2000). The EM bacterial solution is currently used in several large-scale final disposal sites of Karadiyana dumping site, Kerawalapitiya compost plant, and Aruwakkalu sanitary landfill. Therefore, EM bacterial solution was planned to be used for the odor control in the proposed ISWM facility to be implemented in Kekirawa Pradeshiya Sabha.

The minimum application rates of the EM bacterial solution mentioned below are defined based on the application rates available in the Karadiyana dumping site, Kerawalapitiya compost plant, and Aruwakkalu sanitary landfill (Table 4.12). The recommended rate of application may vary from 10–50% of the addition of EM bacterial solution. It varies on adverse weather conditions depending on the severity of the odor.

Table 4.12: Solution preparation, application rate, and frequency of application of EM bacteria

Location	**Rate**	**Method of application**	**Time of application**	**Frequency**
Unloading area	Treatment of 10 MT of MSW: Require 2 L of EM bacterial solution diluted with clean water at a 1:10 ratio	Spray using a mist bowser	During unloading	Continuous until unloading is finished
Waste disposal area of the controlled landfill	Treatment of 10 MT of MSW: Require 2.5 L of EM bacterial solution diluted with clean water at a 1:10 ratio	Spray using a jet bowser	When the severity of odor increases	Hourly treatment between 06:00 a.m. to 22:00 p.m.

Leachate collection tank	10 L of EM bacterial solution for 100 m^3 of leachate	Direct application by manually	Morning	Daily
Leachate collection network	1 L of EM bacterial solution for 10 m^3 of leachate	Direct application by manually	Continuous application	Hourly treatment between 06:00 a.m. to 22:00 p.m.
Garbage-collecting vehicles	0.25 L of EM bacterial solution for one vehicle	Direct application by manually or mechanically	When leaving the facility	Daily

The different options of the application of effective bacteria installed are depicted in Figures 4.21 to 4.24.

Option 1

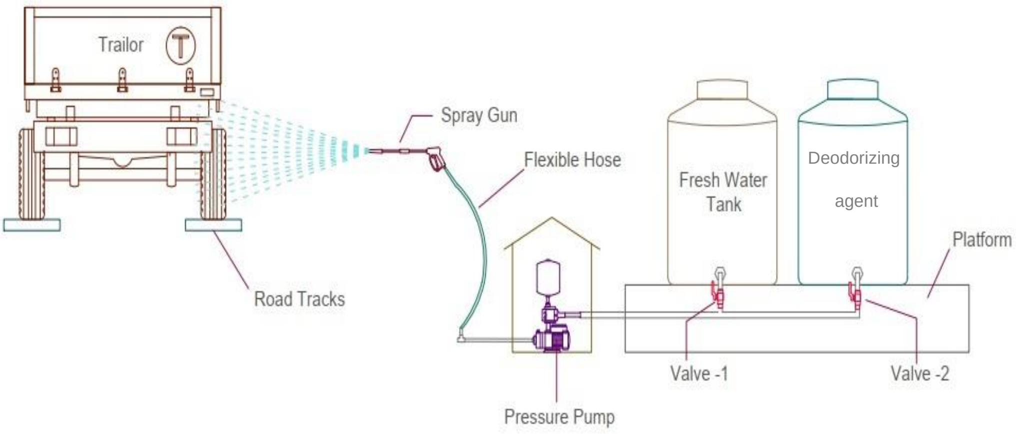


Figure 4.21: Schematic diagram of a typical deodorization system
(Manual application of deodorizing agents to a tractor)

Option 2

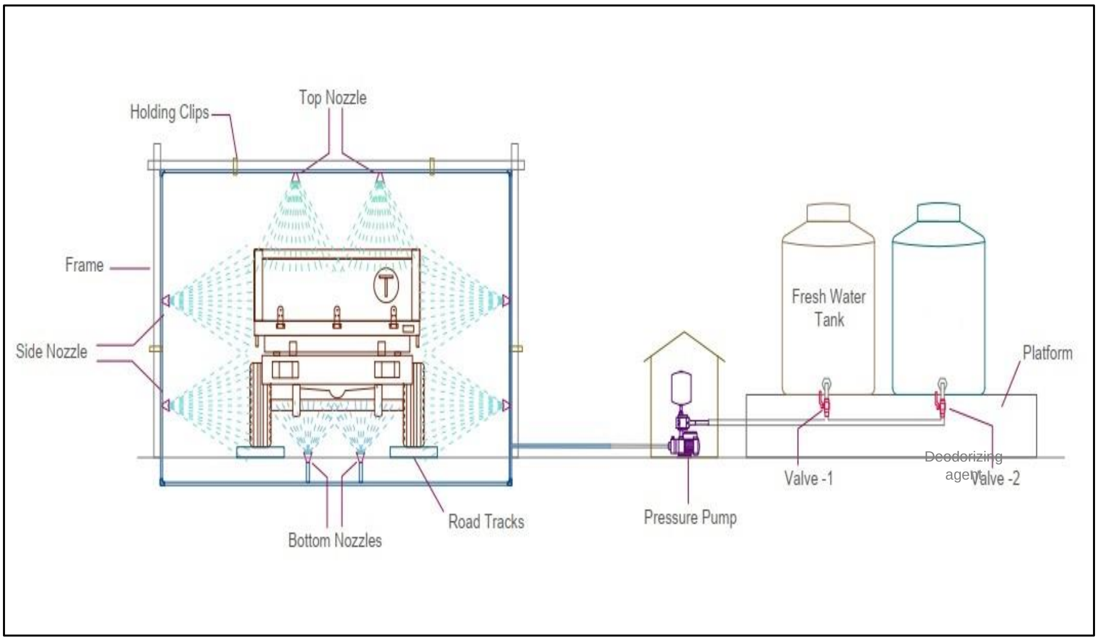


Figure 4.22: Schematic diagram of a typical deodorization system (Automated application of deodorizing agents to a tractor)

Option 3

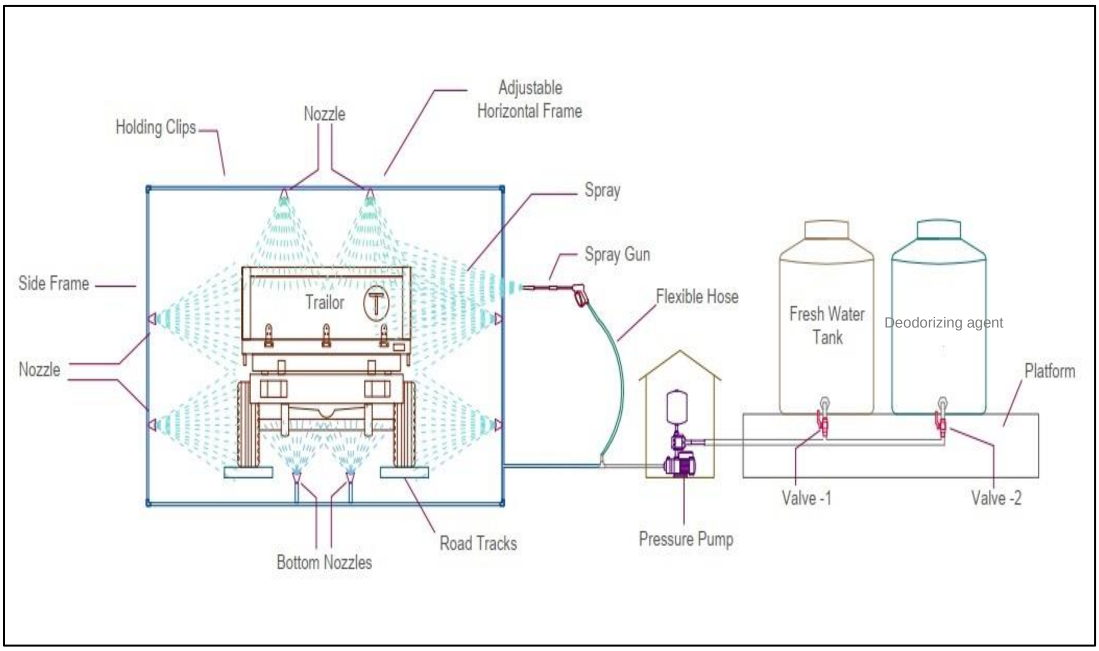


Figure 4.23: Schematic diagram of a typical deodorization system (Manual and automated applications of deodorizing agents to a tractor)

Option 4

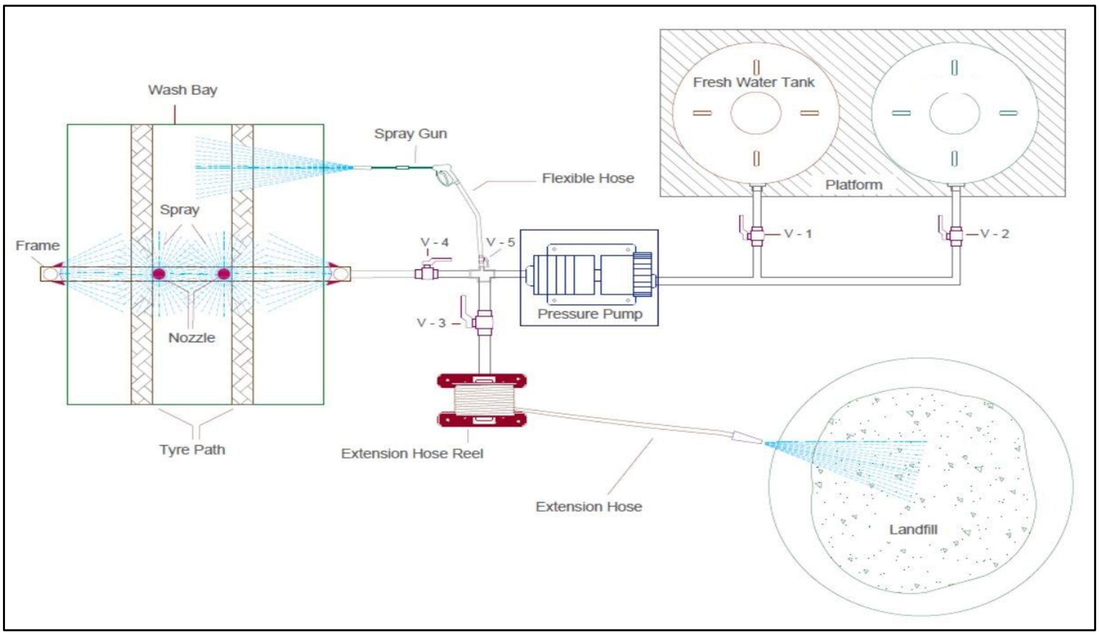


Figure 4.24: Schematic diagram of a typical deodorization system
(Manual and automated applications of deodorizing agents to several locations)

4.3.2 GPS tracking system

GPS tracking system for garbage-collecting vehicles and other mobile machinery is important to improve the efficiency of the proposed ISWM system. Garbage-collecting vehicles from the source of generation to the proposed plant are often in operation every day. However, the routes through which they travel may not be the same every day. Hence, the efficiency of such vehicles could not be assessed without a GPS tracking system. Further, the other machinery at work in the compost plant and controlled landfill needs to work for a dedicated number of hours before service. Such data may not be possible to gather without the GPS tracking system.

The architecture of the entire GPS system proposed is depicted in Figure 4.25. The proposed ISWM framework can be mounted or fitted in a secured location of vehicles and machinery. With the system being ready, one can track the vehicle easily utilizing a mobile phone by dialing the portable number of the SIM joined to the GSM modem. In such a case, the information could be retrieved as a short message on the mobile phone. This framework permits tracking the vehicle easily. This framework, as shown in Figure 4.25, comprises a microcontroller, GPS module, and GSM modem and DC control supply. GPS module gets the area data from satellites as scope and longitude. The microcontroller forms this data and sends it to the GSM modem. The GSM modem then sends the data to the cell phone.

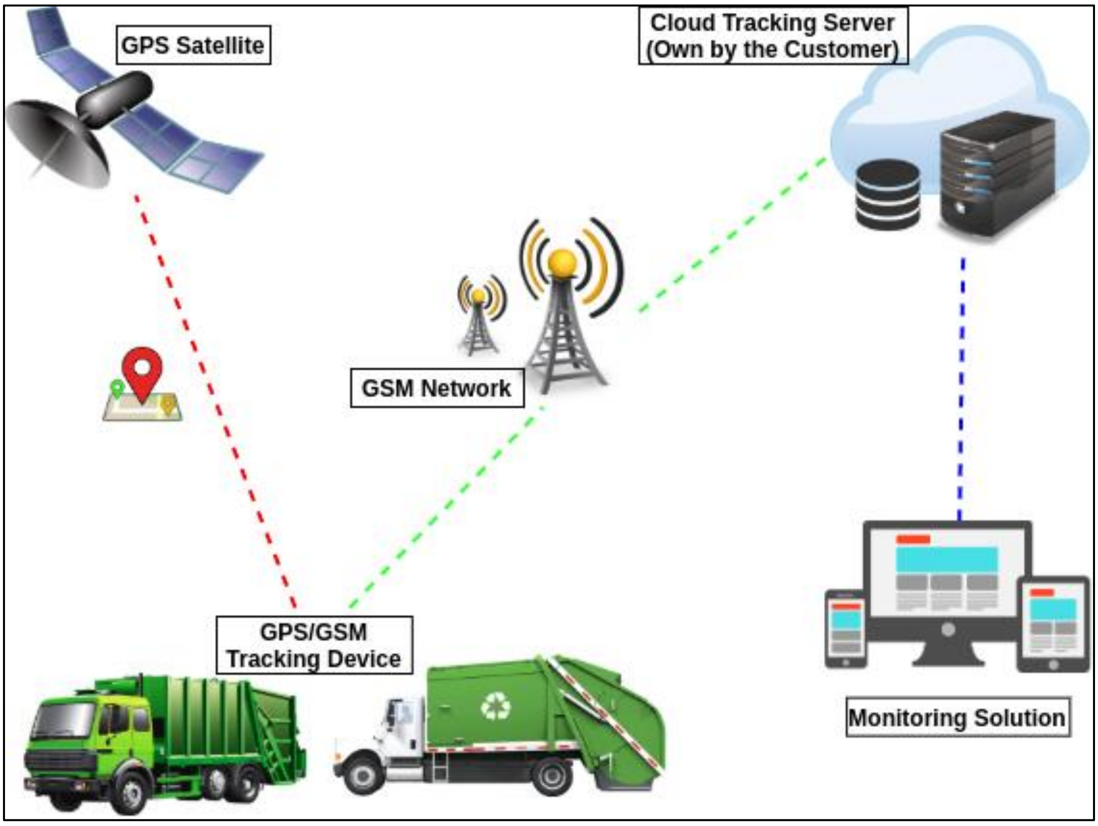


Figure 4.25: Architecture of the GPS tracking system

The vehicle tracking module is placed in a vehicle and powered up so that by entering the vehicle number, one can retrieve the status of the vehicle as “running/parking” and the traveling distance of the vehicle. If the GPS/GSM module is disconnected from the power, it appears to be “offline.” The information or data so retrieved will be stored in a commercially available cloud system so that a separate server framework needs not to be maintained. Only conventional computer and network facilities are required to be procured for the hardware system. A competent authority should analyze data so gathered, and feedback should be given to those who engaged in the system for improved service delivery.

4.3.3 Value addition to final compost product

The value addition is done based on the characteristics of the final compost product produced during the implementation of the compost plant. Table 4.13 shows the characteristics of MSW compost samples collected from compost plants in Sri Lanka (Karunarathna et al., 2013).

Table 4.13: Characteristics of compost samples collected

Parameter	Maximum value	Minimum value	Tolerance limits
pH	8.9	6.9	6.5–8.5
Electrical Conductivity (dS/m) (1:5)	8.9	1.3	-
Moisture (%)	41.0	7.6	25
Organic Carbon, % by mass, minimum)	44.3	21.9	20
Nitrogen content, % by mass, minimum	1.8	0.1	1.0
Phosphorous content, as P_2O_5, % by mass, min	1.4	0.0	0.5
Potassium content, as K_2O, % by mass, minimum	2.3	0.5	1.0
C:N	46.0	16.2	25–30

The minimum value of the total nitrogen level calculated (0.1% by mass) does not comply with the minimum level of total nitrogen to be maintained as per the SLS 1246:2003.

This study focused only on increasing the minimum level of total nitrogen measured (0.1% by mass) up to 1%. Therefore, Calcium Nitrate (powdered form) was decided to be added to enhance the total nitrogen level in the final compost product.

The details of the Calcium Nitrate used for the calculations are depicted in Table 4.14.

Table 4.14: Details of the Calcium Nitrate used

Description	**Details**
Chemical name	Calcium Nitrate
CAS number	1347-34-4
Purity	99%
Calcium (% by mass as Ca)	16.5% (Minimum)
Nitrate Nitrogen as N	11.5% (Minimum)
Ammoniacal Nitrogen as N	0.0%
Ammonium Nitrate (NH_4NO_3)	0.0%
Water content	29% (Minimum)

The amount of Calcium Nitrate to be added to enhance the total nitrogen to 1% by mass is as follows.

Calcium Nitrate to be added (Minimum) $= \dfrac{(1-0.1)\times 100 \times 100}{99 \times 11.5}$

$= 7.9$ g

Therefore, 7.9 g of Calcium Nitrate is required to be added to 100 g of compost.

The quantity of Calcium Nitrate required per day is as follows.

Calcium Nitrate to be added (Minimum) per 100 g of the final compost	=	7.9 g
Calcium Nitrate to be added (Minimum) per 1 kg of the final compost	=	79 g
Expected capacity of the final compost Product (average)	=	3,000 kg/day

Quantity of Calcium Nitrate required per day = $\frac{79 \times 3{,}000}{1000}$

= 237 kg/day

A rotary drum mixer is fixed at the value addition area. A quantity of 250 kg of final compost product and 19.75 kg of Calcium Nitrate (powdered) are added using a skid steer loader and mixed properly. After mixing, value-added compost will be packed in moisture-proof and strong packages or containers. It could be different sizes; 1 kg, 2 kg, 5 kg, 10 kg, 20 kg, or 25 kg.

4.3.4 Value addition to leachate

The value addition is done based on the characteristics of leachate generated during the implementation of the compost plant. A similar study was carried out by the University of Moratuwa in 2020 to evaluate the characteristics of leachate generated from the Karadiyana compost plant. The results are depicted in Table 4.15.

The results were compared with the Draft Specification for Liquid Organic Fertilizers by Sri Lanka Standard Institution.

Table 4.15: Characteristics of leachate

Parameter	**Levels in raw leachate**	**Tolerance limits**	**Remarks**
pH	7.5±0.1	6.0–8.5	Comply
Total Dissolved Solids (mg/L)	1,1903±51.9	Not available	-
Electrical Conductivity (dS/m)	17.814±0.5	20	Comply
Colour			
436 nm (m^{-1})	9±0.5	Not available	-
525 nm (m^{-1})	8.3±0.5	Not available	-
620 nm (m^{-1})	7±0.5	Not available	-

BOD (mg/L)	777.2±128.9	Not available	-
COD (mg/L)	10,684.0±243.2	Not available	-
Turbidity (NTU)	15.9±0.2	Not available	-
Orthophosphates as P (mg/L)	1.2±0.1	Not available	-
Total Phosphorus as P_2O_5, % by mass, minimum	0.001	0.5	Not comply
TKN as N (mg/l)	1,920.5±25.3	Not available	-
Nitrate as N (mg/L)	64.1±2.6	Not available	-
Nitrite as N (mg/L)	Not detected	Not available	-
Total Nitrogen as N, % by mass, minimum	0.2	1.0	Not comply

The following calculation enumerates the method of the calculation of existing levels of total nitrogen in raw leachate.

Total Nitrogen as N (Minimum) = TKN as N + Nitrate as N + Nitrite as N

= (1,920.5 – 25.3) + (64.1 – 2.6) + 0

= 1,956.7 mg/L as N

Total Nitrogen as N (Maximum) = TKN as N + Nitrate as N + Nitrite as N

= (1,920.5 + 25.3) + (64.1 + 2.6) + 0

= 2,012.5 mg/L as N

Density of leachate = 1,010 kg/m^3

Total Nitrogen as N (Minimum) = $\frac{1{,}956.7 \times 100}{1{,}010}$

= 0.2% by mass

This study focused only on increasing the total nitrogen level measured (0.2% by mass) up to the minimum level of total nitrogen to be maintained (1% by mass) as per the Draft Specification for Liquid Organic Fertilizers by Sri Lanka Standard Institution. Therefore, Calcium Nitrate was decided to be added to enhance the total nitrogen level in the raw leachate. The details of the Calcium Nitrate used for the calculations are depicted in Table 4.12.

The amount of Calcium Nitrate to be added to enhance the total nitrogen to 1% by mass is as follows.

Calcium Nitrate to be added (Minimum) = $\frac{(1-0.2)\times 100 \times 100}{99 \times 11.5}$

= 7.1 g

Therefore, 7.1 g of Calcium Nitrate as N is required to be added to 100 mL leachate to comply with the minimum level of total nitrogen to be maintained as per the Draft Specification for Liquid Organic Fertilizers by Sri Lanka Standard Institution.

The quantity of Calcium Nitrate required per day is as follows.

The leachate generation on average during composting is 75 L/MT

Leachate generation on average during composting per day = 75 L/MT

Total generation of leachate per day = 75 x 13.1

= 982.5 L/day

Volume of leachate to be recirculated = 982.5 x 47.1%

= 462.76 L/day

Volume of the leachate to be used for for producing liquid fertilizer = 982.5 – 462.76

= 520 L/day

Calcium Nitrate to be added (Minimum) per 100 mL of final compost = 7.1 g

Calcium Nitrate to be added (Minimum) per 1 L of final compost = 71 g

Quantity of Calcium Nitrate required per day = $\frac{71 \times 520}{1000}$

= 36.92 kg/day

The total quantity of Calcium Nitrate (powdered form) required is 36.92 kg/day. An agitator is fixed inside the 5,000 L tank to mix Calcium Nitrate with leachate uniformly. The leachate will be filtered to remove suspended solids before filling into bottles. A filling machine and bottles for storing purposes are required to be purchased. The capacities of 1-, 5-, and 10-L bottles or cans are suitable for storing and selling purposes.

4.4 Monetary analysis for the long-term sustenance of the proposed ISWM framework

4.4.1 Financial analysis for the proposed ISWM framework

Financial analysis was carried out to evaluate whether the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha is financially profitable or not. The following sections enumerate the summary of the details of the financial analysis carried out. The detailed financial analysis is given in Annexure 4.9.

4.4.1.1 Capital expenditure

The summary of the capital expenditure incurred for the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha is depicted in Table 4.16.

Table 4.16: Summary of the capital expenditure incurred

Item no.	Description of the item	Total amount (SLR)
1	Preliminary investigations	3,730,000
2	Sorting at source	500,000
3	Collection and transport	15,250,000
4	Compost plant and office premises	183,672,500
5	Recycling and reusing waste	500,000
6	Controlled landfill and Constructed wetland	20,794,000
A	Total amount (Item no. 1 to 6)	224,446,500
B	Contingencies (5%)	11,222,325
C	Total amount (A + B)	235,668,825
D	VAT (8%)	18,853,506
E	Grand total (C + D)	**254,522,331**

The total capital incurred for the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha is SLR 254.52 million, including VAT.

4.4.1.2 Operation and maintenance cost

The summary of the O&M costs incurred during the operation of the proposed ISWM framework in Kekirawa Pradeshiya Sabha is depicted in Table 4.17.

Table 4.17: Summary of the O&M cost incurred

Item No.	Description of the item	Unit rate (SLR)	Sub-total (SLR) per annum
1	**Environmental monitoring**		
1.1	Environmental monitoring aspects, including gas in the controlled landfill, water quality in the nearby canal network, groundwater quality, etc.	60,000 per year	60,000
2	**Source-segregation**		
2.1	Distribution of leaflets, propaganda campaigns through public announcements from time to time during the operation	500,000 per year	500,000
3	**Collection and transport:**		
3.1	Preventive Maintenance of all vehicles involved in the collection	300,000 per month	3,600,000
3.2	Corrective Maintenance of all vehicles involved in the collection	300,000 per month	3,600,000
3.3	Major repair for vehicular fleet	1,000,000 per year	1,000,000
3.4	Management of GPS-assisted garbage-collecting vehicular tracking system	10,000 per month	120,000
3.5	Fueling for the vehicular fleet (Assuming eight numbers of vehicles running 40 km on average for a day)	8,000 per day	2,920,000
4	**Compost plant**		
4.1	Training for employees	50,000 per year	50,000

4.2	Machinery and equipment maintenance	100,000 per month	1,200,000
4.3	Fuel cost for machinery	1,000 per day	365,000
4.4	Electricity, water, telecommunication	300,000 per month	3,600,000
4.5	Cost of EM bacterial solutions for odor control (EM bacterial solution will be sprayed to the landfill and compost plant, if necessary)	100,000 per month	1,200,000
4.6	Packaging of finished compost and leachate (Two workers for packaging finished compost product - 3 MT/day)	2,500 per day	912,500
4.7	Packaging of finished liquid fertilizer (Two workers for packaging finished compost product - 500 L/day)	2,500 per day	912,500
4.8	Value addition to the finished compost and liquid fertilizer	2,500 per day	912,500
4.9	Main office/administration cost, including stationery	50,000 per month	600,000
4.10	Building maintenance cost	100,000 per month	1,200,000
4.11	CCTV network maintenance	10,000 per 3 months	40,000
4.12	Approval renewals (EPL)	50,000 per annum	50,000
4.13	Cost for personal protective gears for employees	100,000 per month	1,200,000

4.14	Welfare and medical expenditure for employees	142,500 per month	1,710,000
4.15	Cost of maintaining security	100,000 per month	1,200,000
5	**Recycling and reusing waste:**		
5.1	All costs related to this item are taken care of under composting section. Therefore, please refer the Item no. 04	-	-
6	**Controlled landfill:**		
6.1	Supply of soil suitable for sub-base (1 m^3 is around 2,000 and needs 2 m^3 for a day including daily cover, etc.)	3,000 per day	1,095,000
6.2	Tipping fee to be paid to the Waste-to-Energy plant, including transport	3,000 per ton	9,855,000
6.3	All the other costs related to the controlled landfill site is allocated under composting	-	-
7	**Others**		
7.1	Salaries and wages (including new recruitments)	855,000 per month	10,260,000
Annual total (O&M cost)			**48,162,500**

The total annual O&M cost incurred during the implementation of the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha is SLR 48.16 million.

4.4.1.3 Revenue generation

The summary of the revenue generated during the operation of the proposed ISWM framework in Kekirawa Pradeshiya Sabha is depicted in Table 4.18.

Table 4.18: Summary of the revenue generation

Item No.	Description of the item	Unit rate (SLR)	Sub-total (SLR) per annum
1	Collection tariff from commercial establishments (200 numbers within the territory of Kekirawa Pradeshiya Sabha area where the collection is done)	1,000 per month per entity	2,400,000
2	Selling of recyclables	12,000 per month	144,000
3	Selling of construction and demolition waste for filling	10,000 per month	120,000
4	Selling of value-added compost (3,000 kg/day)	25 per 1 kg of finished compost	27,375,000
5	Selling of value-added leachate (liquid fertilizer - 400 L/day)	40 L per 1 L of liquid fertilizer	5,840,000
5	Accepting MSW under emergency case (1 MT at a rate of SLR 1,500); Anticipating 30 MT per month	180,000 per month	2,160,000
Annual total (Revenue generation)			**38,039,000**

The total annual revenue generation during the implementation of the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha is SLR 38.039 million.

4.4.1.4 Financial feasibility

The financial analysis was carried out for 24 years, of which 23 years are operational. Based on the capital cost, O&M cost, and revenue generation calculated above, cash flow was prepared. The NPV was obtained as SLR -175.13 million at an interest rate of 10%. The IRR was obtained as 4%. Since the NPV showed a negative value, IRR was very low; hence, the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha is not financially feasible. Therefore, economic feasibility was carried out.

4.4.2 Economic analysis for the proposed ISWM framework

The economic analysis was carried out to evaluate whether the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha is economically feasible. Under economic analysis, indirect costs and benefits are taken into account.

The major indirect benefits are as follows:

1. The emission of GHG will be greatly reduced as a result of the proposed ISWM facility.
2. The ISWM project will certainly enhance land value appreciation and revaluation.
3. City development, road development, and city beautification will minimize health concerns.
4. Improvements in health and childcare, tourist attraction, and the promotion of tourism are expected.
5. Direct and indirect employment opportunities will be generated.

The infrastructure improvements to be carried out during the implementation of the proposed ISWM framework will assist Kekirawa Pradeshiya Sabha in delivering more effective infrastructure services and providing a better environment and quality of life than would otherwise exist.

This study only evaluated the indirect benefits gained through reducing the emission of GHG. The details are as follows.

4.4.2.1 Estimation of the reduction of GHG emissions

a) Methane Generation

The total amount of methane generated in the dumpsite was calculated using the default method stated in the IPCC guidelines (2000). The methane generation was calculated before and after implementing the proposed ISWM facility in Kekirawa Pradeshiya Sabha.

<u>Methane generation before implementing the proposed ISWM facility</u>

Methane generation = $\left(\mathrm{W} \times \mathrm{MCF} \times \mathrm{DOC} \times \mathrm{DOC_F} \times \mathrm{F} \times \frac{16}{12}\right) \times (1 - \mathrm{R}) \times (1 - \mathrm{OX})$

DOC = (0.4 x A) + (0.17 x B) + (0.15 x C) + (0.3 x D)

= (0.4 x 0.18) + (0.17 x 0.3) + (0.15 x 0.513) + (0.3 x 0.007)

= 0.2

W = 41 x 365 / 1000

= 14.965 $\mathrm{GgYr^{-1}}$

MCF = 0.4

$\mathrm{DOC_f}$ = 0.77

F = 0.6

R = 0

OX = 0

Methane generation before implementing the proposed ISWM facility

$$= \frac{14.965 \times 0.4 \times 0.2 \times 0.77 \times 0.6 \times 16 \times (1 - 0) \times (1 - 0)}{12}$$

= 0.75 $\mathrm{GgYr^{-1}}$

Methane generation after implementing the proposed ISWM facility

W = 41 x 0.6 x 0.25 x 365 / 1000

= 2.245 $GgYr^{-1}$

Methane generation after implementing the proposed ISWM facility

$$= \frac{2.245 \times 0.4 \times 0.2 \times 0.77 \times 0.6 \times 16 \times (1-0) \times (1-0)}{12}$$

= 0.11 $GgYr^{-1}$

Therefore, the reduction of methane emission due to the implementation of the proposed ISWM framework in Kekirawa Pradeshiya Sabha was 0.64 $GgYr^{-1}$.

CO_2 equivalence = 36 x 0.64

= 23.04 $GgYr^{-1}$

Carbon equivalence = 23.04 x 12/44

= 6.28 $GgYr^{-1}$

Monetary value of the global warming impact

= 6.28 x 1,000 x 13.2 x 199.54

= SLR 16,541,067.84

The indirect benefit gained through the reduction of GHG emission of the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha was SLR 16.54 million.

4.4.2.2 Economic feasibility

The summary of the details of the economic analysis carried out is depicted in Table 4.19. The detailed economic analysis is given in Annexure 4.10.

Table 4.19: Summary of the economic analysis

Description	**Value**
Capital cost	SLR 235,668,825
O&M cost (annual)	SLR 48,162,500
Revenue generation (annual)	SLR 38,039,000
Indirect benefit due to the reduction of GHG emissions (annual)	SLR 16,376,022
NPV at an interest rate of 10%	SLR 66,522,277
IRR	12%

Based on the results as depicted in Table 4.19, it can be stated that the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha was economically feasible.

5. DISCUSSION

MSWM has become a universal issue that affects every individual in the world (Kaza et al., 2018). The increase in the generation of MSW worldwide demands the development of MSWM strategies to ensure a sustainable environment (Khandelwal, 2019). Such strategies to be developed should be environmentally, socially, and financially feasible, and legally acceptable (Abdel-Shafy and Mansour, 2018). The ISWM concept provides a multi-disciplinary and comprehensive approach for MSWM (Abdoli et al., 2016), addressing all aspects of MSWM, including generation, source-segregation, collection and transport, sorting, recovery, treatment, and disposal by carefully examining local needs and conditions. ISWM emphasizes the need to implement the 3R principle based on the circular economy concept (Wilson et al., 2013). The circular economy concept strives to limit pollution potential while maximizing the resource potential of waste (Dumlao-Tan and Halog, 2017). The process “Recycle” is a highly promoted strategy in the circular economy, which is also a key element of ISWM. However, waste minimization and reduction of the use of resources are also required under the circular economy concept (Bermejo, 2014).

ISWM with the cope of circular economy perspectives has been practiced worldwide for MSWM operations. Schneider et al. (2017) identified the potential of the application circular economy concept for recyclable waste accumulated in Ho Chi Minh City, Vietnam. Salguero-Puerta et al. (2019) manifested that the application of the circular economy concept for MSWM at the University of Lome, Togo, was successful and recommended to be used for the entire country. Ilic and Nikolic (2016) proposed an innovative strategy for integrating the best Zero Waste initiatives in municipalities in Serbia using the circular economy concept. Bekchanov and Mirzabaev (2018) carried out a study on the circular economy for composting in Sri Lanka and came up with several recommendations to reduce waste-related pollution and improve the health of the soil. The recommendations made by the study carried out by Samarasinghe et al. (2021) to transform to a circular economy for plastic waste in Sri Lanka are source-segregation of plastic wastes, landfill mining to collect non-recyclable plastics for energy production, and integration of formal and informal sectors. It is obvious that ISWM, with the incorporation of circular economy, is successful in MSWM operations worldwide.

In Sri Lanka, MSWM has become a national issue (Karunarathne, 2015). Many urban areas in Sri Lanka are facing severe difficulties in managing 10–50 MT/day of MSW (Saja et al., 2021). In Sri Lanka, the major emphasis is placed on landfills, and it has become the common practice though it should be the least preferred option of ISWM hierarchy (Karunarathne, 2015). In 2019, Sri Lanka produced more than 260 open dumps of various magnitudes in the country (Jayaweera et al., 2019). The National Action Plan of Sri Lanka has highlighted that the haphazard disposal of MSW is one of the major causes of environmental degradation (Bandara, 2011). As a long-lasting solution to MSWM in Sri Lanka, the application of the ISWM approach for MSWM has been promoted by the government's new policy on "Vistas of Prosperity and Splendor," the National Physical Plan prepared by the Department of Physical Planning, the Draft National Environmental Policy, 2021, Ministry of Environment, CEA, and various governmental and non-governmental organizations in the country. Though such initiatives have been taken, implementing the ISWM approach for MSWM in Sri Lanka is still a question. Therefore, it is prudent that ISWM, with the incorporation of circular economy perspectives, provides a long-lasting solution to MSWM in Sri Lanka.

The study focused on developing an ISWM framework by incorporating circular economy perspectives to be applied for the MSWM operations carried out by local authorities in Sri Lanka. The proposed ISWM framework was applied for the MSWM operations carried out by Kekirawa Pradeshiya Sabha and evaluated the long-term sustenance of the proposed ISWM framework by carrying out an economic analysis.

The present status of MSWM operations carried out by Kekirawa Pradeshiya Sabha was evaluated through a questionnaire survey, field visits, meetings with officials involved in existing MSWM practices, and a literature survey. It was identified that the current MSWM operations carried out by Kekirawa Pradeshiya Sabha are not up to a satisfactory level. During the study, several gaps were identified in the current MSWM practices. Such gaps identified were lack of MSW collection, unavailability of source-segregation, non-availability of a place for collecting construction and demolition waste, lack of garbage-collecting vehicles, open dumping, odor emanates from the open dump, spreading of flies, rodents, and other insects, unavailability of a mechanism to collect and treat leachate accumulated in the open dump, and poor aesthetic appearance. Collection of mixed waste, poor MSW collection, littering, and open dumping are current issues identified in MSWM practices carried out by developing countries (Trinh et al., 2021; Trinh et al., 2021; Noufal et al., 2020). Fernando (2019) highlighted administrative issues pertaining to the current MSWM practices in Sri Lanka. Poor public participation, financial constraints, and unavailability of suitable lands for the disposal of MSW were identified as the key issues, which affect the successful implementation of the MSWM system (Bandara, 2011).

An ISWM framework was developed by giving due consideration by way of MSW prevention, reuse and recycling, composting, and final disposal in an environmentally acceptable way with controlled landfilling. The 3R concept was highly promoted, and through which MSW to be disposed of in the form of a landfill will be greatly reduced. The circular economy perspectives were incorporated into the proposed ISWM framework developed by carefully analyzing the reuse potential of by-products generated from the proposed MSWM techniques. Such initiatives proposed are explained below.

The design period of the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha was ten years. The design period was selected based on the area of the land provided by Kekirawa Pradeshiya Sabha for constructing the proposed ISWM facility. If greater design periods are selected, phase-wise development is encouraged under the proposed ISWM framework. Since the design period is ten years, no phase-wise construction was proposed. The following features were taken into consideration under the proposed ISWM framework for Kekirawa Pradeshiya Sabha. The features were; (1) Reduce the amount of MSW generation through the implementation of the 3R concept, (2) Increase the MSW collection by improving the vehicular fleet and workforce, (3) Enhance reuse and recycle potential with the provision of a resource center, (4) Construct a composting facility for biodegradables, including value-addition to final compost and leachate, (5) Construct a facility for the collection and pre-processing of construction and demolition waste, and (6) Construct a facility for controlled landfilling for residues. The residues to be disposed of at the controlled landfill will be mined after keeping at the landfill for a minimum of 1-year and sent to a Waste-to-Energy plant for generating electricity. Since the residues disposed of at the controlled landfill will be mined, the lifespan of the controlled landfill will be extended. Further, only fly ash generated during incineration of residues at the Waste-to-Energy plant will be disposed of at a controlled landfill. The quantity of fly ash will only be the amount that cannot be reused or recycled, and it accounts for 1.3% of the total MSW collected.

The implementation of the 3R concept was the first step to reduce the MSW generation under the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha. The ISWM, based on the 3R concept, aims to improve overall waste management operations from all the waste-generating sectors, including MSW, while involving all the stakeholders in the waste sector (Memon, 2010). According to Malakahmad et al. (2010), the ISWM necessitates the employment of appropriate methodologies, technologies, and management systems to reduce waste generation and increase the reuse and recycle rate. Under this study, it was proposed to have capacity-building programs for all stakeholders involved in the MSWM practices to promote the 3R concept. Further, propaganda work for the reduction, reuse, and recycling of MSW among people through media, paper, NGO involvement for door-to-door campaigns, etc., was proposed to be conducted. Kurian (2012) pointed out that any solution proposed for the MSWM operations should address MSW reduction, source-segregation, and community-level implementation; otherwise, it becomes unsustainable.

Source-segregation is a mandatory requirement to be satisfied under the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha. Under the proposed ISWM framework, MSW generated is subjected to sorting at source into categories such as biodegradables, recyclables, construction and demolition waste, street sweeping waste, and non-biodegradables. The Solid Waste Management Rules (2016), prepared by the Union Ministry of Environment, Forests and Climate Change, India, mandated the source-segregation before handing the MSW to waste collectors. Bortoleto et al. (2006) highlighted that the quality of the recyclable waste was improved because the majority of the community in Porto Alegre, Brazil, accepted and helped to source separation through a selective collection. According to the proposed ISWM framework, making people aware of the source-segregation efforts should be done in the form of leaflets distributed by visiting door-to-door. In this effort, the assistance of NGOs, societies, and popular personalities could be looked for. According to Asam et al. (2018), the efficiency of source-segregation in semi-urban and rural areas of Pakistan was improved from 0% to 52% due to the implementation of awareness campaigns. Saja et al. (2021) manifested that a comprehensive source-segregation is not possible in congested cities of Sri Lanka; hence, it was proposed to provide sorting facilities at final disposal sites.

Hazra and Goel (2009) manifested that the efficiency of the collection of MSW is affected by lack of garbage-collecting vehicles, improper planning of collection routes, unavailability of proper collection schedules, and improper ways of MSW collection. Vidanaarachchi et al. (2006) highlighted that the total coverage of the MSW collection is low in the Southern Province of Sri Lanka due to the aging of the existing vehicular fleet used for MSW collection and recommended increasing the collection of MSW with an immediate effect. Due to the unavailability of adequate garbage-collecting vehicles and the aging of the existing vehicular fleet, the current collection of MSW by Kekirawa Pradeshiya Sabha is 17% of the total MSW collection. The current collection (17%) of MSW by Kekirawa Pradeshiya Sabha will be increased to 50% from the total MSW generation with the proposed ISWM framework. The collection of source-segregated MSW will be increased by strengthening the existing vehicular fleet. Two compactors with a capacity of 6–8 m^3 each will be provided, and collection routes will be optimized to collect the 50% of MSW generated within the territory of Kekirawa Pradeshiya Sabha. The collection schedules and collection routes will be optimized under the proposed ISWM framework; hence, the effectiveness of MSW collection and transport was planned to be increased in Kekirawa Pradeshiya Sabha.

Rai et al. (2019) manifested that the inefficiencies in MSW collection resulted in extra investment for waiting times. Further, Rai et al. (2019) pointed out that the poor collection of MSW leads to open burning and improper dumping at the source by MSW generators.

The ISWM framework developed proposed composting as a long-lasting solution for the final disposal of biodegradables. Therefore, a fully-fledged compost plant was designed for this study. The compost plant is capable of handling the design capacity of 13.8 MT/day of biodegradable waste to be received at the end of the design period (10 years). The method of composting proposed was passively aerated windrow composting. Favorable C:N ratio was proposed to be maintained in the feedstock, and bulking agents will be stored to be used to balance the C:N ratio. Herity (2003) manifested that the bulking agents are to be added to balance the C:N ratio and to maintain moisture content and porosity of the final feedstock to be composted. Moreover, successful implementation of source-segregation and carrying out shredding operations, turning of windrow piles, and maintaining favorable moisture content and temperature should be strictly followed during composting to obtain high-quality compost product. Richard (1992) pointed out that the type of feedstock used, extend of source-segregation, the method utilized for composting, and the maturation period are some of the major factors which influence the final quality of compost.

The expected outcome of the compost was 3.5 MT/day. The final quality of the compost shall comply with the minimum level of total nitrogen to be maintained as per the SLS 1246:2003 - Specification for Compost from Municipal Solid Waste and Agricultural Waste. Based on the results obtained from the study carried out by Karunarathna et al. (2013) manifested that the minimum value of nitrogen, phosphorous, and potassium in the samples analyzed were 0.1%, 0.0%, and 0.5% by mass. The minimum values measured were less than the tolerance limit values as stipulated for nitrogen (1% by mass), phosphorous (0.5% by mass), and potassium (1% by mass) in the SLS 1246:2003. The FAO (2001) specified that the Nitrogen content in the organic fertilizer should not be less than 1%, while the Phosphorous and Potassium content should not be less than 1.5%. Barker (1997) manifested that the

Nitrogen content should be greater than 1% in the final compost to be used for agricultural purposes. Generally, compost has an optimum nitrogen content which is required for plant growth (Khater, 2015). Further, compost fertilizer releases nutrients gradually through mineralization (Ayilara et al., 2020). Kludge et al. (2008) specified that nitrogen content in compost is rather low in the short term, but application over a longer period provides a measurable effect. Since Kekirawa is a small-scale agriculture-based city, the value-added compost will completely be utilized for agricultural lands in Kekirawa.

The minimum Nitrogen level measured through the study carried out by Karunarathna et al. (2013) was 0.1% by mass (Table 4.13). The low content of nitrogen in compost does not enhance plant growth (Ayilara et al., 2020). In such circumstances, the addition of nutrient-rich substrate will enhance the nutritive and agronomic value of the final compost. Additives will enhance the availability and nutrient content in the final compost product (Gabhane et al., 2012; Morales et al., 2016). The study focused only on increasing the minimum level of total nitrogen measured (0.1% by mass) up to 1%. Ammonia (NH_3), Ammonium Nitrate (NH_4NO_3), Urea [$CO(NH_2)_2$], Calcium Nitrate [$Ca(NO_3)_2$], and Ammonium Sulphate [$(NH_4)_2SO_4$] are nitrogen-based fertilizers used in Sri Lanka. Mengel (1986) pointed out the percentages of nitrogen by mass of different nitrogen-based fertilizers, and the details are depicted in Table 5.1.

Table 5.1: Percentage of nitrogen by mass of different fertilizers

Fertilizer	**Percentages of nitrogen by mass**
Ammonium Nitrate (NH_4NO_3)	33.5%
Ammonium Sulphate [$(NH_4)_2SO_4$]	20.5%
Calcium Nitrate [$Ca(NO_3)_2$]	15.5%
Urea [$CO(NH_2)_2$]	45%

Over the other types of nitrogen-based fertilizers, Calcium Nitrate provides fast-acting nitrate and strength-building calcium. Other than that, Calcium Nitrate increases the pH; hence, acidic conditions of soil will be neutralized. By adding Calcium Nitrate, calcium deficiencies of soil and certain crops (e.g., tomatoes) will be sought out (Grant, 2021). Calcium Nitrate also protects plants from diseases, especially from "Blossom end rot." Therefore, Calcium Nitrate (powdered form) was decided to be added to enhance the total nitrogen level in the final compost product. A quantity of 250 kg of final compost product and 19.75 kg of Calcium Nitrate (powdered) are added using a skid steer loader and mixed properly.

The leachate generation from the biodegradable waste to be composted was estimated as 75 L/MT. The typical quantities of leachate generation during composting are 75–100 L/MT (Liu et al., 2010, 2015; Hashemi et al., 2017). Therefore, a total quantity of 1,000 L/day of leachate will be generated from the proposed compost plant to be implemented in Kekirawa Pradeshiya Sabha. Based on the literature, the leachate generated from the plants with capacities ranging from 1,000–1,500 MT/day generates 4–400 m^3/day of leachate (Bakhshoodeh et al., 2017; He et al., 2015). The recirculation of leachate reduces the total amount of leachate produced by 47.1% (Bilgili et al., 2007). A quantity of 500 L/day of leachate will be recirculated to the windrow piles in the active composting area and curing area. Therefore, the quantity of excess leachate was calculated as 500 L/day, which will be used to produce liquid fertilizer. The total nitrogen and total phosphorous levels measured in the leachate collected from the Karadiyana compost plant by the University of Moratuwa were 1,984.6 mg/L and 5.3 mg/L, respectively. Sanadia et al. (2019) highlighted that the characteristics of leachate derived from MSW diverge rapidly based on the source of MSW generated and the age of leachate. Based on the study carried out by Sanadi et al. (2019) pointed out that the total nitrogen level measured in the leachate derived from MSW was 630–2,438 mg/L.

The minimum total nitrogen level measured (0.2% by mass) in raw leachate does not comply with the minimum level of total nitrogen (1%) to be maintained as per the Draft Specification for Liquid Organic Fertilizers by Sri Lanka Standard Institution. The study focused only on increasing the minimum level of total nitrogen measured (0.1% by mass) up to 1%. Therefore, a value addition process will be carried out only to enhance the total nitrogen level in raw leachate to 1% by mass. As explained above, Calcium Nitrate was planned to be added to enhance the final quality of leachate to be used as a liquid fertilizer. Calcium Nitrate is completely soluble in water (IFFCO, 2016). The total quantity of Calcium Nitrate (powdered form) required is 36.92 kg/day. An agitator is fixed inside the 5,000 L tank to mix Calcium Nitrate with leachate uniformly. The leachate will be filtered to remove suspended solids before filling into bottles. A filling machine and bottles for storing purposes are required to be purchased. The capacities of 1-, 5-, and 10-L bottles or cans are suitable for storing and selling purposes.

A resource collection center for the collection of recyclables (2.9 MT/day) will be built within the same premises. The materials collected in the resource center will be sold to the collectors registered with the CEA.

The construction and demolition waste collected (0.5 MT/day) will be gone through a pre-processing step. A quantity of 0.35 MT/day of pre-processed construction and demolition waste will be used as a filling material, while 0.1 MT/day will be reused or recycled, and the rest will be sent to the controlled landfill. Islam et al. (2019) manifested that the materials like brick, timber, ceramic, glass, metal, concrete can be reused. Jane et al. (2018) pointed out that 75% of the concrete debris can be used as aggregates for fresh concrete after crushing into small sizes. Zhao et al. (2010) manifested that majority of broken bricks can be used as a raw material for manufacturing bricks. The crushed mortar can be used as a fine aggregate (Islam et al., 2019). De-nailed and cleaned timber boards can be used for construction works. Gilpin et al. (2004) indicated that the greater portion of recycled aggregates derived from construction and demolition waste is used for filling operations.

A controlled landfill will be built in the same land next to the compost plant to dispose of the quantity of 10.1 MT/day of non-biodegradable waste (7.0 MT/day) together with a part of the residues from the compost plant (3 MT/day), and street sweeping and drain cleaning waste (0.1 MT/day). The controlled landfill is 8 m in height, with a projected area of approximately 95-perch. The entire landfill will be operated in two layers, each of which has a height of 4 m. The landfill could be operative only for about 21 months due to space limitations. A sandwiched layer of liner materials (clay layer and geo-fabric layer) will be provided for controlling groundwater pollution. A drainage network will be built at the perimeter of the landfill to collect and direct leachate and leachate-rich stormwater to the constructed wetland (nature-based solution) for subsequent treatment. The treated wastewater will be utilized for irrigation of vegetation in the buffer zone. The excess amount will be discharged to the roadside drainage.

A 10% of the waste materials disposed of at the controlled landfill will be degraded with time (1-year minimum), and thereafter, the landfill is mined, and waste materials (9 MT/day) will be sent to a Waste-to-Energy plant for producing energy. Bharadwaj et al. (2015) indicated that the energy recovery by incineration of MSW after removing all recyclables is a suitable option. A calorific value of 8–12 MJ/kg is required in the waste being incinerated for effective energy generation (Melikoglu, 2013). The calorific value of the MSW collected from Kekirawa Pradeshiya Sabha to be sent for the Waste-to-Energy plant was estimated as 8.7 MJ/kg. The electricity generation is 0.2 MW. The bottom ash (1.35 MT/day) generated from the plant will be used as a reuse material for manufacturing paving blocks, curbstones, etc. The fly ash (0.3 MT/day) generated from the plant will be disposed of at a sanitary landfill. Brunner and Rechberger (2015) specified that the MSW to bottom ash ratio in terms of mass is approximately 4:1, while bottom ash to fly ash is 10:1. Since the waste disposed of in the controlled landfill is mined and sent for incineration, the landfill lifespan will be enhanced.

For the smooth functioning of the operations of the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha, a committee for decision-making at the local authority level should be appointed. This committee must be empowered to operate the entire asset base related to the proposed ISWM framework with a transparent institutional model. Such a committee needs to meet at least once a week to look into the insights of the operations of the proposed ISWM framework. If necessary, for issues to have arisen, corrective actions need to be taken. The committee should look into the monitoring of the whole process, matters on service delivery, tax collection, revenue generations, and asset management concerning the ISWM efforts.

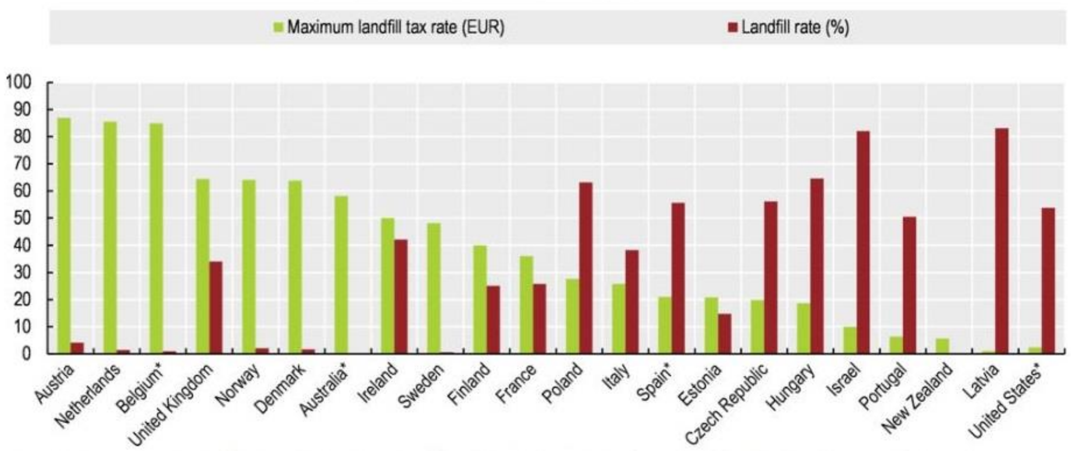
The total capital expenditure for the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha is SLR 254,522,331. The O&M annual expenditure to be incurred for the proposed ISWM framework is estimated as SLR 48,162,500 per annum. The income generated from the proposed ISWM framework is estimated as SLR 38,039,000 per annum.

Based on the financial analysis, the NPV was obtained as SLR -175.13 million at an interest rate of 10%. The IRR was obtained as 4%. Since the NPV showed a negative value, IRR was very low; hence, the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha is not financially feasible. The main reason for receiving a negative value for NPV and a very low value for IRR was the lower annual revenue generation with respect to the higher annual expenditure. Therefore, the financial analysis suggested considering tariff revisions and indirect economic benefits.

OECD (2019) manifested that OECD countries practice economic instruments which help to increase revenue generation and to reduce waste landfilling. The taxes for incineration and landfilling in several OECD countries promote reuse and recycling efforts. All OECD countries established an extended producer responsibility scheme for packaging waste; hence, recycling efforts were highly strengthened. Further, a fee was collected from the producers for their MSW. Purchasing of green materials was also promoted among people in several OECD countries, which led to the circular economy. In OECD countries, financial commitment from both government and private sector for MSWM was encouraged. Thereby, investment for MSWM was increased in countries like the Netherlands, Korea, Estonia, and Slovenia from $50 per capita in 2000 to $200 per capita in 2012.

The tariff system derived for MSWM shall recover the cost incurred for MSWM practices. According to OECD (2019), a volume-based pricing mechanism was introduced by the Netherlands, Korea, and the Czech Republic to recover the cost for

MSWM. The concept of pay-as-you-throw is commonly used for the calculation of a tariff for MSWM. The “Polluter Pays Principle” encouraged recycling over the reduction of landfilling and incineration in OECD countries. Figure 5.1 shows the comparison of landfill tax rate and landfill rate. Based on the data as depicted in Table 5.1 manifested that greater landfill tax rates greatly reduce landfill rates.



Note: *tax rates refer to Flanders for Belgium, to New South Wales for Australia, to Catalonia for Spain, and to New Jersey, North Carolina, Mississippi and Indiana for the United States.

Source: OECD (2016b), "Municipal waste", OECD Environment Statistics (database); OECD (2017a), "Environmental policy instruments", OECD Environment Statistics (database).

Figure 5.1: MSW landfilling and tax rates in 2013

A study was carried out by the team of Sevanatha Resource Center in 2012 in Ratnapura to evaluate the willingness of residents to pay a tariff for accepting MSW generated by themselves. The 13% of the households interviewed agreed to pay about SLR 30 per month, and 29% of households agreed to pay up to SLR 50 per month as a tariff. The 47% of the households interviewed stated that they could pay more than SLR 50 if high-quality MSWM service is provided on a regular basis. The balance 11% of households declined to pay any tariff. Out of 50 people who were in non-residential units interviewed, 32% of respondents agreed to pay less than SLR 200 per month, and 34% of respondents agreed to pay up to SLR 500 per month as a tariff for accepting the MSW generated by them. Furthermore, 14% of respondents stated that they could pay SLR 500, while 5% of respondents stated that they could pay SLR 1,000 if high-quality MSWM service is provided on a regular basis. The 15% of respondents declined to pay any tariff for MSWM operations. Accordingly, it was recommended to collect a tariff of SLR 50 per month from households, while SLR 500 per month from non-residential entities by providing a high-quality MSWM service. This initiative further strengthens the revenues.

Selling of value-added compost and liquid fertilizer at costs of SLR 25 and SLR 40 will generate more revenues compared to the selling of compost and leachate without any value-addition. Selling of reuse and recyclable materials and pre-processed construction and demolition waste will also generate revenues. O&M costs incurred during the operation were made minimal by optimizing the entire ISWM practices.

Since the financial analysis showed a negative NPV and a very low IRR, an economic analysis was carried out to evaluate the economic feasibility of the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha. Indirect benefits, which were not included in the financial analysis was taken into account during economic analysis. ISWM, with the incorporation of circular economy perspectives, provides many indirect benefits in terms of environmental and social perspectives. Some of the indirect benefits are improved health and safety, reduced GHG emissions, improved living standard of people, increased land value, and employment opportunities. The costs of these impacts are not directly visible in the market; however, the monetary values of these indirect benefits need to be known to conduct a comprehensive economic analysis.

This study only focused on calculating the indirect benefit gained through the reduction of GHG emissions. But the actual indirect benefit is greater than the calculated indirect benefit used for the economic analysis. The indirect benefit gained through the reduction of GHG emission of the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha was SLR 16.54 million. Based on the economic analysis, the NPV was obtained as SLR 66.52 million at an interest rate of 10%. The IRR was obtained as 12%. Thereby, the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha is economically feasible.

With the proposed ISWM framework developed through the study, it is expected that the service delivery would be improved with the improved willingness to pay, improved tariff collection from commercial and business entities, and the proper administration through capacity building. The proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha undoubtedly yields improved environmental sustainability with reduced pollution potential in terms of groundwater, surface water, land, and air. Public nuisance in terms of odor will be greatly lessened, and aesthetic appearance will be incredibly increased. Biodiversity in the area will then be enhanced. The social status of the neighboring people in the present open dump will be improved. The health conditions of the people will be better with the proposed ISWM framework. Less GHG emissions could be expected as open dumps cease with the proposed ISWM facility, and substantial economic growth could be expected.

Therefore, the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha is feasible from a national economic viewpoint; hence, the framework guarantees long-term sustenance.

6. CONCLUSION

This study was carried out to develop an ISWM framework based on the circular economy perspectives and to evaluate the long-term sustenance of the ISWM framework developed through a comprehensive economic analysis. Based on the findings of the study, the following conclusions were made.

1. In 2020, the total generation of MSW in Sri Lanka was 8,141 MT/day, but 3,854 MT/day was collected by local authorities, which accounted for 47% of the total MSW generation. There were 339 open dumps reported in 2020 in the country, causing enormous damage to the environment.

2. Poorly managed MSW affects to health and well-being of people, pollutes oceans, inland water bodies, and land, clogs drains, causes flooding, spreads diseases, produces air pollutants, harms flora and fauna, and obstructs resource recovery.

3. The major causes which prevent the implementation of a well-developed MSWM system across the country are inadequate physical and human resources made available for the MSWM practices, poor technical knowhow, and experience in the latest technologies to be practiced by developed countries for the MSWM practices, a lack of public participation in implementing the 3R concept and source-segregation, public opposition against construction of final disposal facilities such as compost plants, sanitary landfills, etc. Further, lack of political support for establishing cluster-based mass-scale final disposal facilities, inadequate funds allocated for MSWM practices, and failure to implement the "Polluter Pays Principle" also affects the improper MSWM within the country.

4. Therefore, there is a need to formulate and implement an ISWM framework for the MSWM in Sri Lanka addressing all aspects of MSWM practices such as generation, source-segregation, collection and transport, sorting, recovery, treatment, and final disposal of MSW.

5. The government’s new policy on “Vistas of Prosperity and Splendor,” National Physical Plan prepared by the Department of Physical Planning, and Draft National Environmental Policy, 2021, mandates that the MSW shall be managed in an integrated manner within the country. Other than that, the ISWM principle is highly encouraged by the Ministry of Environment, CEA, and various organizations in Sri Lanka. Despite the fact that all of the national policies, laws, and regulations are in place to promote the ISWM principle, implementing an ISWM concept is still a question.

6. The new concept of “Circular Economy” has rapidly expanded worldwide over the last decade and has vastly been applied to MSWM to reduce the amount of MSW produced globally by transforming it into resources. Thereby, the quantity of MSW to be disposed of in landfills is minimized.

7. Based on the proposed ISWM framework, minimization of the MSW generation is given priority through the implementation of the 3R concept. The MSW collected is subjected to source-segregation into categories such as biodegradable waste, recyclable waste, construction and demolition waste, street sweeping and drain cleaning waste, and non-biodegradable waste. These components are collected separately on pre-determined days and times so that the public is notified of the schedule for a given week.

8. Each component is collected and transported to the designated locations for further treatment. The biodegradable waste is transported to a compost plant, while the recyclable waste is brought to a resource center. Construction and demolition waste is transported to the construction and demolition waste collection yard. In the meantime, street sweeping and drain cleaning waste and non-biodegradables are sent to a controlled landfill. The collection and transport of source-segregated MSW to the collection center/transfer station/proposed facility are done by respective local authorities.

9. Biodegradable waste received to the compost plant is subjected to windrow composting so that compost can be produced. The compost undergoes a value

addition process to enhance the final quality of compost. A part of the leachate generated during composting is recirculated, while the rest is used for producing liquid fertilizer. A part of residues generated during composting is used as reuse and recyclable materials and used for covering windrow piles formed in active composting and curing areas. The rest of the residues are sent to the controlled landfill.

10. The recyclable waste collected is unloaded at the resource center. The area dedicated for storing recyclable waste in the resource center is partitioned mainly into six compartments to store plastic, metal, glass, paper, polythene, and PET bottles separately. The recyclable waste received to the resource center is resorted and stored at the designated compartment. Once bulk quantities are collected, the recyclable waste will be sold to third-party recyclable waste collectors at nominal prices.

11. The construction and demolition waste collected is unloaded at the construction and demolition waste collection yard. The materials like asbestos, wood, and tiles are used as reuse and recyclable materials. The other waste is pre-processed (crushing into small sizes) and used as a filling material.

12. The non-biodegradable waste, together with a part of the residues from the compost plant and street sweeping and drain cleaning waste, are disposed of at the controlled landfill. A part of the waste materials disposed of at the controlled landfill is degraded with time, and thereafter, the landfill is mined, and waste materials will be sent to a Waste-to-Energy plant for producing energy. The bottom ash generated from the plant is used as a reuse material for manufacturing paving blocks, curbstones, etc. The fly ash generated from the plant is disposed of at a secure landfill.

13. The legal and administrative framework needs to be strengthened to ensure the smooth operation of the proposed ISWM framework from MSW generation until final disposal.

14. The Kekirawa Pradeshiya Sabha does not have a proper MSWM system in place. The open dumping of all MSW collected as only the final disposal technique practiced by Kekirawa Pradeshiya Sabha since 2003. Hence, the implementation of an ISWM framework based on the circular economy perspectives and under the purview of the present administrative framework for Kekirawa Pradeshiya Sabha is of utmost importance.

15. The ISWM framework developed was applied to Kekirawa Pradeshiya Sabha includes the following key features. The generation of MSW is reduced through the application of the 3R concept. Source-segregation into categories such as biodegradable waste, recyclable waste, construction and demolition waste, street sweeping and drain cleaning waste, and non-biodegradable waste becomes mandatory under the proposed ISWM framework, and only source-segregated MSW will be collected by Kekirawa Pradeshiya Sabha.

16. At present, only 17% of the generation within the Kekirawa Pradeshiya Sabha area is collected, and with a supply of two garbage compactors (6-8 m^3 each), the percentage coverage of collection of MSW could be increased to 50%. The current schedules of MSW collection were revised to obtain optimum benefits.

17. The proposed ISWM facility for the Kekirawa Pradeshiya Sabha will be established in the 3-acre land, which is currently being used by the Kekirawa Pradeshiya Sabha to dispose of the mixed waste collected.

18. The design horizon is ten years. The proposed ISWM facility comprises a full-fledged compost plant, resource center, controlled landfill, office premises, construction and demolition waste collection yard, and necessary infrastructure facilities.

19. A fully-fledged compost plant for biodegradables with the use of passive aeration method (windrow method) will be established in a 150-perch land parcel to manage the 13.8 MT/day of biodegradable waste collected. The quantity of final compost generated is 3.5 MT/day. A weight of 79 g of Calcium

Nitrate (powdered form) was estimated to be added to 1 kg of the final compost product as a value-addition.

20. The quantity of excess leachate generated is 500 L/day, which will be used to produce liquid fertilizer. A weight of 71 g/day of Calcium Nitrate (powdered form) was estimated to be added to 1 L of the raw leachate to produce liquid fertilizer as a value-addition.

21. A resource collection center for the collection of recyclables (2.9 MT/day) will be built within the same premises. The materials collected in the resource center will be sold to the collectors registered with the CEA.

22. A controlled landfill will be built in the same land next to the compost plant to dispose of the quantity of 10.1 MT/day of non-biodegradable waste (7.0 MT/day) together with a part of the residues from the compost plant (3 MT/day), and street sweeping and drain cleaning waste (0.1 MT/day). The controlled landfill is 8 m in height, with a projected area of approximately 95-perch. The entire landfill will be operated in two layers, each of which has a height of 4 m. The landfill could be operative only for about 21 months due to space limitations. A sandwiched layer of liner materials (clay layer and geo-fabric layer) will be provided for controlling groundwater pollution. A drainage network will be built at the perimeter of the landfill to collect and direct leachate and leachate-rich stormwater to the constructed wetland (nature-based solution) for subsequent treatment. The treated wastewater will be utilized for irrigation of vegetation in the buffer zone. The excess amount will be discharged to the roadside drainage.

23. A 10% of the waste materials disposed of at the controlled landfill will be degraded with time, and thereafter, the landfill is mined, and waste materials (9 MT/day) will be sent to a Waste-to-Energy plant for producing energy. Thereby, the landfill operations can be extended. The electricity generation is 0.2 MW. The bottom ash (1.35 MT/day) generated from the plant will be used as a reuse material for manufacturing paving blocks, curbstones, etc. The fly

ash (0.3 MT/day) generated from the plant will be disposed of at a sanitary landfill.

24. Construction and demolition waste (0.5 MT/day) will be collected. The waste materials will undergo pre-processing. A quantity of 0.35 MT/day of pre-processed construction and demolition waste will be used for filling purposes, while 0.1 MT/day will be reused, and the rest (0.05 MT/day) will be sent to the controlled landfill.

25. Capacity building of the garbage handling personnel, including training, propaganda campaigns for beneficiaries, and awareness campaigns for all stakeholders, will be provided. The grievance redress mechanism for the proposed ISWM framework is prepared and will be kept at strategic locations for all stakeholders to air their grievances.

26. The total capital expenditure for the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha is SLR 254,522,331. The O&M annual expenditure to be incurred for the proposed ISWM framework is estimated as SLR 48,162,500 per annum. The income generated from the proposed ISWM framework is estimated as SLR 38,039,000 per annum.

27. Based on the financial analysis, the NPV was obtained as SLR -175.13 million at an interest rate of 10%. The IRR was obtained as 4%. Since the NPV showed a negative value, IRR was very low; hence, the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha is not financially feasible.

28. Thereby, economic analysis was carried out by incorporating indirect benefits, which were not included in the financial analysis. The indirect benefit gained through the reduction of GHG emission of the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha was SLR 16.54 million. Based on the economic analysis, the NPV was obtained as SLR 66.52 million at an interest rate of 10%. The IRR was obtained as 12%. Thereby, the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha is economically feasible.

29. Based on the proposed ISWM framework to be implemented in Kekirawa Pradeshiya Sabha, the current practice of open dumping will completely be halted. Further, 1.3% of residues (fly ash) from the total waste collected will only be disposed of in a secure landfill, while the rest (98.7%) will be used for different purposes. Therefore, it can be stated that both products and by-products are converted into resources; hence, the circular economy concept is satisfied by the proposed ISWM framework.

30. The proposed ISWM framework is replicable in many cities, having a multitude of smallholder agricultural farms, and are currently faced with the dilemma of disposing of MSW in a productive manner. The major advantage of applying this framework to cities having a multitude of smallholder agricultural farms compared to other cities is the higher demand from the farmers to purchase the value-added organic solid and liquid fertilizers to be used in their farmlands. Further, the pre-processed construction and demolition waste can easily be sold to farmers to construct low-cost structures within their farmlands.

31. To conclude, the proposed ISWM framework appears viable from a national economic viewpoint. The proposed ISWM framework provides a long-lasting solution to Sri Lanka’s current MSWM dilemma. Therefore, the proposed ISWM framework can be used as a role model for the MSWM by other local authorities of Sri Lanka, especially for local authorities having a multitude of smallholder agricultural farms and are currently faced with the dilemma of disposing of MSW in a productive manner.

7. RECOMMENDATIONS

The following recommendations were made to ensure the smooth functioning of the proposed ISWM framework developed under the study.

1. The 3R concept is to be implemented, and local authorities should have the main responsibility to promote the 3R concept among residents. Propaganda work for promoting the 3R concept among people through media, newspapers, NGO involvement for door-to-door campaigns, etc., are conducted.
2. Source-segregation of MSW should be made mandatory. The collection of MSW should be carried out only if MSW is sorted into biodegradable waste, recyclable waste, construction and demolition waste, street sweeping and drain cleaning waste, and non-biodegradable waste by respective local authorities.
3. Application of market-based instruments, including the “Polluter Pays Principle,” should be recognized for effective MSWM. Local authorities shall be encouraged to adopt activities for effective revenue generation mechanisms adopting the “Polluter Pays Principle” to self-finance MSWM practices.
4. Private sector participation should be encouraged to involve in the collection and transport of source-segregated MSW. Further, the involvement of the public sector in implementing state-of-art technologies for final disposal, such as Waste-to-Energy, landfilling, etc., are also recommended.
5. A cluster-based approach is recommended to be implemented for the proposed ISWM framework developed under this study rather than adopting individual local authorities.
6. A few more medium-scale secure landfills of the size of approximately 100 MT/day should be constructed in suitable locations to cover the island and to meet the material balance during the coming years with the support of bilateral/multilateral lending agencies.

7. A tipping fee should be charged when source-segregated MSW is accepted to be managed by other local authorities.

8. Institutional mechanisms should be established to prevent hazardous/ biomedical/healthcare/industrial waste from entering into the MSW streams and also to prevent such waste from entering into the natural environment.

9. Institutional strengthening and capacity-building requirements shall be addressed through WMA-WP and NSWMSC to promote the effective MSWM.

10. Efficient laws, regulations, and legislation enforcement should be prioritized to ensure effective MSWM practices. Regular monitoring and an evaluation system shall be established to identify deficiencies and impose improvements to the MSWM practices.

11. Environmental Police network shall be used with sufficient legal backing to improve the effectiveness of the implementation of the proposed ISWM framework developed under this study.

12. The availability of annual performance monitoring, recording, and reporting systems shall be made legally mandatory for service providers, enforcement authorities, and other institutions at the local authority, provincial, and national levels involved in the MSWM sector.

13. The establishment of laboratories with trained staff will be accompanied to monitor the quality of the final compost product and liquid fertilizer in a regular manner. Based on the measurements, value-addition will be altered.

14. The existing training facility at Karadiyana should be strengthened to meet the education and training demand of the country.

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Annexures

Annexure 3.1: Questionnaire survey report

Questionnaire Survey

1.0 General Information

1.1 Type of Local Authority (LA) *[Please **highlight** the relevant box(es)]*

Municipal council (MC) ☐
Urban council (UC) ☐
Pradeshiya Sabha (PS) ☒

1.2 (a) Name of the Local Authority, District, and Province

Name : Kekirawa Pradeshiya Sabha (Kekirawa PS)
District : Anuradhapura
Province : North Central

(b) Please attach the list of Grama Niladhari (GN) Divisions in your Local Authority

69 GNDs (Refer to attachment 1)

1.3 Demographic data of the Local Authority

Land extent of LA (km^2)	**Population**	**Population density ($Persons/km^2$)**	**Year of census**
529	74,823	142	2012
529	86,104	163	2018

(Source of data: Census data, 2012 and data available in the Kekirawa PS)

1.4 Land use zoning of the LA

Land use zoning	**Area (km^2)**	**Percentage (%)**
Residential	No data provided	No data provided
Commercial		
Industrial		
Institutional		
Agricultural		
Open space/park		
Other *(Specify)*		
Total	**529**	

1.5 Do you have a person in-charge of a division/unit for Solid Waste Management in your Local Authority?

*[Please **highlight** the relevant box]*

Yes ☒ No ☐

If YES, please indicate the name/designation of in-charge of division or unit together with contact numbers

Name : Mr. W.M.C.M. Nandasooriya
Designation : Technical Officer
Contact Number(s) : +94766031471

1.6 Please list the number of personnel engaged in Solid Waste Management practices

Profession	**Number of persons**
Engineer	0
Technical officer	1
Medical Officer of Health (MOH)	0
Public Health Inspector (PHI)	0
Supervisor	2
Driver	2 (permanent) and 2 (temporary)
Laborer (sweepers, etc.) Permanent/Temporary	18 (permanent) and 8 (temporary)
Other *(Please specify)*	0
Total	**33**

1.7 Have you ever done a survey on Solid Waste Management in your Local Authority up to now? *[Please **highlight** the relevant box]*

Yes ☐ No ☒

(*Please attach the relevant documents/reports*) **If YES**, who has done? *[Please **highlight** the relevant box (es)]*

Local Authority (LA) ☐

Non-government organization (NGO) ☐

Name of the NGO: Contact Number:

Community Based Organization (CBO) ☐

Name of the CBO: Contact Number:

Local Authority with NGO/CBO ☐

Name of the NGO/CBO: Contact Number:

Other *(Please specify)*:

If YES, how did you collect the information/data? *[Please **highlight** the relevant box (es)]*

Questionnaire developed/and or filled by Local Authority
Questionnaire developed/and or filled by NGO/CBO
Scientific study done by any party
Other *(Please specify)*

Not relevant

1.8 What is your annual budget for last three years for Solid Waste Management in your Local Authority?

Capital expenditure

Annual budget for health services including solid waste management:

Amount: 200,000.00 SLR;	Year: 2020	***(Estimated)***
Amount: 13,100.00 SLR;	Year: 2019	
Amount: 13,200.00 SLR;	Year: 2018	

Annual budget approved for a given fiscal year for all operations:

Amount: 22,834,000.00 SLR;	Year: 2020	***(Estimated)***
Amount: 19,328,702.47 SLR;	Year: 2019	
Amount: 19,505,581.31 SLR;	Year: 2018	

Percentage (%) of budget allocated for health services including solid waste management out of the total:

Percentage: 0.9 %	Year: 2020	***(Estimated)***
Percentage: 0.07 %	Year: 2019	
Percentage: 0.07 %	Year: 2018	

Recurrent expenditure

Annual budget for health services including solid waste management:

Amount: 21,700,452.00 SLR;	Year: 2020	***(Estimated)***
Amount: 13,229,552.55 SLR;	Year: 2019	
Amount: 15,313,530.18 SLR;	Year: 2018	

Annual budget approved for a given fiscal year for all operations:

Amount: 92,703,217.00 SLR;	Year: 2020	***(Estimated)***
Amount: 68,745,574.37 SLR;	Year: 2019	
Amount: 38,669,289.16 SLR;	Year: 2018	

Percentage (%) of budget allocated for health services including solid waste management out of the total:

Percentage: 24 %	Year: 2020	***(Estimated)***
Percentage: 19 %	Year: 2019	
Percentage: 40 %	Year: 2018	

2.0 Solid Waste Generation & Sorting at Source

2.1 What is the approximate generation of waste (Metric tons per day) in your Local Authority?

Generation within the LA : 41 MT/day
Generation from outside but dumped in this respective LA : 0 MT/day
(Source/Reference: Data available in the Kekirawa PS)

2.2 What are the major sources of solid waste generation in your Local Authority?

Sources of waste collected	Collected by the UC or not	Predominant type of waste
Household	Yes	Organic
Commercial (Market, shopping centers, etc.)	Yes	Organic/polythene/ plastic
Institutional (Police station, schools, etc.)	Yes	Organic
Street sweepings/ dirt from canals	Yes	Grass
Construction and demolition	No	Inert materials
Hotels and restaurants	Yes	Organic/polythene/ plastic/cardboard
Sanitation residues or `night-soil'	No	-
Agricultural waste	Yes	Plastic/polythene
Hospital & clinical waste	No	-
E-waste	Yes	Computer parts, TV parts, batteries
Hazardous waste and discarded fiber	No	-
Total collected (MT/day)	**7**	**-**

Source: Data available in the Kekirawa PS Year: 2019

2.3 What is the composition of solid waste being generated? *(Please attach the source of information & data)*

Type	Composition	
	MT/day	**%**
Biodegradable (Short term) e.g.: food, food waste	No composition test results are available. This will be amended once the relevant data is received from the Kekirawa PS officials.	-
Biodegradable (Long term) e.g.: cardboard, coconut shell, branches of trees		
Paper		
Wood/timber		
Sawdust/paddy husk		
Textiles		
Polythene/plastic/polymer		
Building waste (Demolition & construction)		
Metal (Iron)/non-metal (Aluminum etc.)		

Slaughterhouse waste		
Glass		
Street sweeping		
Other		
Night soil		
Hospital & clinical		
E-waste		
Porcelain		
Total	**7**	**-**
Moisture content of the total waste (%)	No data available	-
Calorific value of the total waste (MJ/kg)		

Based on the available data,

Biodegradable: non-biodegradable = 60:40 %

2.4 Does your Local Authority encourage the citizens on separation of waste at source? *[Please **highlight** the relevant box]*

Yes ☒ No ☐

IF YES, how did you do it? *[Please **highlight** the relevant box (es)]*

- Knowledge & awareness programme (KAP) on waste separation at source: Yes
    - How many programmes did you do by last 2 years? 4
    - How many people did attend to each program? 100 participants for each
    - Distribution of waste separation Bin/Bags: No
      (Either with current fee or subsidized rate)
      Green - Degradable Waste
      Orange - Plastic Waste
      Red - Glass Waste
      Blue - Paper Waste
      Brown - Metal & Coconut shells)
- How many waste bins/bags did you distribute among residents (last 2 years)? No bins distributed among people by the PS
    - Distribution of home composting bins *(Either with current fee or subsidized rate):* No
- How many home composting bins did you distribute for last two years? No bins distributed among people by the PS
    - Other *(Please specify)*
- Informed to the public through announcing campaigns
- Informed to the public by distributing the leaflets
- Informed about the separation of MSW at source while collecting waste by the UC personnel

If YES to question 2.4: Where/how did you get the support (Funding/resources) in implementing above-mentioned program(s) as one entity?

Designated Authority	Amount of money received, or other resources obtained (SLR)
Provincial Council budget	-
Local Authority budget	Allocation from the yearly budget
National Solid Waste Management Support Centre (NSWMSC)	-
Central Environment Authority (CEA) *(Central Environment Authority e.g. Pilisaru Project)*	-
Waste Management Authority (WMA) *(Please specify the programme/project)*	-
Non-Governmental Organization (NGO) *(Please specify the programme/project)*	-
Community Based Organization (CBO) *(Please specify the program/project)*	-
Other programme(s) *(Please specify)*	-

2.5 Do your Local Authority citizens practice any of the followings?

Methods	Yes	No	Name of the GND	Quantity (Mt/day)	Percentage (%)
Home composting		X			
Open burning	X		Though people are informed not to burn MSW in open air, people do open burning		
Open dumping (street side dumping)	X		During night times, garbage bags (mixed waste) are kept at roadside		
Manage in a pit	X		Most of the residents manage garbage pits at their own places		
Compost and handing over the rest LA		X			
Handing over the entire waste to LA	X		Mixed waste is handed over to PS waste collection vehicles		
Reuse/recycling (*please specify the items) e.g. PET bottles, Cardboard, etc.*	X		Recyclable waste is sold to the third-party private recycling waste collectors by the residents.		

Source: Data available in the Kekirawa PS Year: 2019

2.6 Do your Local Authority citizens separate or sort waste at the source?

Yes ☐ No ☒

If YES, what do they sort?

[Please highlight the relevant box(es)]

Organic ☐
Paper ☐
Wood/timber ☐
Textiles ☐
Polythene ☐
Plastic ☐
Metal/Non-metal ☐
Glass ☐

If NO, what do you do for total waste generated?

Mixed waste is handed over to the PS waste collection vehicles. Though the compactor is dedicated for the collection of biodegradable waste only, people handover mix waste to the compactor as well. Several types of waste (glass, metal, PET bottles, cardboard) are separated by the public and those recyclables are sold to the third party private recyclable waste collectors.

If YES, what do they do for sorted waste? *[Please highlight the relevant box(es)]*

Trade-off ☐
Reuse ☐
Recycle ☐
Other (Specify)

- If they trade-off how much they can earn? Not relevant

3.0 Collection, Sorting for Recyclables and Transport

3.1 Does your Local Authority have regular waste collection procedure?

Yes ☒ No ☐

If yes, how much solid waste being collected by Local Authority? 7 MT/day

If yes, how often is the solid waste collected? *[Please tick the relevant box(es)]*
If there is a solid waste collection ***timetable****, please attach*

Frequency	Biodegradable waste (MT/day)	Non-biodegradable waste (MT/day)	As a bulk (MT/day)
Thrice a day	Collection schedule is given in the Attachment 2.		
Twice a day			
Daily			
Once in two			
Once in three days			
Once a week			
Twice a week			
Thrice a week			
Other (specify)			

Note:
Though some of the vehicles (compactor – 1 nos and tractor – 1 nos) are allocated to collect the biodegradable and non-biodegradable waste separately, people handover mixed waste to the garbage collection vehicles.

3.2 Who engage in collection of solid waste in your Local Authority? [*Please highlight the relevant box(es)]*

Collected by the Local Authority ☒
Collected by the Local Authority's subcontractor *(specify)* ☐
No collection service (done by house owner) ☐
Other *(Specify)* ☐

3.3 What are the methods deployed for waste collection in Local Authority? *Please attach the data (if available)*

Method	Yes/ No	Qty generated (MT/day)	Qty collected (MT/day)	Biodegradable waste Collected (MT/day)	Non-biodegradable waste collected (MT/day)
Door to Door collection	Yes	No data available			
Bell collection	Yes				
Communal collection Curbside collection Bin kept at the roadside	Yes				
Others *(Specify)*	-				
Total	**-**	**41**	**7**	**4.2**	**2.8**

3.4 Are your Local Authority people aware of the solid waste collection time & the date? *(Please attach the available data)*

Yes ☒ No ☐

3.5 Data on the collection *(reasons and remarks)*

Please fill the following table (*Please attach the data (**Route map**), if available) – No route map on collection is made.*

Frequency	**Waste collection quantity (MT/day)**	**Waste collection system**				**% Waste collection**	**Reasons/ remarks**
		Main roads	**By roads**	**Cart roads**	**Foot roads**		
Thrice a day							
Twice a day							
Daily	-	X	X	X		-	-
Once in two days							
Once in three days							
Once a week							
Twice a week	-	X	X			-	-
Thrice a week	-	X	X			-	-
Other *(Specify)*							
Total	**On average 7 MT/day**						

Sorting of recyclables

3.6 Does your majority of Local Authority citizens practice sorting for collected waste?

Yes ☐

No[A] ☒

Partially ☐

Note:

[A] – Few citizens handover sorted waste to the PS garbage collection vehicles. The recyclable waste handed over by the citizens is stored at a collection center maintained by the Kekirawa PS. Once adequate quantities are collected, the recyclables will be sold to the third party private recyclable waste collectors (Refer to Attachment 3).

If YES, what are the major categories of solid waste been sorted? *(Please attach available data sheet)*

Category	Sorted Yes/No	Purpose	Quantity (MT/day)	Percentage (%)
Organic waste (e.g. food waste)	No			
Wood/timber	No			
Polythene	No			
Paper/cardboard	Yes	Few citizens handover recyclable waste (paper/cardboard, plastic, metal, glass, PET bottles) to the PS garbage collection vehicles. This is not popular among majority of the PS citizens.		
Plastic	Yes			
Metal(iron)/ Non- Metal (Aluminium)	Yes			
PET bottles	Yes			
Glass	Yes			
Other *(Specify)*				

3.7 **If YES to 3.6,** why does LA decide to practice the solid waste sorting? *[Please tick the relevant box(es)]*

As a policy/strategy/guideline of Local Authority ☒

As a policy/strategy/guideline of Provincial Council ☐

Central government policy/strategy/guidelines ☒

Other (Specify*):*

3.8 What are the vehicular fleets used for waste collection/transport in your Local Authority?

Vehicle type	Number of vehicles in operation	Average capacity per vehicle	Additional number of vehicles required	Commuted in			
				Main Roads	By Roads	Cart Roads	Foot Roads
Vehicles for solid waste collection/transport							
Compactor truck	0	12-14 m^3	-				
Compactor truck	1	6-8 m^3	-	√	√		
Compactor truck	0	3 m^3	-				
Skip hoist	0	-	-				
Tipper	0	10 m^3	-				
Tipper	0	8.5m^3	-				
Tipper	0	3 m^3	-				
Tractor with trailer[A]	5	100 ft^3	-	√	√		
Two-wheel tractor with trailer	0	-	1				
Dump truck	0	3 m^3	-				
Hand cart	0	-	4				

Three-wheeler (Garbage vehicle)	0	-	-				
Other *(Specify)*	0	-	-				
Other vehicles for solid waste activities							
Poster removal machine	0		-				
Mechanical sweeper machine	0		-				
Litter picking machine	0		-				
Bobcat (skid steer loader)	0		-				
Re-loader	0		-				
Propaganda vehicle	0		-				
Tractor with compartmentalized trailer	0		-				
Gully bowser (3 m^3)	2		-				

Source: Data available in the Kekirawa PS Year: 2019

Note: *^{A} – Though the 5 nos of tractors are available, 3 nos of tractors are in working condition*

3.9 What would be the distance traveled per day?

Vehicle type	**Average distance traveled per one trip (both up and down)**	**Average time taken per trip (both up & down)**	**Number of trips per day**	**Total km traveled per day**
Vehicles for solid waste collection/ transport				
Compactor truck (12-14 m^3)				
Compactor truck (6-8 m^3)	70	8	1	70
Compactor truck (3 m^3)				
Skip hoist				
Tipper (10 m^3)				
Tipper (8.5 m^3)				
Tipper (3 m^3)				
Tractor with trailer (100 ft^3)	25	8	1	25
Two-wheel tractor with trailer				
Dump truck				

Hand cart				
Three-wheeler				
Other *(Specify)*				
Other vehicles for solid waste activities				
Poster removal machine				
Mechanical sweeper machine				
Litter picking machine				
Bobcat (skid steer loader)				
Re-loader				
Propaganda vehicle				
Tractor with compartmentalized trailer				
Other *(Specify)*				

4.0 Transfer and Transport

4.1 Does your LA have waste transfer station?

Yes ☐ No ☒

If YES, what are the types of Transfer Stations? Please fill the following table (*Please attach the data, if available)*

Type	**Location Name (GN Division)**	**Total area (m^2)**	**Area filled up to now (m^3)**	**Number of years of operation up to now**	**Quantity of waste coming in per day (MT/Day)**	**Quantity of waste going out per day (MT/Day)**
Open space	There is no waste transfer station. Hence, not applicable.					
Open space with covers						
Containers/Trailers /Skipper						
Other *(Specify)*						

4.2 Do you practice waste sorting at transfer station?

Yes ☐ No ☒

If YES, what are the quantity being sorted? **Not applicable**

If YES, what do they do with the sorted waste? *[Please tick the relevant box(es]*

Trade-off
Reuse
Recycling
Other (*Please specify)*

Not applicable

If YES, what are the major categories and quantity of sorted waste? *[Please tick the relevant box(es)]*

Category	**Quantity (MT/Day)**
Organic	**Not applicable**
Paper	
Wood/Timber	
Textiles	
Polythene	
Plastic	
Metal/Non-metal	
Glass	
Other *(Specify)*	

4.3 Data on the Transport from transfer station

Please fill the following table (*Please attach the data, if available)*

Frequency	**Waste collection quantity (MT/day)**	**Type of vehicles used**	**Number of kilometers travelled up to final disposal site**	**Average number of hours (both up & down) travelled per day**
Thrice a day	**Not applicable**			
Twice a day				
Daily				
Once in two days				
Once in three days				
Once a week				
Twice a week				
Thrice a week				
Other*s*				
Total				

5.0 Pre-treatment and Final disposal

5.1 (a) What are the pretreatment and final disposal methods in your Local Authority? *[Please tick the relevant box(es)]*

Category	**Yes**	**No**	**Type and quantity (MT/day) subjected to final disposal**									
	*Please put "***X***" mark*		**Organ.**	**Paper**	**Wood**	**Textile**	**Polyth**	**Plastic**	**Metal**	**Glass**	**Others**	**Clinic.**
Pre-treatment	**No pre-treatment of solid waste being practiced**											
Composting												
Biogas generation												
Other *(Specify)*												
Final disposal												
Open dumping as a whole		X										
Open dumping only non-biodegradable component												
Open dumping except biodegradable and recyclables, but residues from the composting are disposed												
Land filling with soil cover												
Sanitary landfilling												
Burying of waste												
Incineration												
Open burning												
Waste to energy												
Other *(Specify)*												

(b) What are the vehicular fleets using at waste disposal site in your Local Authority?

Vehicle type	Number of vehicles in operation	Average capacity (m^3) per vehicle	Additional number of vehicles required
Long arm excavator	No permanent vehicles available at the dumping site. A JCB owned by the PS is used to level the garbage disposed at the open dump whenever necessary.		
Bulldozer			
Compactors			
Backhoe loader			
Bobcat			
Other (specify)			

(c) Does your Local Authority have already identified or proposed site for solid waste disposal?

Yes ☒ No ☐

If YES, please what are they?

The existing dumping site is located at Embulgaswewa, Kekirawa. The area of the land is 3 acres. Since the undisturbed area (no solid waste has been disposed yet) in the existing dumping site is sufficient for the proposed solid waste management practices, this land will be used for the proposed developments related to the solid waste management.

5.2 If you practice ***open dumping (whole waste), open dumping (only non-*** biodegradable ***component) land filling with covering of soil or sanitary land filling, burying of waste*** please fill the following table

Items	**Disposal site**		
	Site 1	**Site 2**	**Site 3**
Name of the site	Embulgaswewa		
Total area (acres)	3		
Number of workers at the site	-		
Year in which disposal is started	2003		
Estimated life span of the site (years)	-		
After filling up the site, availability of rehabilitation plan *(please indicate Yes/No)*	No		

Amount of waste (MT/Day) disposed on Daily	7 MT/day		
Type of waste subjected to final disposal (MT/Day) - Bulk	X		
Average distance from collection area to the site (km)	70 km		
Type of stray animals on site - **Dogs** - Cows - **Cranes**	**X** **X**		
Any waste pickers or scavengers on site *(indicate Yes/No)*	No		

(a) Do you have any *issue(s)/negative impact(s)* during *construction and/or operation* when open dumping (whole waste), **open dumping (non-biodegradable and non-recyclable component including residues from the composting)**, land filling with covering of soil, sanitary landfilling or burying of waste? [Please tick the *relevant box(es]*

And

Have you done any environment and/or social study to mitigate following issues? If yes, please specify. If you have any report/document, please attach.

Issue	Mitigatory measures
Health problems	So far, no actions taken by the Kekirawa PS. Further, no complaints have been received from the public on current solid waste management practices.
Public nuisance	
Unauthorized dumping and scavenging activities	
Accessibility to the site	
Legal issues related to the site	
Land ownership issues related to the site	
Problems caused by damage, blockings and covering of drainage systems *(Streams, rivers, lagoons, reservoirs, etc.)*	
Stagnation of water	
Contamination issues due to leachate seeping through the ground and wells	
Destroying of natural habitat *(Flora* and *fauna)*	

5.3 If you practice **incineration or any burning,** please fill the following table (*Please attached the data or information, If available*)

Items	**Incineration or burning site**		
	Site 1	**Site 2**	**Site 3**
Name of the site	**Not applicable**		
Total capacity of the facility per day (MT/Day)			
Number of workers at the site			
Year in which incineration or burning is started			
Amount of waste (MT/Day) incinerated or burning: – Thrice a day – Twice a day – Daily – Once in two days – Once in three days – Once a week – Twice a week – Thrice a week – Other *(specify)*			
Type of waste being incinerated -Biodegradable (MT/Day) -Non-biodegradable (MT/Day) -Bulk (MT/Day)			
Number of hours of operation per day			
Operating temperatures			
Operational safety measures *(indicate Yes/No)*			
Fuel source			
Average distance from collection area to the site (km)			

(a) Do you have any ***issue(s)/negative impact(s)*** from the **incineration or any burning** during ***construction and/or operation?*** *[Please tick the relevant box(es]*

and

Have you done any environment and/or social study to mitigate following issues? If yes, please specify. If you have any report/document, please attach.

Issue	**Mitigatory measures**
Air pollution *(PM, SOx, NOx, HCl)*	**Not applicable**
Public nuisance *(Insects/Odour/Noise/Aesthetic/Dust)*	
Ash *(fly ash & bottom ash)*	
Water pollution *(Surface & ground)*	
Health impacts (*respiratory*)	
Legal issues related to the site	
Land ownership issues related to the site	
Other (Specify)	

5.4 If you practice **composting** please fill the following table (*Please attached the data or information, If available*) –
If YES, what are the major categories of sorted waste? *[Please tick the relevant box (es)]*

Organic (food)
Paper
Garden waste
Market waste
Night soil

Not applicable

Items	**Composting site**		
	Site 1	**Site 2**	**Site 3**
Name of the site	**Not applicable**		
Total area (ha)			
Number of workers at the site			
Year in which composting is commences			
Estimated life span of the site (year)			
Amount of waste (MT/Day) composed on – Thrice a day – Twice a day – **Daily** – Once in two days – Once in three days – Once a week – Twice a week – Thrice a week – Other *(specify*			
Type of waste being composted -Bio degradable (MT/Day) -Bulk (MT/Day)			

Type of composting method - Windrow - Aerobic - Anaerobic - Semi Aerobic - Vermin composting	
Processing period of the composting facility	
Any additives *[Please indicate Yes (if yes, please specify) or No]*	
Quality of final compost *(Sri Lanka Standard 1246:2003)*	
Price of 1 kg of compost *(SLR)*	
Average distance from collection area to the site (Km)	
Type of stray animals on site -Elephants -Deer -Dogs -Cats -Cows/cattle/buffalo -Crows/cranes -Brahmani kites -Pigs -Other *(Specify)*	
Any waste pickers or scavengers on site	
Production level of compost (MT/month)	

(a) Do you have any ***issue(s)/negative impact(s)*** from the ***composting*** during ***construction and/or operation?*** *[Please tick the relevant box(es]*

and

Have you done any environment and/or social study to mitigate following issues? If yes, please specify. If you have any report/document, please attach.

Issue	Mitigatory measures
Health problems	**Not applicable**
Contamination issues due to leachate seep through the ground and wells	
Public nuisance *(Insects/odour/noise/ aesthetic)*	
Unauthorized dumping and scavenging activities	
Accessibility to the site	
Legal issues related to the site	
Land ownership issues related to the site	
Flooding of the site	
Stagnation of water	
Destroying of natural habitat *(Flora and fauna)*	
Other *(Specify)*	

5.5 If you practice **Biogas,** please fill the following table (*Please attached the data or information, If available*)

Yes ☐ No ☒

If YES, what are the major categories of sorted waste? *[Please tick the relevant box(es)]*

Organic (food waste)
Paper
Wood/timber/garden waste
Other *(Specify)*

Not applicable

Items	**Biogas site**		
	Site 1	**Site 2**	**Site 3**
Name of the site	**Not applicable**		
Total area (ha)			
Number of workers			
Year in which Biogas is commences			
Estimated life span of the site (year)			
Amount of waste (MT/Day) dispatched on – Thrice a day – Twice a day – Daily – Once in two days – Once in three days – Once a week – Twice a week – Thrice a week – Other *(specify)*			
Type of waste being used -Biodegradable (MT/Day) -Bulk (MT/Day)			
Processing period of the biogas facility			
Any additives *[Please indicate Yes (if yes, please specify) or No]*			
Average distance from collection area to the site (km)			
Type of stray animals on site -Elephants -Other *(Specify)*			
Any waste pickers or scavengers on site			
Amount of biogas produced (L/day)			

(a) Do you have any ***issue(s)/negative impact(s)*** from the ***biogas facility*** during ***construction and/or operation?*** *[Please tick the relevant box(es)]*

and

Have you done any environment and/or social study to mitigate following issues? If yes, please specify. If you have any report/document, please attach.

Issue	**Mitigatory measures**
Health problems	**Not applicable**
Green House Gas (GHG) emission	
Contamination issues due to leachate seep through the ground and wells	
Public nuisance *(Insects/odour/aesthetic/dust/litter)*	
Unauthorized dumping and scavenging activities	
Accessibility to the site	
Legal issues related to the site	
Land ownership issues related to the site	
Other *(Specify)*	

5.6 If you practice **Waste to energy,** please fill the following table (*Please attached the data or information, If available*)

If YES, what are the major categories of sorted waste? *[Please tick the relevant box (es)]*

Organic (e.g. food waste)
Paper
Wood/Timber
Textiles
Polythene
Plastic
Other (Specify*)*

Not applicable

If you have relevant data/information on ***Waste to energy***; Please fill the following table *(Please attached the data or information, If available)*

Items	**Waste to energy site**		
	Site 1	**Site 2**	**Site 3**
Name of the site	**Not applicable**		
Total area (ha)			
Number of workers			
Year in which Waste to energy commences			
Estimated life span of the site (year)			
Amount of waste (MT/Day) transported – Thrice a day – Twice a day			

– Daily – Once in two days – Once in three days – Once a week – Twice a week – Thrice a week – Other *(specify)*	
Type of waste being used -Bio degradable (MT/Day) -Non bio degradable (MT/Day) -Bulk (MT/Day)	
Average distance from collection area to the site (Km)	
Type of stray animals on site – Elephants – Deer – Dogs – Cats – Cows/ cattle/ buffalo – Crows – Brahmani kites – Pigs – Other (Specify)	
Amount of power generated (MW)	

(a) Do you have any ***issue(s)/negative impact(s)*** from the ***waste to energy facility*** during ***construction and/or operation?*** *[Please tick the relevant box(es]*

and

Have you done any environment and/or social study to mitigate following issues? If yes, please specify. If you have any report/document please attach.

Issue	Mitigatory measures
Health problems	**Not applicable**
Green House Gas (GHG) emission	
Contamination issues due to leachate seep through the ground and wells	
Public nuisance *(Insects/Odor/Aesthetic/dust/litter)*	
Unauthorized dumping and scavenging activities	
Accessibility to the site	
Legal issues related to the site	
Other (Specify)	

5.7 *Does* your Local Authority plan to go for safe solid waste disposal techniques or practice?

Yes ☒ No ☐

If YES, what are the techniques planned or planning for solid waste disposal in your Local Authority?

- Establish a fully fletched composting plant
- Prepare a solid waste management plan covering the entire PS

6.0 Institutional and Managerial Aspects

6.1 Do you think the existing practice(s) of solid waste management is efficient? *(From generation to final disposal)*?

Yes ☐ No ☒

If No, please list at which stage you are faced with an issue? *[Please highlight the relevant box (es)]*

Solid waste generation & sorting at source	☒
Waste collection, sorting for recyclables & transport	☒
Waste transfer and transport	☐
Pretreatment and final disposal	☒
Other *(Specify)*	

6.2 If you are faced with *issues* at *waste generation* & *sorting at source* stage? If yes please list out the reason(s) *[Please highlight the relevant box(es)]*

Lack of awareness of people on sorting waste at source	☐
Lack of awareness of people on hazardous waste (*e.g. CFL bulb*)	☐
Lack of commitment of people on sorting waste at source	☒
Lack of awareness of people on waste as an environmental issue	☐
Lack of financial allocation in facilitating such awareness program to the stakeholders	☐
Poor leadership and backing	☐
Other *(Specify)* – Satisfactory	

(a) In your opinion, what should be the solution(s) for the above-mentioned issues?

- Sorted MSW is only to be accepted by the garbage collection vehicles.
- Awareness programs are to be organized to inform to public on waste generation & sorting at source stage
- Legal actions/fining system should be implemented to ensure proper source separation of MSW at household level.

(b) In your LA, what level of influence exerted on households for sorting at source?

Legal and Kekirawa PS commitments towards accepting sorted waste

6.3 If you are faced with issues at *waste collection, sorting for recyclables & transport* stage? please list out the reasons *[Please highlight the relevant box(es)]*

Financial allocation (capital and recurrent expenditure) ☐
Lack of proper collection, sorting of recyclable system ☒
Lack of proper collection system for hazardous waste ☐
Lack of technical support from LA staff/workers ☐
In-adequacy of vehicles, labors, etc. ☒
Other *(Specify)* ____________________

In your opinion, what should be the solution(s) for the above-mentioned issues?

- Small scale vehicles (hand cart, two-wheeled tractor, etc.) are to be provided to collect the MSW in card roads and foot roads.
- Global Positioning System (GPS) facilities are to be installed to the garbage collection vehicles; hence, the locations of the vehicles can be traced online. Therefore, the efficiency of collection can be improved.

6.4 If you are faced with issues at ***waste transfer transport*** stage? please list out the reasons *[Please tick the relevant box(es)]*
Note; *If your Local Authority does not have a transfer station, please ignore this question regarding to waste transfer*

Financial allocation (capital and recurrent expenditure)

Lack of proper space for transfer station

Lack of technical support from LA staff/workers

Lack of locations

Poor accessibility to the transfer station

In-adequacy of vehicles, labors, etc.

Public nuisance

Poor leadership and backing

Other *(Specify)* ____________________

Not applicable

In your opinion, what should be the solution(s) for the above-mentioned issues?

Not applicable

6.5 If you are faced issues at ***Pretreatment and final disposal*** stage, please list out the reasons *[Please highlight the relevant box(es)]*

Pretreatment (Composting)

Inadequate finance ☒

Lack of proper waste pretreatment sites ☒

Lack of proper waste pretreatment techniques ☒

Inadequacy of technical knowledge on waste pretreatment techniques ☒

Poor leadership and backing ☐

Other *(Specify)* ____________________

Final Disposal

Inadequate finance ☒

Lack of proper waste disposal sites ☒

Lack of proper waste disposal techniques ☒

(e.g. sanitary land filling, composting, etc.)

Adequacy of technical knowledge on waste disposal techniques ☒

Poor leadership and backing ☐

Other *(Specify)* ____________________

In your opinion, what should be the solution(s) for the above-mentioned issues?

- A fully fletched composting plant together with other necessary facilities are to be established.
- Workers are required to be trained properly for the smooth operation of the facility.
- A proper monitoring mechanism should be in-place to monitor the efficiency of entire SWM system

6.6 How do you expect government/donor agency/NGO to help you to build up or make a better solid waste management practice in your LA?

Adequate funding mechanism is required to be provided for the implementation and smooth operation of proper SWM plan. Further, necessary training facilities are to be made available for the workers on regular basis.

6.7 What are the external forces or bottlenecks identified so as to disturbed smooth functioning of solid waste management?

No

6.8 Are you aware of recent legislation [policies or law (s), regulation(s), explicit and implicit, national /local, enactment] related to Solid Waste Management? If yes, what are they?

CEA regulations

6.9 Do you believe that the present legislation is good enough to continue solid waste management effectively and efficiently?

More than enough ☐
Just enough ☒
Good with some further enforcement ☐
Obsolete or non-appropriate ☐
Very poor ☐
No idea ☐

6.10 Is your Local Authority encouraged by economic instruments at national or local level related to solid waste management?

Incentive/subsidies	☐
Low-interest finance	☐
Tax exemption	☐
Profit sharing	☐

Other *(Specify):* No

6.11 Is your citizen encouraged by economic instruments at national or local level related to solid waste management?

Incentive/subsidies	☐
Low-interest finance	☐
Tax exemption	☐
Charges/fines	☐

Other *(Specify)*: No

6.12 Is your Local Authority planning to collect "a service charge" from citizens?

No

6.13 How do you derive benefits from above-mentioned economic instrument?

Not applicable

6.14 Does your Local Authority have joint projects with partnerships between other local authorities and or other stakeholders including national government related to waste management? If yes please specify

No

6.15 Does your Local Authority have the provision for information sharing with other relevant stakeholders about solid waste related matters, particularly in decision making? If yes, please explain

No

6.16 What percentage of citizens in your LA knows about Reduce, Reuse and Recycle (3R) principles (or the equivalent)?

Very few (approximately 5 % from the total population)

If you do not have data, give us your rule of thumb for estimation:

Date available hence; not required.

6.17 What percentage of citizens in your LA practices Reduce, Reuse and Recycle (3R) principles (or the equivalent)?

5 % from the total population

If you do not have data, give us your rule of thumb for estimation:

Date available; hence, not required.

6.18 If you have any comments you would like to make concerning the solid waste management practices or want to expand on your answer to previous questions then please do so here or on a separate paper.

A fully fletched composting plant together with other necessary facilities are to be established in the proposed land. Meantime, workers are required to be trained properly for the smooth operation of the facility.

6.19 Contact details of the LA:

- Name : Mr. H.M.S.A.B. Herath
  Designation : Mayor of the Kekirawa PS
  Email : kekirawasabha@gmail.com

- Name : Ms. L.W.K. Shymali Shirani
  Designation : Secretary
  Email : kekirawasabha@gmail.com

- Name : Mr. W.M.C.M. Nandasooriya
  Designation : Technical Officer
  Email : kekirawasabha@gmail.com

- Name : Mr. S. Wijayananda
  Designation : Supervisor
  Email : kekirawasabha@gmail.com
- Name : Ms. Tharanga Thennakoon
  Designation : Development Officer
  Email : kekirawasabha@gmail.com

Summary

1.0 Minimization of solid waste generation & household sorting

Excellent ☐
Very good ☐
Good ☐
Poor **X**
No idea ☐

Justification

Mixed waste is handed over to the garbage collection vehicles by the residents. The commitment towards the household sorting by the residents is poor.

2.0 Waste collection, sorting for recyclables & transport

Excellent ☐
Very good ☐
Good ☐
Poor **X**
No idea ☐

Justification

MSW is not collected in cart roads and foot roads due to the unavailability of small-scale vehicles (e.g., hand carts, two-wheel tractors, etc.). Sorting for recyclables by the residents and workers are poor. But PS buy recyclables (plastic, PET bottles, metals, etc.) from the residents.

3.0 Waste transfer and transport

Excellent ☐
Very good ☐
Good ☐
Poor **X**
No idea ☐

Justification

No waste transfer station is available.

4.0 Final disposal

Excellent ☐
Very good ☐
Good ☐
Poor X
No idea ☐

Justification

- Open dumping as a whole is currently practiced by the PS.
- No mitigatory measures are taken to minimize impacts due to the open dumping of mixed waste to the dumping site located at the Embulgaswewa.
- No proper drainage management system is functioned.
- No proper leachate treatment is available.

Special remarks

Approvals required to be obtained for the project

a. Central Environmental Authority (CEA)

Approval from the CEA needs to be obtained for the composting plant and other related facilities.

b. Forest Department

Approval from the Forest Department needs to be obtained since the land proposed to establish a fully fletched composting facility is next to the forest reservation.

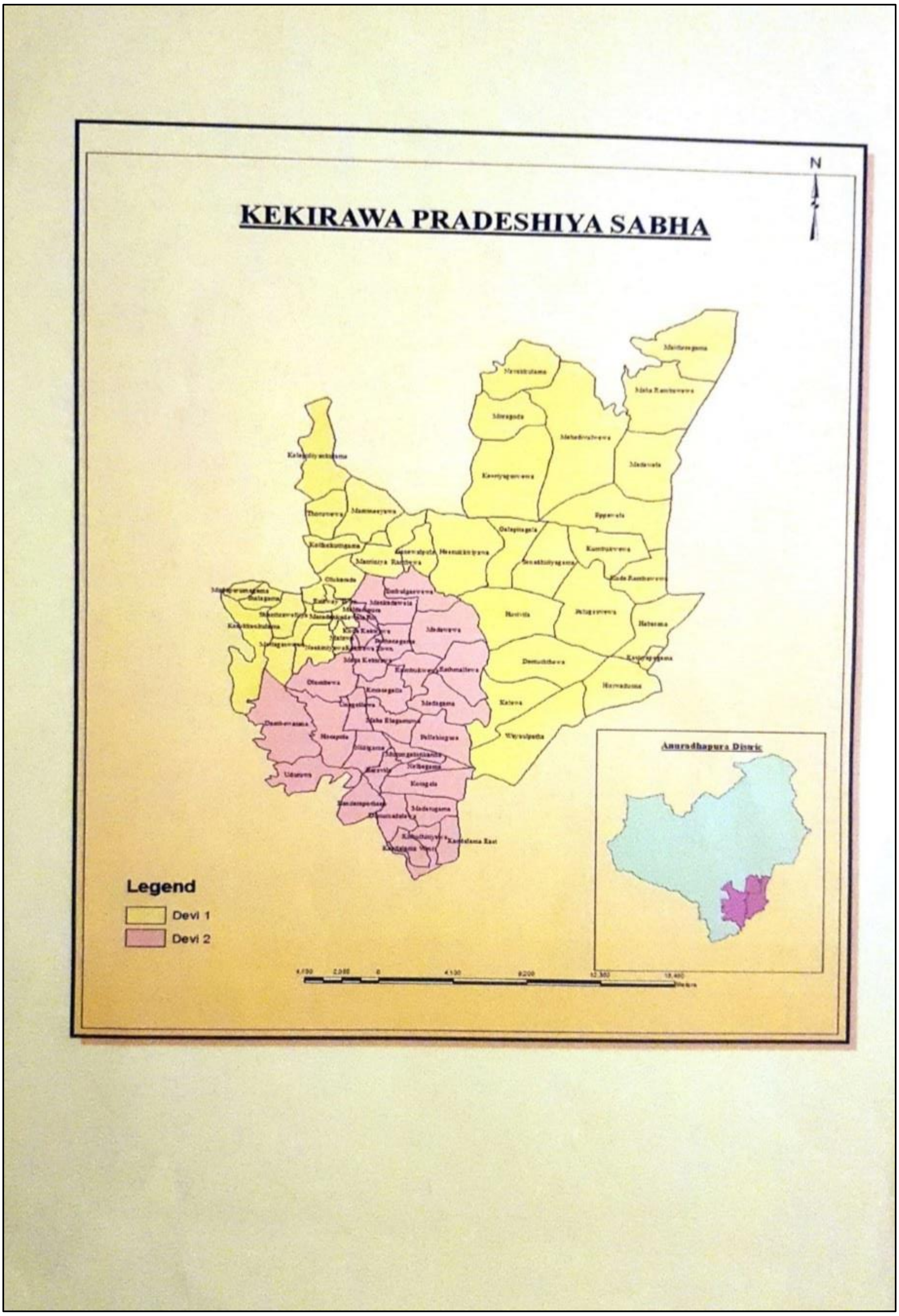
c. Urban Development Authority (UDA)

Approval from the UDA is required to be obtained for the proposed project. This will ensure that the proposed development conforms to the development plan of the Kekirawa prepared by the UDA.

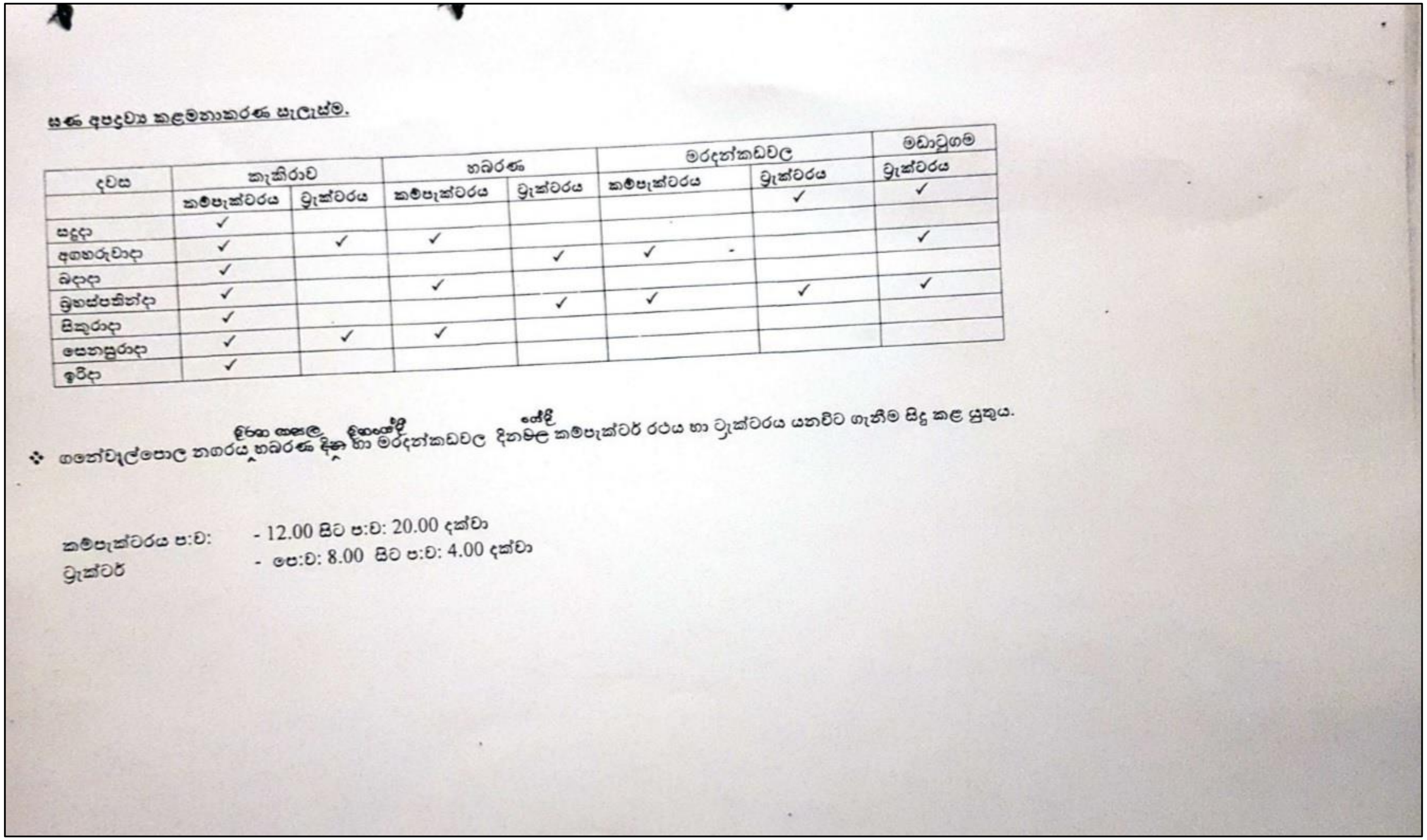
d. Road Development Authority (RDA)

Approval from the RDA is to be obtained since the existing culvert in front of the proposed land is to be expanded. Meantime, roadside drains have to be constructed.

Attachment 1: Details of the GNDs in Kekirawa PS



Attachment 2: Waste collection schedule practiced by the Kekirawa PS



ඝණ අපද්‍රව්‍ය කළමනාකරණ සැලැස්ම.

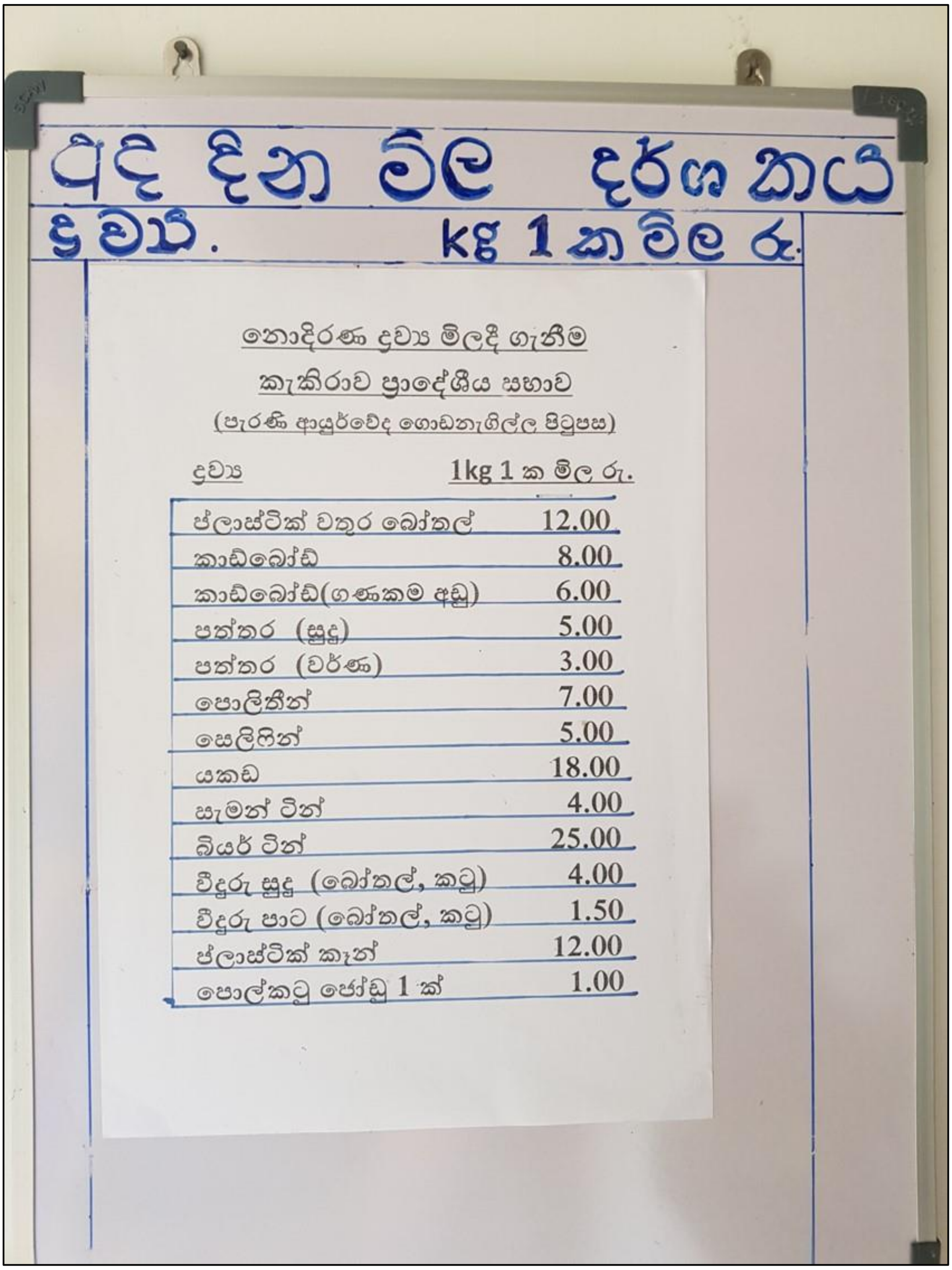
දවස	කැකිරාව		හබරණ		මරදන්කඩවල		මඩාටුගම
	කම්පැක්ටරය	ට්‍රැක්ටරය	කම්පැක්ටරය	ට්‍රැක්ටරය	කම්පැක්ටරය	ට්‍රැක්ටරය	ට්‍රැක්ටරය
සඳුදා	✓					✓	✓
අඟහරුවාදා	✓	✓	✓				
බදාදා	✓			✓	✓		✓
බ්‍රහස්පතින්දා	✓		✓				
සිකුරාදා	✓			✓	✓	✓	✓
සෙනසුරාදා	✓	✓	✓				
ඉරිදා	✓						

- ගනේවැල්පොල නගරය [illegible] හබරණ දින [illegible] හා මරදන්කඩවල දිනවල ගේදී කම්පැක්ටර් රථය හා ට්‍රැක්ටරය යනවිට ගැනීම සිදු කළ යුතුය.

කම්පැක්ටරය ප:ව: - 12.00 සිට ප:ව: 20.00 දක්වා

ට්‍රැක්ටර් - පෙ:ව: 8.00 සිට ප:ව: 4.00 දක්වා

Attachment 3: Price schedule for buying and selling of recyclable waste



අද දින මිල දර්ශකය

ද්‍රව්‍ය.	kg 1 ක මිල රු.

නොදිරණ ද්‍රව්‍ය මිලදී ගැනීම

කැකිරාව ප්‍රාදේශීය සභාව

(පැරණි ආයුර්වේද ගොඩනැගිල්ල පිටුපස)

ද්‍රව්‍ය	1kg 1 ක මිල රු.
ප්ලාස්ටික් වතුර බෝතල්	12.00
කාඩ්බෝඩ්	8.00
කාඩ්බෝඩ්(ගණකම අඩු)	6.00
පත්තර (සුදු)	5.00
පත්තර (වර්ණ)	3.00
පොලිතීන්	7.00
සෙලිෆින්	5.00
යකඩ	18.00
සැමන් ටින්	4.00
බියර් ටින්	25.00
වීදුරු සුදු (බෝතල්, කටු)	4.00
වීදුරු පාට (බෝතල්, කටු)	1.50
ප්ලාස්ටික් කෑන්	12.00
පොල්කටු ජෝඩු 1 ක්	1.00

Annexure 3.2: Bill of quantities

Item No.	Description of the item	Unit	Qty	Rate (SLR)	Amount (SLR)
1	Preliminary investigations:				
1.1	Drone survey of the entire land (3-acres land) to be utilized for proposed ISWM facility	Lump sum	-	-	30,000
1.2	Soil investigations to be carried out at selected locations to evaluate the ground conditions	Lump sum	-	-	1,000,000
1.3	Slope stability analysis for the controlled landfill	Lump sum	-	-	2,000,000
1.4	Laboratory investigation on permeability test	Lump sum	-	-	200,000
1.5	Hydrological study	Lump sum	-	-	500,000
2	Sorting at the source:				
2.1	Distribution of leaflets, Propaganda campaign through public announcements, Announcements through religious leaders	Lump sum	-	-	500,000
3	Collection and transport:				
3.1	Distribution of leaflets, Propaganda campaign through public announcements	Lump sum	-	-	250,000
3.2	Procurement of garbage compactor of 6–8 m^3 to be included to the collection vehicular fleet	Nr	2	7,000,000	14,000,000
3.3	GPS-assisted garbage-carrying vehicular tracking system for tracking vehicles	Lump sum	-	-	1,000,000
4	Compost plant				
4.1	Desk-type workshop of two days duration, Hands-on experience training in a solid waste management yard in Colombo for all employees involved in ISWM and Desk-type workshop of half a day for Council Members Mobilization and construction of workers huts	Lump sum	-	-	500,000
4.2	Clearing site vegetation, bushes, shrubs, trees, and removing all debris away from	m^2	12,150	300	3,645,000

	the site. This includes removing of topsoil to an average depth 150 mm, disposal of materials away from the site.				
4.3	Substructure details of the compost plant				
4.3.4	Construction of footings in compost plant area where existing soil condition is accepted for shallow foundation – 2.1 m x 2.1 m x 0.4 m footing [16T16 @125 c/c B(L), 16T16 @125 c/c B(S), 14T12 @150 c/c T(L), 14T12 @150 c/c T(S)], 0.3 m x 0.6 m column [8T16, T10 @ 150 c/c stirrups], excavation and backfilling, formwork and Concreting (Grade 25)	Nr	40	215,000	8,600,000
4.3.5	Construction of tie beam connecting all footings - 0.3 m x 0.45 m [3T16 B, 2T16 T, and T12 @ 150 c/c stirrups, Grade 25	lm	850	11,500	9,775,000
4.4	Superstructure details of the compost plant				
4.4.1	Building for the composting process (125 mm thick Grade 25 reinforced concrete, fabricating, erecting, fixing of steel I sections, trusses, purlins, and Zn/Al roofing sheets, etc.). The building area includes all the unit processes to be done in the compost plant under cover	m^2	3,000	25,000	75,000,000
4.5	Office and dining area for office staff				
4.5.1	Pad footings as a type of the foundation of the office area including dining and washrooms for office staff, tie beam connecting all footing, floor concreting (100 mm thick Grade 25 reinforced concrete), steel I sections as columns, roof with Zn/Al sheets, half board glass type panels for partitions,	m^2	45	40,000	1,800,000

	brick/block exterior walls, gypsum board ceiling, floor carpet, etc.)				
4.5.2	Pad footings as a type of the foundation of the dining area including male and female washrooms for workers, tie beam connecting all footing, floor concreting (100 mm thick Grade 25 reinforced concrete), steel I sections as columns, roof with Zn/Al sheets, partitions, floor rendering, etc.	m^2	55	30,000	1,650,000
4.5.3	Sanitary appliance [supply and installation of good quality water closet (2 nos), squatting pad (3 nos), shower (6 nos), floor gully (14 nos), tap (12 nos), washbasin (5 nos), sink (3 nos), bidet shower (5 nos), angle valves (16 nos), mirror (3 nos), etc.	Lump sum	-	-	250,000
4.5.4	Plumbing works (uPVC pipes for water supply and drainage)	Lump sum	-	-	500,000
4.5.5	Supply and installation of 2000 L water tanks	Nr	5	50,000	250,000
4.5.6	Construction of a supporting structure (6 m height) to support 2 tanks (2000 L each)	Lump sum	-	-	550,000
4.5.7	Supply and installation of compact wastewater treatment plant (capacity is 4 m^3/day)	Nr	1	2,000,000	2,000,000
4.5.8	Construction of an underground collection tank (capacity is 8 m^3)	Nr	1	750,000	750,000
4.5.9	Wheel washing area (100 mm thick Grade 25 single reinforcement net with middle drain and grating)	Lump sum	-	-	1,000,000
4.6	Watcher's hut (half board glass type panels for walls)	Nr	2	275,000	550,000
4.7	Parking for vehicles of office staff and workers; Pad footings as a type of the foundation, tie beam connecting all footing, GI pipe	m^2	150	12,500	1,875,000

	as columns, roof with Zn/Al sheets, floor concreting (100 mm Grade 25), etc.				
4.8	Laying of interlocking paving in the parking area for garbage-carrying vehicles and in front of the office. Rate to include spreading, leveling, and compacting of quarry dust layer.	m^2	1,250	3,100	3,875,000
4.9	Infrastructure facilities				
4.9.1	Supply of water from the NWS&DB main	Lump sum	-	-	100,000
4.9.2	Supply of 3-phase electricity from the CEB main including the supply and installation of a transformer	Lump sum	-	-	1,500,000
4.9.3	Supply and installation of lights as per the drawings	Nr	75	6,000	450,000
4.9.4	Supply and installation of plug bases as per the drawings	Nr	100	1,500	150,000
4.9.5	Supply and laying of wires as per the drawings	m	2500	325	812,500
4.9.6	Supply and installation of wall-mounted type Distribution Board including necessary CT's, protection relays, internal connections, and all other accessories required.	Lump sum	-	-	1,000,000
4.9.7	Lightning arrester	Lump sum	-	-	2,000,000
4.10	Access internal roads				
4.10.1	Filling and compaction of the dense graded aggregate base of 200 mm thick	m^3	300	6,000	1,800,000
4.10.2	Applying of bituminous prime coat on top of the fully prepared aggregate layer and blotting material	m^2	1,500	275	412,500
4.11	Boundary fence				

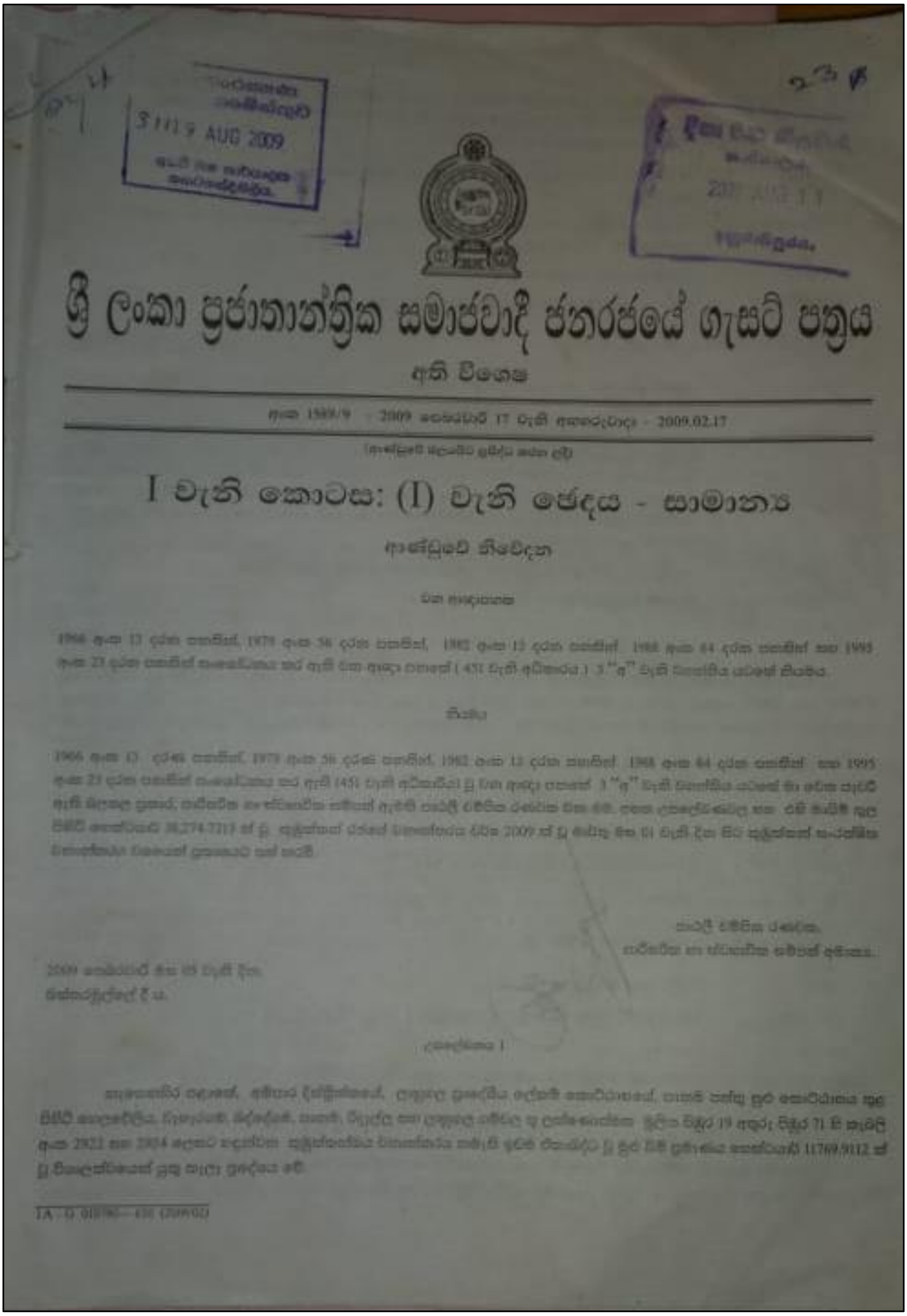
4.11.1	Supply and fixing of green PVC coated galvanized chain link fence	m	600	10,500	6,300,000
4.11.2	Supply and fixing of gates	Nr	2	22,500	45,000
4.12	Drainage system				
4.12.1	Leachate collection drain (Internal depth of 300 mm and width of 300 mm concrete drain. Wall thickness is 100 mm and drains are covered with gratings. This includes excavation, formwork, reinforcement, concreting, and fixing of gratings)	m	400	8,500	3,400,000
4.12.2	Rainwater harvesting system (collection tank of 10 m^3 [pvc], submersible pump, and reticulation network)	Lump sum	-	-	500,000
4.12.3	Stormwater collection main drain (Internal depth of 1,000 mm and width of 1,000 mm reinforced concrete drain. Wall thickness is 200 mm. This includes excavation, formwork, reinforcement, concreting, etc.)	m	440	21,000	9,240,000
4.12.4	Stormwater collection drains (Internal depth of 500 mm and width of 500 mm reinforced concrete drain. Wall thickness is 125 mm. This includes excavation, formwork, reinforcement, concreting, and fixing of gratings)	m	300	16,000	4,800,000
4.12.5	Manholes (internal width of 1,000 mm and length of 1,000 mm and depth starting from 600 m depth. The manholes are constructed with reinforced concrete of grade 25 and are covered with water seal lid (cover) made of GI.	Nr	6	50,000	300,000
4.13	Leachate collection, storage, and reticulation system				
4.13.1	Construction of a Grade 35 reinforced concrete underground sump having	Nr	1	1,750,000	1,750,000

	internal dimensions of 3 m long, 3 m wide, and 4 m deep including top manhole				
4.13.2	Leachate reticulation system	m	150	950	142,500
4.14	Equipment/machinery				
4.14.1	Shredding machine	Nr	1	5,000,000	5,000,000
4.14.2	Sieving machine	Nr	1	6,000,000	6,000,000
4.14.3	Submersible cutter pump	Nr	2	500,000	1,000,000
4.14.4	Weighbridge	Nr	1	10,000,000	10,000,000
4.14.5	Odor control facility	Lump sum	-	3,000,000	3,000,000
4.14.6	Skid steer loader	Nr	1	4,000,000	4,000,000
4.15	Supply and planting of tree belt (Plants of suitable species which are not less than 2.0 m in height and girth not less than 300 mm planted, and natured)	Nr	40	16,250	650,000
4.16	Computers (4 nos), networking facility, and printers (2 nos)	Lump sum	-	-	1,000,000
4.17	Office equipment (tables, chairs, racks, cupboards, etc.)	Lump sum	-	-	1,000,000
4.18	CCTV network for compost yard (20 nos of bullet type cameras including a display panel, cabling, data storage for 2 days, networking, etc.)	Lump sum	-	-	2,000,000
4.19	Approvals to be obtained for both compost plant and controlled landfill	Lump sum	-	-	1,750,000
4.20	Personal protective gears	Lump sum	-	-	1,000,000
5	Recycling and reusing waste:				
5.1	Distribution of leaflets, Propaganda campaign through public announcements	Lump sum	-	-	500,000
6	Controlled landfill and Constructed wetland:				
6.1	Distribution of leaflets,		-	-	250,000

	Propaganda campaign through public announcements	Lump sum			
6.2	Desk-type workshop of two days duration, Hands-on experience training in a solid waste management yard in Colombo for employees involved in ISWM	Lump sum	-	-	250,000
6.3	Trimming, leveling, and compaction of existing ground	m^2	2,500	70	175,000
6.4	Supply and laying of soil layer of 1 m and dynamic compaction	m^3	2,500	3,500	8,750,000
6.5	Supply and laying of 30 cm clay	m^3	75	10,000	750,000
6.6	Supply and laying of non-woven geotextile layer extended up to the outer edge of the embankment	m^2	2,500	650	1,625,000
6.7	Supply and laying of thin about 15 cm soil layer	m^3	40	2,700	108,000
6.8	Construction of tipping pad				
6.8.1	Supply and laying of soil layer of 2 m thick and compaction	m^3	200	3,000	600,000
6.8.2	Filling and compaction of the dense graded aggregate base of 225 mm thick on top of the properly finished soil	m^3	25	6,000	150,000
6.8.3	Applying of bituminous prime coat on top of the fully prepared aggregate layer and blotting material	m^2	100	275	27,500
6.9	Construction of C&D (construction and demolition waste yard (concrete base and 2-m height wall covering three side except the entrance	m^2	50	14,000	700,000
6.10	Construction of leachate and stormwater drainage network				
6.10.1	Leachate/stormwater collection drain (Internal depth of 600 mm and width of 600 mm reinforced concrete drain. Wall thickness is 100 mm and	m	300	18,000	5,400,000

	drains are covered with gratings. This includes excavation, formwork, reinforcement, concreting, and fixing of gratings)				
6.10.2	Manholes (internal width of 900 mm and length of 900 mm and depth starting from 1000 m depth. The manholes are constructed with reinforced concrete of grade 25 and are covered with water seal lid (cover) made of GI.	Nr	12	45,000	540,000
6.11	Construction of constructed wetland				
6.11.1	Leveling and compaction of existing ground	m^2	300	70	21,000
6.11.2	Supply and laying of soil layer of 300 mm thick and compaction	m^3	100	2,700	270,000
6.11.3	Supply and laying of non-woven geotextile layer extended up to the outer edge of the wall	m^2	300	650	195,000
6.11.4	Construction of boundary walls of the wetland by RRM (350 mm wide 1 m deep)	m^3	35	13,500	472,500
6.11.5	Supply and fixing of asbestos sheets to obtain zigzag configuration	Lump sum	-	-	100,000
6.11.6	Filling of Calicut tiles as the wetland media	m^3	100	500	50,000
6.11.7	Supply and planting a suitable wetland plant	Lump sum	-	-	50,000
6.11.8	Supply of soil for daily cover (2 m^3 will be required to cover the solid waste dumped in the landfill daily. Soil required as a daily cover per month is stored.	m^3	100	2,100	210,000
6.11.9	Personal protective gears	Lump sum	-	-	100,000

Annexure 4.1: Extraordinary Gazette No. 1589/09 dated 2009.02.17



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අංක 1589/9 - 2009 පෙබරවාරි 17 වැනි අඟහරුවාදා - 2009.02.17

I වැනි කොටස: (I) වැනි ඡෙදය - සාමාන්‍ය

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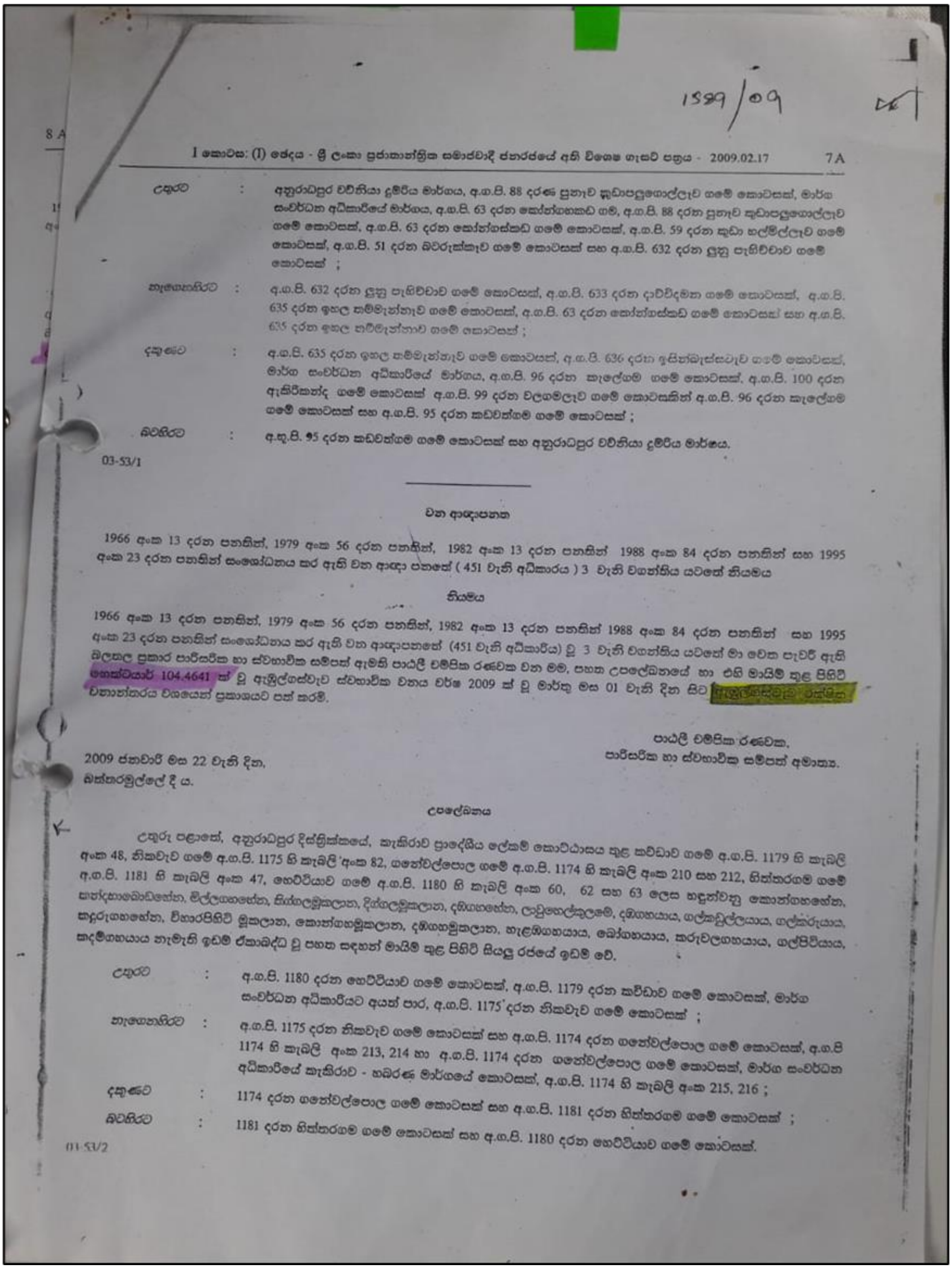

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උතුරට : අනුරාධපුර වව්නියා දුම්රිය මාර්ගය, අ.ග.පි. 88 දරණ පුනාව කුඩාපලුගොල්ලෑව ගමේ කොටසක්, මාර්ග සංවර්ධන අධිකාරියේ මාර්ගය, අ.ග.පි. 63 දරන කෝන්ගහකඩ ගම, අ.ග.පි. 88 දරන පුනාව කුඩාපලුගොල්ලෑව ගමේ කොටසක්, අ.ග.පි. 63 දරන කෝන්ගස්කඩ ගමේ කොටසක්, අ.ග.පි. 59 දරන කුඩා හල්මිල්ලෑව ගමේ කොටසක්, අ.ග.පි. 51 දරන බටරුක්කෑව ගමේ කොටසක් සහ අ.ග.පි. 632 දරන ලුනු පැහිච්චාව ගමේ කොටසක් ;

නැගෙනහිරට : අ.ග.පි. 632 දරන ලුනු පැහිච්චාව ගමේ කොටසක්, අ.ග.පි. 633 දරන දාච්චිදමන ගමේ කොටසක්, අ.ග.පි. 635 දරන ඉහල තම්මැන්නෑව ගමේ කොටසක්, අ.ග.පි. 63 දරන කෝන්ගස්කඩ ගමේ කොටසක් සහ අ.ග.පි. 635 දරන ඉහල තම්මැන්නාව ගමේ කොටසක් ;

දකුණට : අ.ග.පි. 635 දරන ඉහල තම්මැන්නෑව ගමේ කොටසක්, අ.ග.පි. 636 දරන ඉසින්බැස්සෑව ගමේ කොටසක්, මාර්ග සංවර්ධන අධිකාරියේ මාර්ගය, අ.ග.පි. 96 දරන කැලේගම ගමේ කොටසක්, අ.ග.පි. 100 දරන ඇකිරිකන්ද ගමේ කොටසක් අ.ග.පි. 99 දරන වලගමලෑව ගමේ කොටසකින් අ.ග.පි. 96 දරන කැලේගම ගමේ කොටසක් සහ අ.ග.පි. 95 දරන කඩවත්ගම ගමේ කොටසක් ;

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1966 අංක 13 දරන පනතින්, 1979 අංක 56 දරන පනතින්, 1982 අංක 13 දරන පනතින් 1988 අංක 84 දරන පනතින් සහ 1995 අංක 23 දරන පනතින් සංශෝධනය කර ඇති වන ආඥා පනතේ (451 වැනි අධිකාරය) 3 වැනි වගන්තිය යටතේ නියමය

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1966 අංක 13 දරන පනතින්, 1979 අංක 56 දරන පනතින්, 1982 අංක 13 දරන පනතින් 1988 අංක 84 දරන පනතින් සහ 1995 අංක 23 දරන පනතින් සංශෝධනය කර ඇති වන ආඥාපනතේ (451 වැනි අධිකාරිය) වූ 3 වැනි වගන්තිය යටතේ මා වෙත පැවරී ඇති බලතල ප්‍රකාර පාරිසරික හා ස්වභාවික සම්පත් ඇමති පාඨලී චම්පික රණවක වන මම, පහත උපලේඛනයේ හා එහි මායිම් තුළ පිහිටි හෙක්ටයාර් 104.4641 ක් වූ ඇඹිලිගස්වැව ස්වභාවික වනය වර්ෂ 2009 ක් වූ මාර්තු මස 01 වැනි දින සිට [illegible] රක්ෂිත වනාන්තරය වශයෙන් ප්‍රකාශයට පත් කරමි.

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2009 ජනවාරි මස 22 වැනි දින,
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උපලේඛනය

උතුරු පළාතේ, අනුරාධපුර දිස්ත්‍රික්කයේ, කැකිරාව ප්‍රාදේශීය ලේකම් කොට්ඨාසය තුළ කච්ඩාව ගමේ අ.ග.පි. 1179 හි කැබලි අංක 48, නිකවැව ගමේ අ.ග.පි. 1175 හි කැබලි අංක 82, ගනේවල්පොල ගමේ අ.ග.පි. 1174 හි කැබලි අංක 210 සහ 212, හිත්තරගම ගමේ අ.ග.පි. 1181 හි කැබලි අංක 47, හෙට්ටියාව ගමේ අ.ග.පි. 1180 හි කැබලි අංක 60, 62 සහ 63 ලෙස හඳුන්වනු කොන්ගහහේන, සන්දකාගෙබඩහේන, මිල්ලගහහේන, සින්ගලමුකලාන, දිග්ගලමුකලාන, දඹගහහේන, ලාවුහෙල්කුලම, දඹගහයාය, ගල්කඩුල්ලයාය, ගල්කරුයාය, කදුරුගහහේන, විහාරපිහිටි මුකලාන, කොන්ගහමුකලාන, දඹගහමුකලාන, හැළඹගහයාය, බෝගහයාය, කරුවලගහයාය, ගල්පිටියාය, කදම්ගහයාය නැමැති ඉඩම් ඒකාබද්ධ වූ පහත සඳහන් මායිම් තුළ පිහිටි සියලු රජයේ ඉඩම් වේ.

උතුරට : අ.ග.පි. 1180 දරන හෙට්ටියාව ගමේ කොටසක්, අ.ග.පි. 1179 දරන කච්ඩාව ගමේ කොටසක්, මාර්ග සංවර්ධන අධිකාරියට අයත් පාර, අ.ග.පි. 1175 දරන නිකවැව ගමේ කොටසක් ;

නැගෙනහිරට : අ.ග.පි. 1175 දරන නිකවැව ගමේ කොටසක් සහ අ.ග.පි. 1174 දරන ගනේවල්පොල ගමේ කොටසක්, අ.ග.පි 1174 හි කැබලි අංක 213, 214 හා අ.ග.පි. 1174 දරන ගනේවල්පොල ගමේ කොටසක්, මාර්ග සංවර්ධන අධිකාරියේ කැකිරාව - හබරණ මාර්ගයේ කොටසක්, අ.ග.පි. 1174 හි කැබලි අංක 215, 216 ;

දකුණට : 1174 දරන ගනේවල්පොල ගමේ කොටසක් සහ අ.ග.පි. 1181 දරන හිත්තරගම ගමේ කොටසක් ;

බටහිරට : 1181 දරන හිත්තරගම ගමේ කොටසක් සහ අ.ග.පි. 1180 දරන හෙට්ටියාව ගමේ කොටසක්.

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Annexure 4.2: Master plan of the proposed ISWM facility

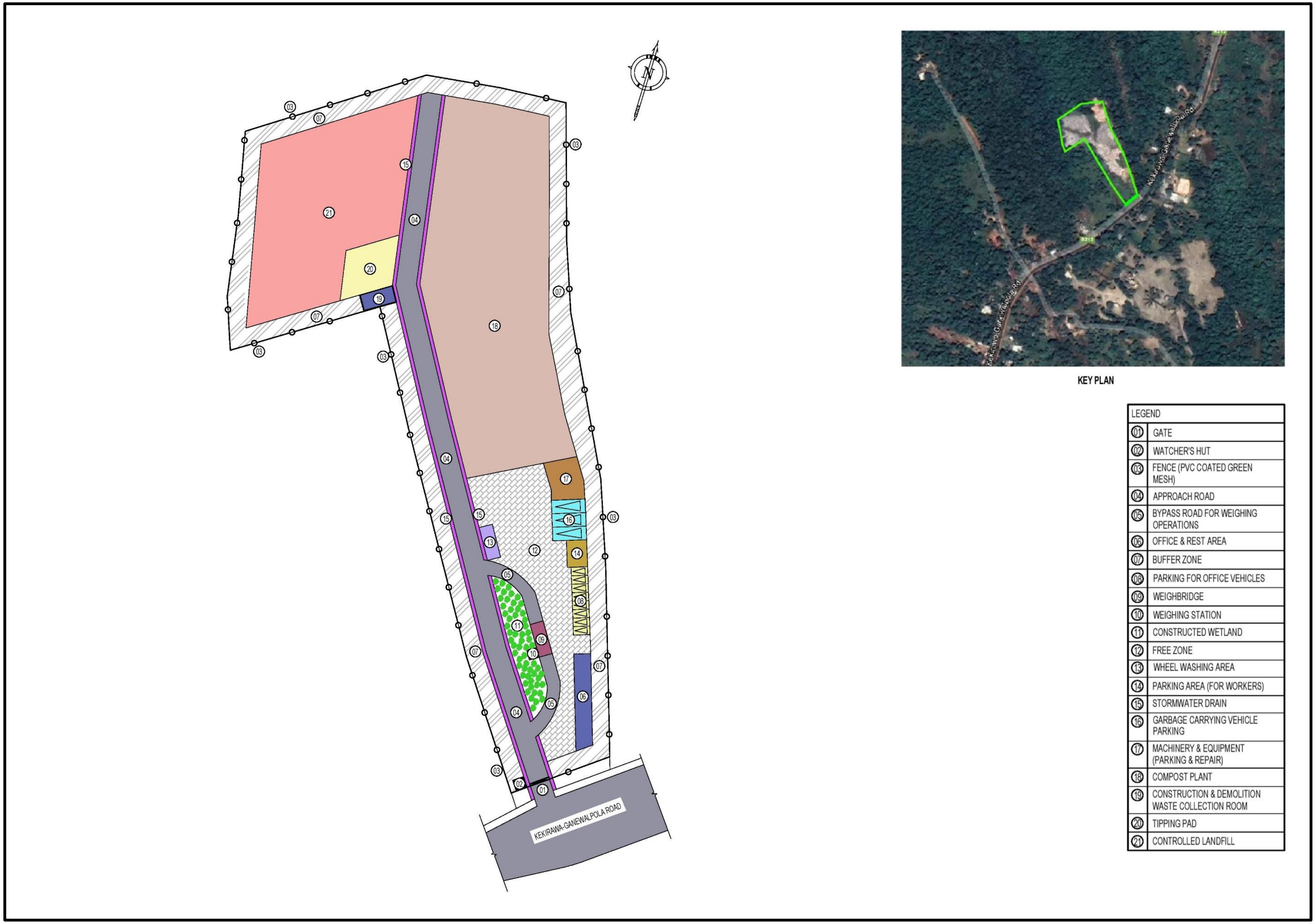


Figure A.1: Proposed master plan of the ISWM facility of Kekirawa PS

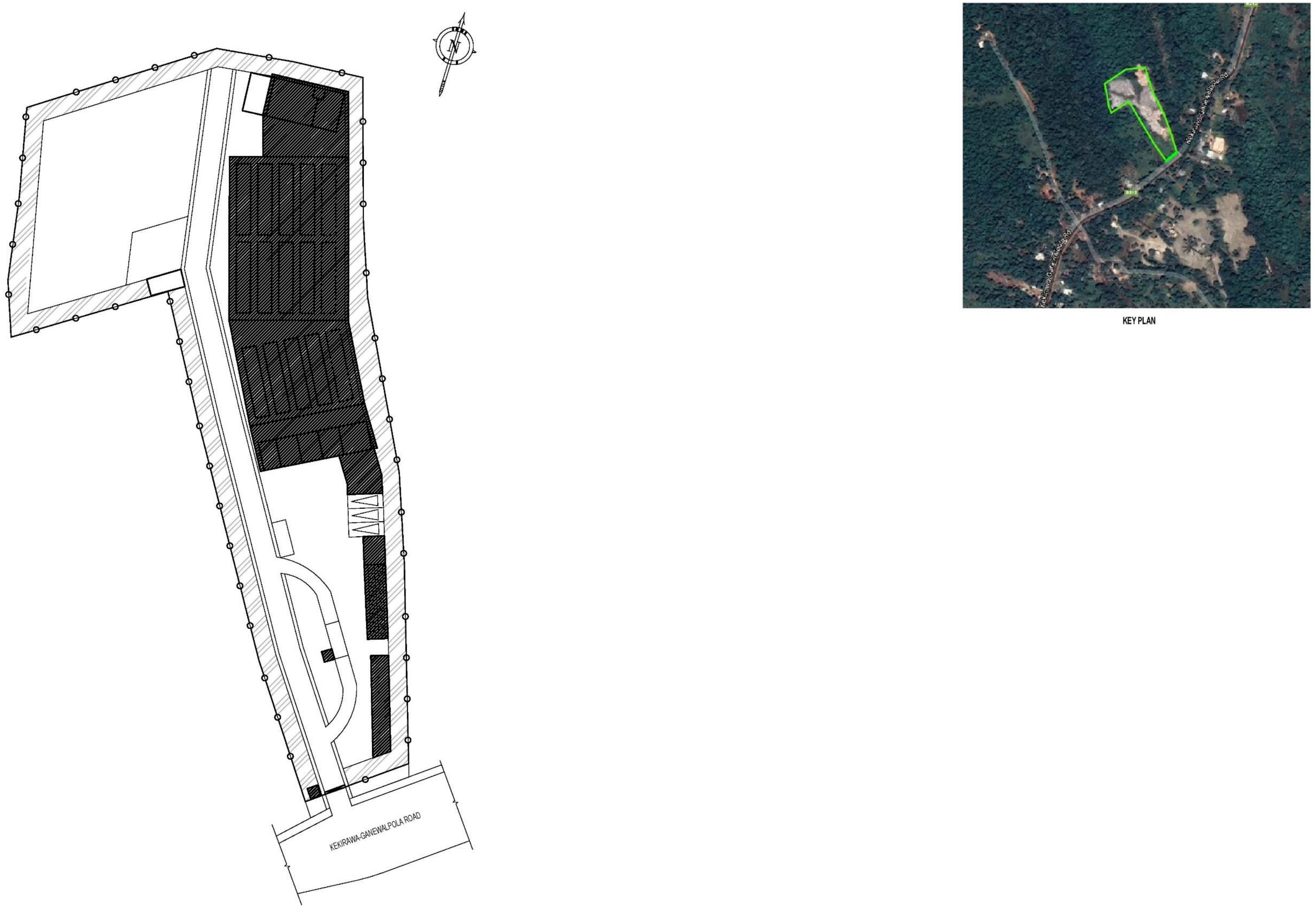


Figure A.2: The roof coverage of the ISWM facility of Kekirawa PS

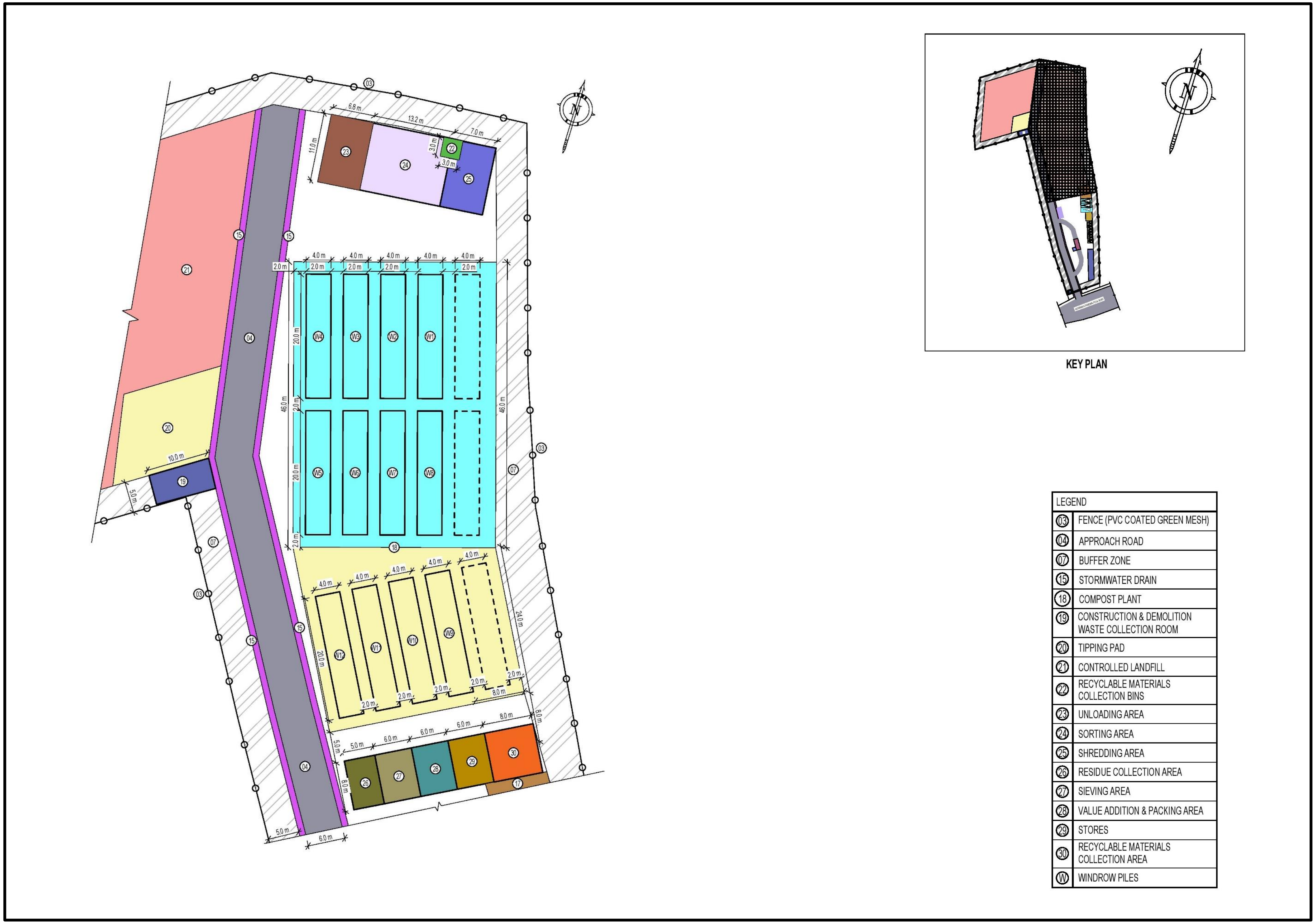


Figure A.3: Compost plant of the proposed ISWM facility of Kekirawa PS

Annexure 4.3: Design calculations of the compost plant

i. Waste generation projections for the 10-year horizon

The waste generation projections for the 10-year horizon are summarized in Table A.1.

Table A.1: Summary of waste generated over the 10-year horizon

Item	**Year**		
	2020 (current)	**2022 (With the proposed project)**	**2030 (End of the design period)**
Total waste generation	41 MT/day	42 MT/day	46 MT/day
Percentage of the total waste collection	17%	50%	50%
Total waste collection	7 MT/day	21 MT/day	23 MT/day
Percentage of the biodegradable waste in the total waste collected	60.0%	60.0%	60.0%
Total biodegradable waste in the total waste collected	4.2 MT/day	12.6 MT/day	13.8 MT/day
Percentage of the non-biodegradable waste to be landfilled	35.0%	35.0%	35.0%
Total non-biodegradable waste to be landfilled	2.45 MT/day	7.35 Mt/day	8.05 MT/day
Percentage of the recyclable or reuse materials in the total waste collected	5.0%	5.0%	5.0%
Total recyclables or reuse materials in the total waste collected	0.35 MT/day	1.5 MT/day	2.0 MT/day
Total construction and demolition waste in the total waste collected	< 0.5MT/day	< 0.5 MT/day	< 0.5 MT/day
Total street sweeping waste in the total waste collected	< 0.1 MT/day	< 0.1 MT/day	< 0.1 MT/day

The compost plant is designed to manage the total biodegradable waste collected for a design horizon of 10-year period. Therefore, the design calculations done for the compost plant is based on the total biodegradable waste collected at the end of the design period (13.8 MT/day).

ii. Calculation of the area required for unloading facility

Assuming seven number of garbage-carrying vehicles arrive at the proposed compost plant within four hours at a given day during morning times, the number of garbage-carrying vehicles to be handled within the unloading area is two vehicles per hour.

The average volume of a garbage-carrying vehicle (modified tractor-trailer) is 4 m^3. The density of the garbage in consolidated form during transporting is 400-600 kg/m^3. Once unloaded, the density of the garbage in an unconsolidated form is taken as 200 kg/m^3.

Calculation

Weight of garbage carried by a vehicle (tractor with a modified trailer) with a capacity of 4 m^3 (maximum waste loading is considered)

= 1300 kg

Density of the garbage when unloaded (unconsolidated form)

= 200 kg/m^3

Volume of the garbage when unloaded = 7 m^3

Height of the garbage pile when unloaded = 1 m (Figure A.4)

Area required for one pile when unloaded = 7 m^2

Average dimensions of a modified tractor-trailer (length × width × height)

= 10 × 6 × 2.5 feet

Average dimensions of one pile when unloaded (assuming a rectangular base at the bottom of the pile when unloaded)

= 2.8 × 2.5 m (L × W)

Number of garbage-carrying vehicles to be handled in the unloading area per hour

= 2

Distance between 2 piles when unloaded = 2 m

Dimensions of the unloading area = 11 × 6.8 m

Clear height of the unloading area = 6 m

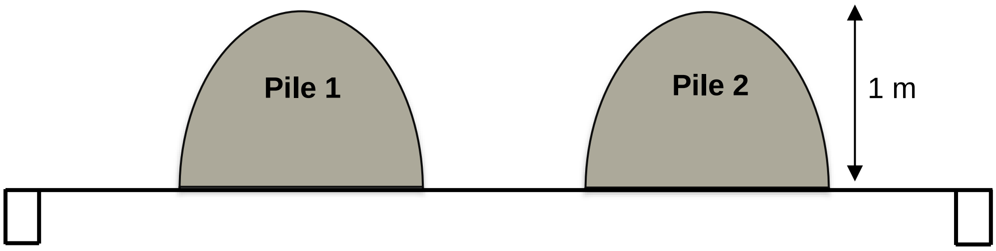


Figure A.4: Section X – X

iii. Calculation of the area required for the sorting facility

Assuming that it takes 30 minutes for sorting of 1 pile and the height of the garbage spread is 25 cm at the time of sorting.

Calculation

Volume of 1 pile (unconsolidated form) = 7 m^3

Height of the garbage spread at the time of sorting = 25 cm

Area required per 1 pile = 7/0.25

= 28 m^2

Number of unloading per hour = 2

Area required for 2 piles = 56 m^2

Distance between 2 piles = 2 m

Dimensions of each spread = 2.5 m × 11.2 m

Dimensions of the sorting area (L × W) = 11 × 13.2 m

iv. Details of the shredding machine and calculation of the area required for installing the shredding machine

The machine should be fixed on a firm concrete base and free from other obstacles. The thickness of the concrete base where the shredding machine is installed is 225 mm.

The production capacity of the machine shall be not less than 4 MT/hour.

The dimensions of the shredding area where the shredding machine is to be installed are 11 × 7 m (length × width).

v. Calculation of the area required for active composting

Passively aerated windrow method is used, and this method involves the feedstock being formed into long, low piles known as windrows.

The windrows are regularly moved or turned [every three (03) days] to re-establish porosity, break up, and blend material. The turning process also reintroduces oxygen into the windrow.

The period of active composting is 8 weeks.

Calculation

Weight of the garbage to be composted = 13.8 MT/day

Loss of weight of the garbage during unloading, sorting, and shredding

= 5%

Actual weight of the garbage to be composted = 13.1 MT/day

Density of compost = 700 kg/m^3

(Density of compost is 400-600 kg/m^3. Since the shredding machine is provided, the density of the compost is taken as 700 kg/m^3).

The volume of garbage to be composted daily = 13100/700

= 19 m^3

The volume of garbage to be composted per week = 19 × 7

= 133 m^3

Number of windrow piles per week = 1

Total number of windrow piles during the period of active composting (8 weeks)

= 8

Space required to erect 2 piles is additionally provided in the concrete pad to facilitate the turning of windrows. Therefore, the concrete pad is designed to set-up 10 piles.

Height of each windrow pile (Figure A.5) = 2.5 m

Bottom width of each windrow pile = 4 m

Minimum distance between 2 windrow piles = 2 m

Length of each windrow pile = 20 m

Total width of the active composting area = 32 m

Total length of the active composting area = 45 m

Dimensions of the active composting area = 32 × 45 m

Clear height of the active composting area = 6 m

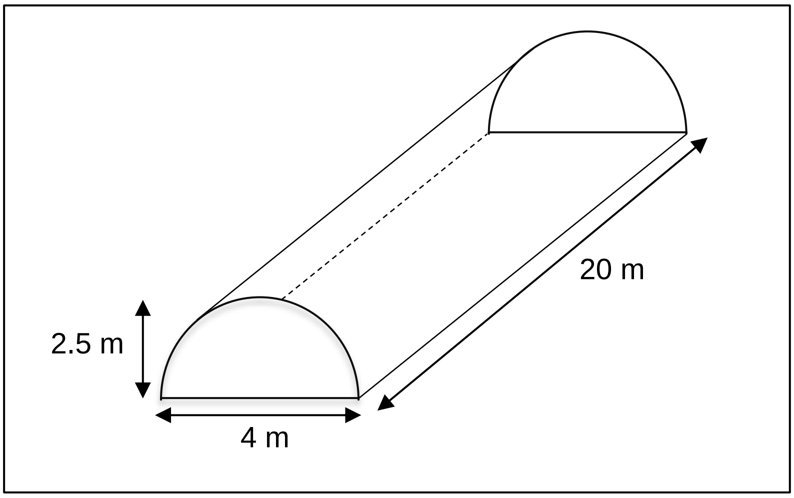


Figure A.5: Dimensions of a windrow pile during active composting

vi. Calculation of the area required for curing

The volume reduction during active composting is 50%. After 8 weeks of the period of active composting, the windrows are moved to the curing area by the skid steer loader. The period of curing is 4 weeks.

Calculation

Volume of the compost after active composting = 133/2

= 66.5 m^3

Since, the volume reduction in the windrow pile during active composting is 50%, 2 windrow piles in the active composting stage can be combined to form a single windrow pile in the curing stage.

Total number of windrow piles during the period of curing (4 weeks)

= 4

Space required to erect 1 pile is additionally provided in the concrete pad to facilitate the turning of windrows. Therefore, the concrete pad is designed to set-up 5 piles.

Height of each windrow pile (Figure A.5) = 2.5 m

Bottom width of each windrow pile = 4 m

Length of each windrow pile = 20 m

Total length of the curing area = 23 m

Total width of the curing area = 32 m

Dimensions of the active composting area = 23 × 32 m

Clear height of the curing area = 6 m

vii. Details of the sieving machine and calculation of the area required for installing the sieving machine

The mature compost after curing, sieves via a sieving machine (trommel) of sieve size is 4 mm.

The machine should be fixed on a firm concrete base and free from other obstacles. The height of the base shall be decided based on the manufacture's recommendations.

The production capacity of the machine shall be not less than 2 MT/hour.

The dimensions of the shredding area where the shredding machine is to be installed are 6 × 8 m (length × width).

viii. Calculation of the area required for value addition and packing

The dimensions of the area provided for value addition and packing is 6 × 8 m (length × width).

The nitrogen, phosphorous, and potassium rich materials are kept inside the area and mixed with the final compost after sieving to improve the quality of the compost.

ix. Calculation of the area required for stores

The quantity of the final compost product is 3,000 kg/day.

The dimensions of the area provided for stores is 6 × 8 m (length × width).

The easy access of vehicles to the stores will be provided. A lockable door will be fixed to ensure the safety of the stores. The floor of the stores will be raised to avoid stormwater entering the floor, and final compost packages will be kept on top of the wood pellets to avoid ground moisture to absorb to the packages.

x. Calculation of the area required for residue collection

The dimensions of the area provided for residue collection is 5 × 8 m (length × width).

The quantity of the residues collected in the residue collection area is 3.45 MT/day. All the residues will be collected and disposed of in the controlled landfill using a tractor at the end of the operations of compost plant in each day.

xi. Calculation of the area required for recyclable materials collection

The dimensions of the area provided for recyclable materials collection is 8 × 8 m (length × width).

The area is partitioned into six number of compartments, and each compartment has a floor area of 5-6 m^2. A half-wall (6 feet high) will be constructed at the perimeter of the area, and compartments will be partitioned by constructing half-walls (block walls with 6 feet high). Gates are fixed to each compartment and access through vehicles is provided

xii. Calculation of the area required for machinery and equipment (parking, repair, etc.)

The area provided for the parking and repairing of machinery and equipment is 10 × 8 m (length × width).

The 6 m wide road is constructed to provide clear access to the area; hence hauling, lifting, and carrier vehicles can easily access the machinery and equipment parking and repair area.

If electric hoist of any other heavy equipment and machinery to be used, structural integrity needs to be ensured.

xiii. Calculation of the area required for the tyre-washing facility

The tyre-washing system should be capable of washing tyres and the body of the garbage-carrying vehicles.

The pit is to be constructed to collect the washed water and the water collected in the pit is to be recirculated after filtration or to be sent to the leachate collection tank.

The system shall comprise of water spray guns and the water will be pressurized through a compressor.

A bay should be designed so that the spray water would not become airborne.

The water supply shall be provided through a 1-inch pipe network.

The angle of the bay shall be maintained as 4 degrees and the dimensions of the bay are 4 m wide and 10 m long.

xiv. Sectional details of the compost plant

The sectional details of the compost plant are depicted in Figures A.6 to A.12.

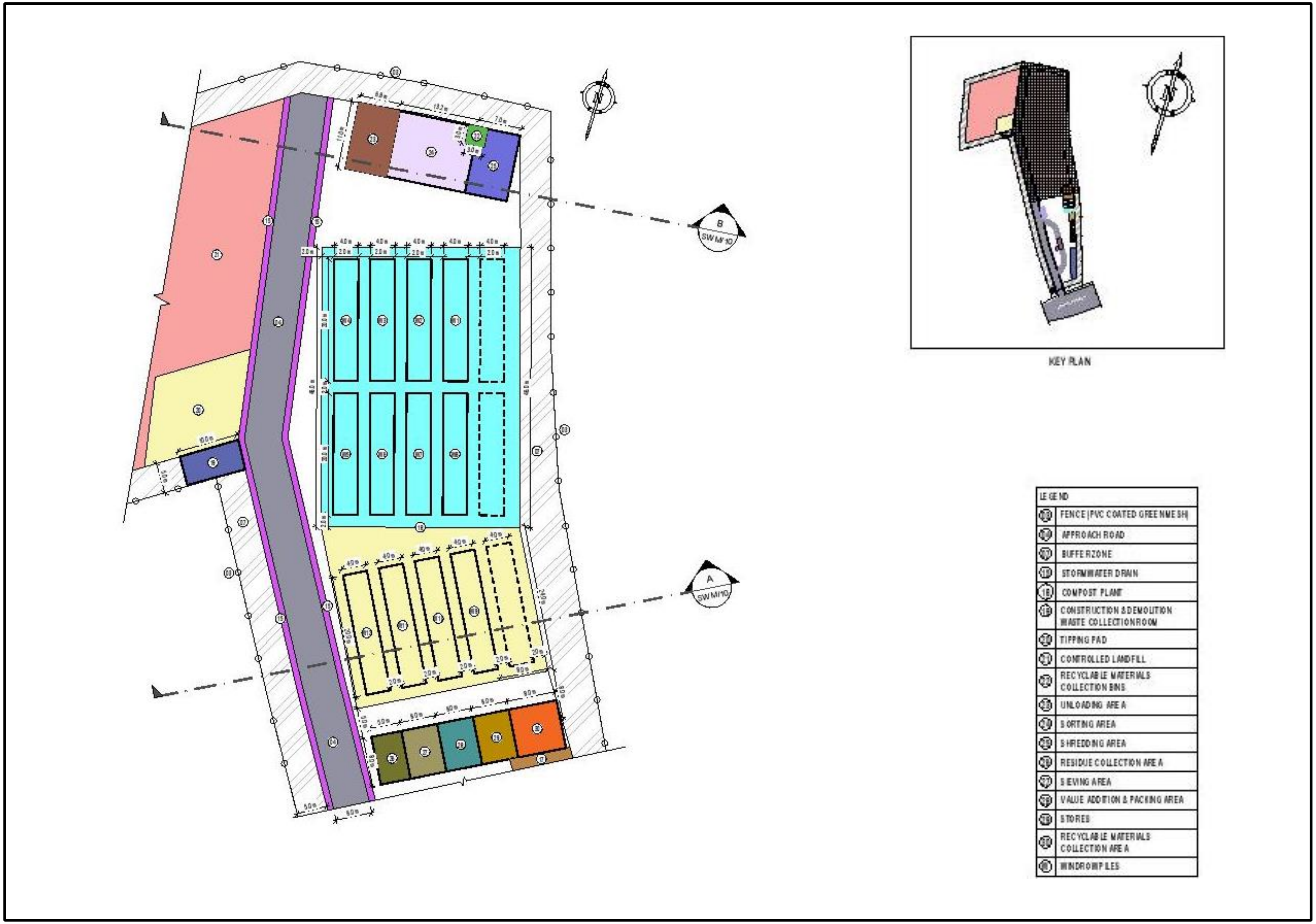
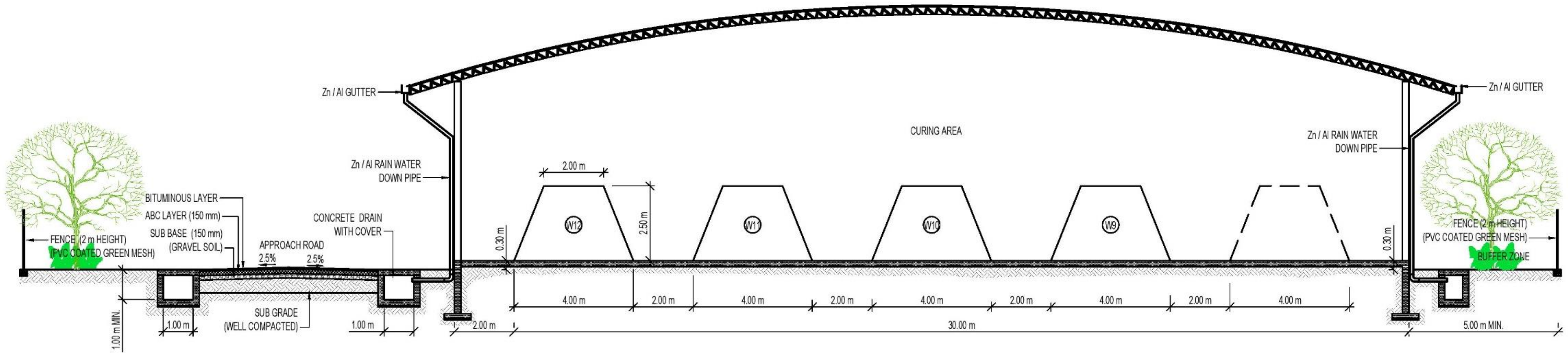
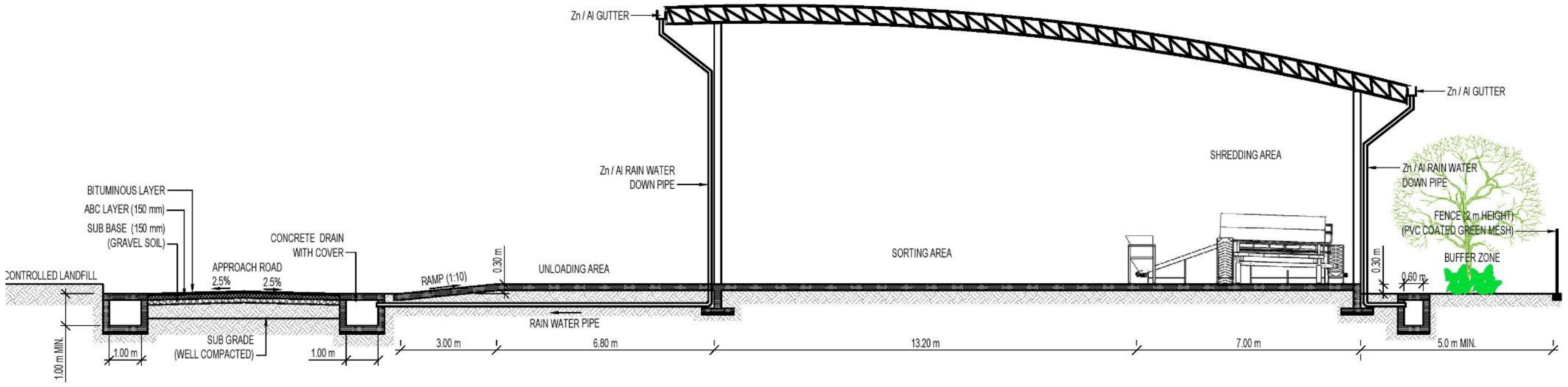


Figure A.6: Layout of the compost plant



SECTION A
SCALE 1:150 SWM/10



SECTION B
SCALE 1:150 SWM/03

Figure A.7: Sections A & B

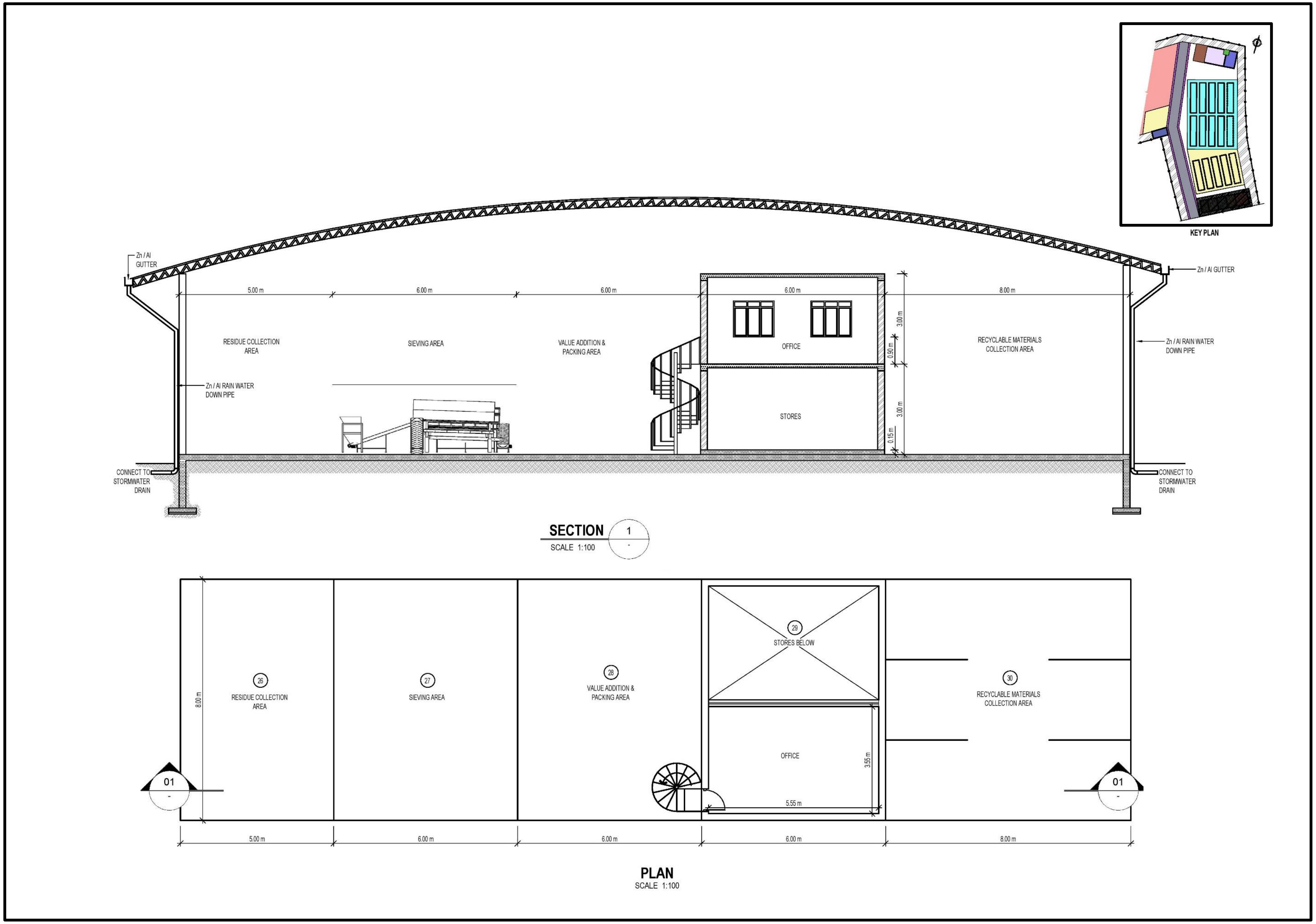


Figure A.8: Section B-B

Annexure 4.4: Design calculations of the controlled landfill

Calculation of the controlled landfill area

Expected waste collection per day at the end of the design period

= 23 MT/day

Note:
Non-biodegradable and non-recyclable waste including street sweepings and drain cleaning waste and residues generated from the compost site are to be transferred to the controlled landfill.

Quantity of the non-biodegradable and non-recyclable including street sweeping and drain cleaning waste collected per day

= 35% of the total waste collected per day

= 23 x 35% MT/day

= 8.05 MT/day

Quantity of the residues generated from the compost plant per day at the end of the design horizon

= 3.45 MT/day

Total quantity of the waste per day to be transferred to the controlled landfill at the end of the design horizon

= (8.05 + 3.45) MT/day

= 11.5 MT/day

Total quantity of the waste per year to be transferred to the controlled landfill at the end of the design horizon

= 365 x 11.5 MT/year

= 4,197 MT/year

Estimated rate of increase (or decrease) of waste generation per year

= 1.10%

Design period of the landfill = 1 year and 9 months

Note: Cumulative amount of MSW to be landfilled is considered.

Total waste generation = $365 (1/2) [W+W(1+x/100)^n] \times n$

where,

W = Total quantity of the waste per day to be transferred to the controlled landfill

X = Estimated rate of increase (or decrease) of waste generation per year

n = Design period of landfill

The cumulative MSW amount to be landfilled at the end of each year is depicted in Table A.2.

Table A.2: Cumulative MSW amount to be landfilled at the end of each year

Years (n)	Total amount of MSW to be landfilled (MT)	Residues from compost plant to be landfilled (MT)	Cumulative amount of MSW to be landfilled (MT)
1	2683	1168	3851
2	2683	1168	7702

Waste generation after 21 months = 7,067 MT

Total volume of waste in 5 years (V_w) (on the assumption of 0.6 MT/m^3 density of waste)

V_w = T/0.6 m^3

= 11,778 m^3

Total volume of daily cover in 5 years (V_{dc}) (on the basis of 15 cm soil cover on top and sides)

V_{dc} = $(0.1V_w)$ m^3

= 1,178 m^3

Total volume required for components of liner system and of cover system (on the assumption of 1.5 m thick liner system including leachate collection layer and 1.0 m thick cover system (V_c)

V_c = (kV_w) m^3

K = 0.25 (8 m high landfill)

V_c = 2,944 m^3

Additional volume likely to become available within 21 months due to settlement of non-biodegradation/inert waste (V_s)

V_s = (mV_w)

m = 0.05

V_s = 589 m^3

Average estimate of landfill capacity (C_i)= $(V_w + V_{dc} + V_c - V_s)\ m^3$

= (11,778 + 1,178 + 2,944 – 589)

= 15,311 m^3

Area required for landfill operations

A_i = $C_i / H_i\ (m^2)$

= 15,311/8

= 1,914 m^2

Total area required (including infrastructural facilities)

A_T = 1.2 Ai

= 2,297 m^2

Recommendations

The area required for the controlled landfilling for 21 months is (at the end of the design period of landfill) 2,297 m^2 (91 perch) for the landfill height of 8 m.

Annexure 4.5: Detailed drawings of the controlled landfill

Figure A.9: Layout of the controlled landfill after the completion of layer-1

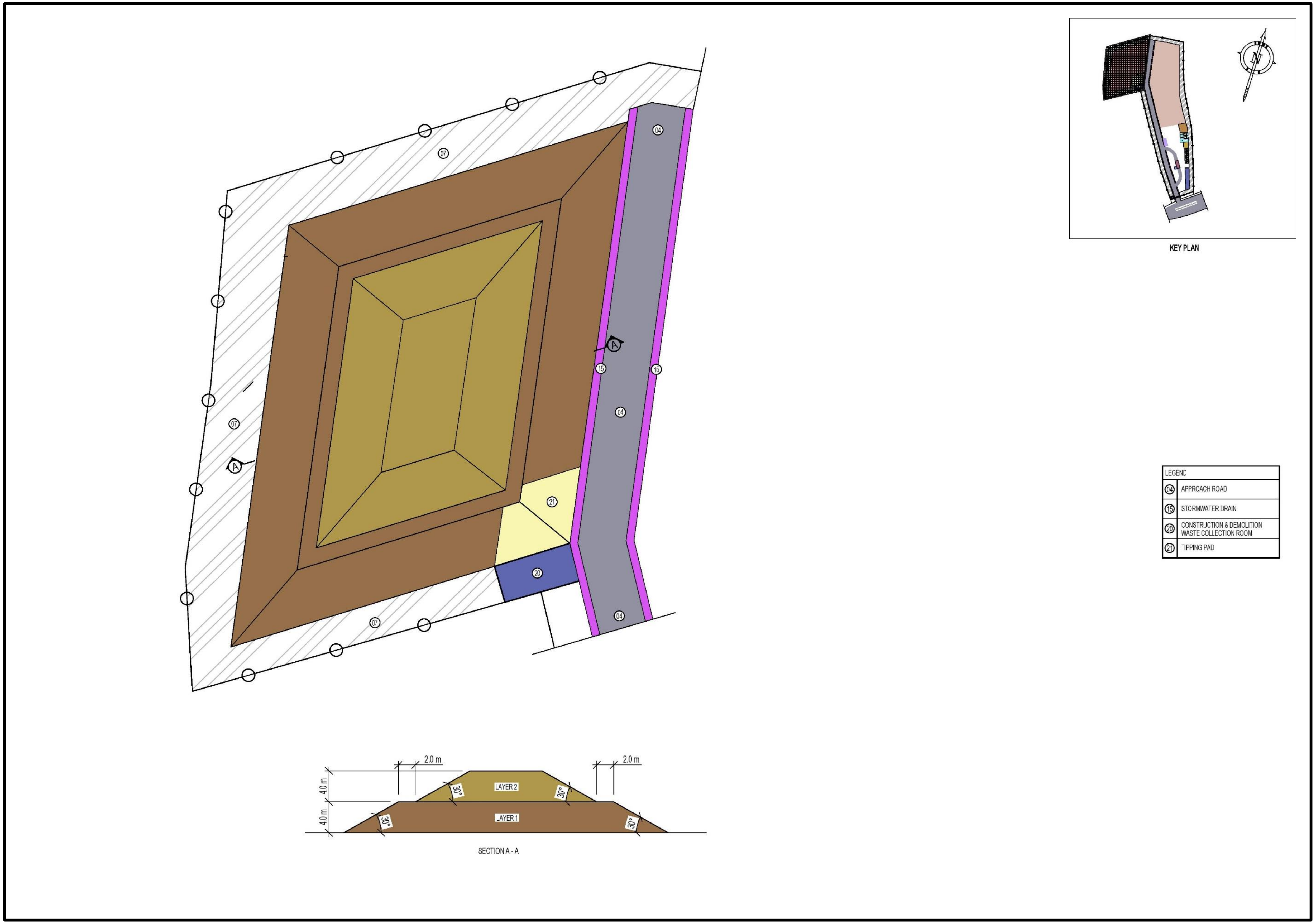


Figure A.10: Layout of the controlled landfill once garbage filling operations are finished

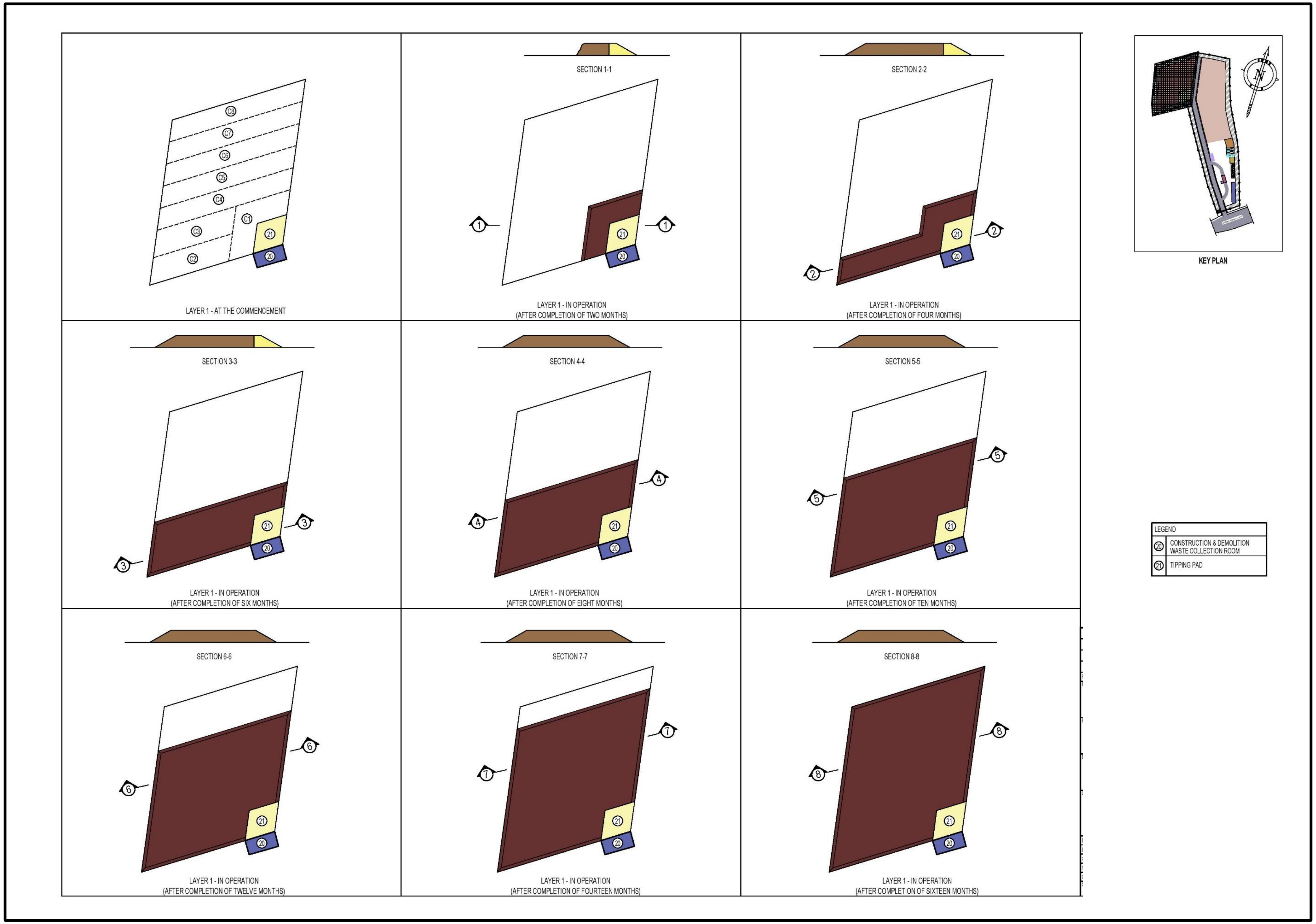


Figure A.11: Progressive development of layer-1 of controlled landfill

Annexure 4.6: Leachate collection system of the proposed ISWM facility

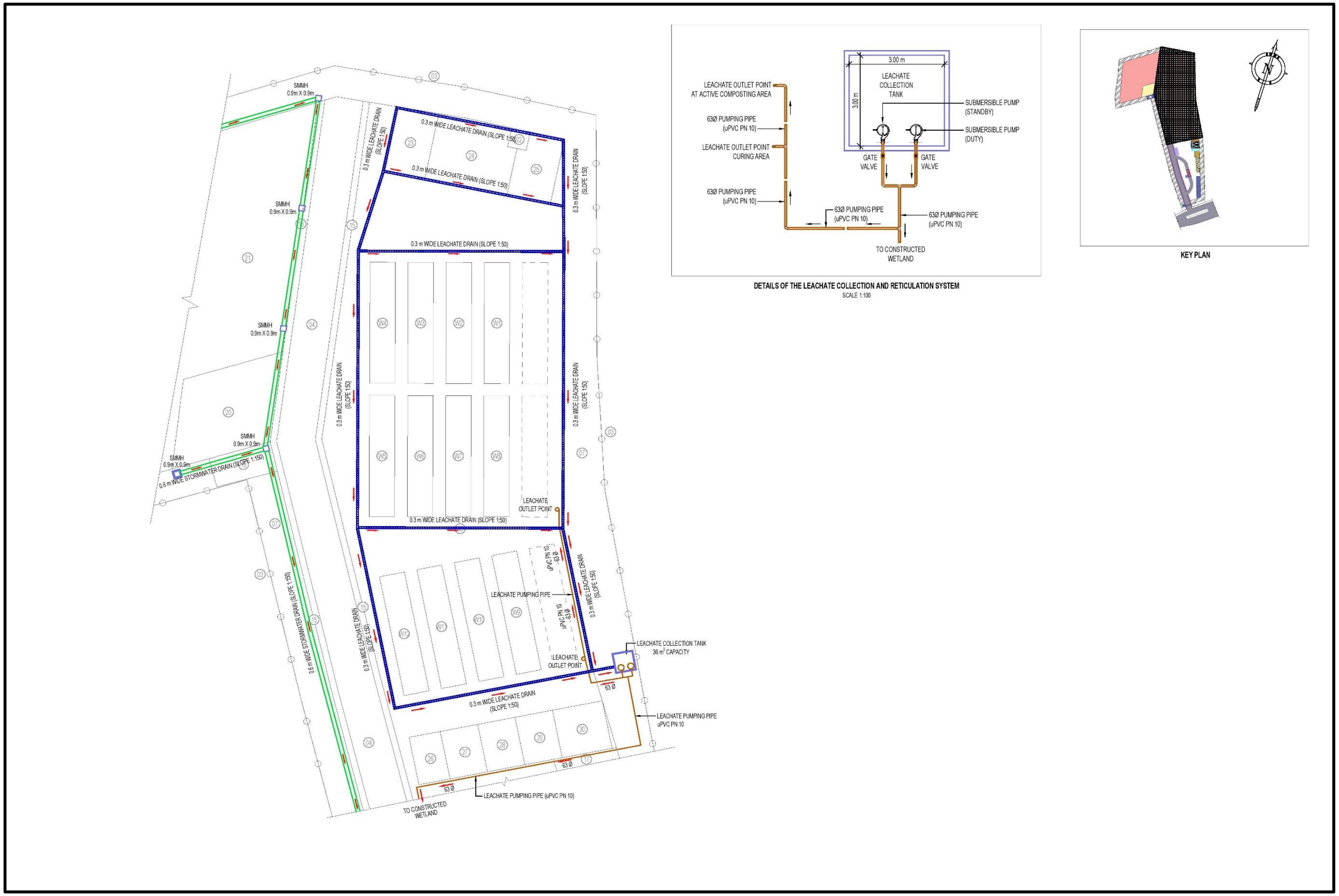
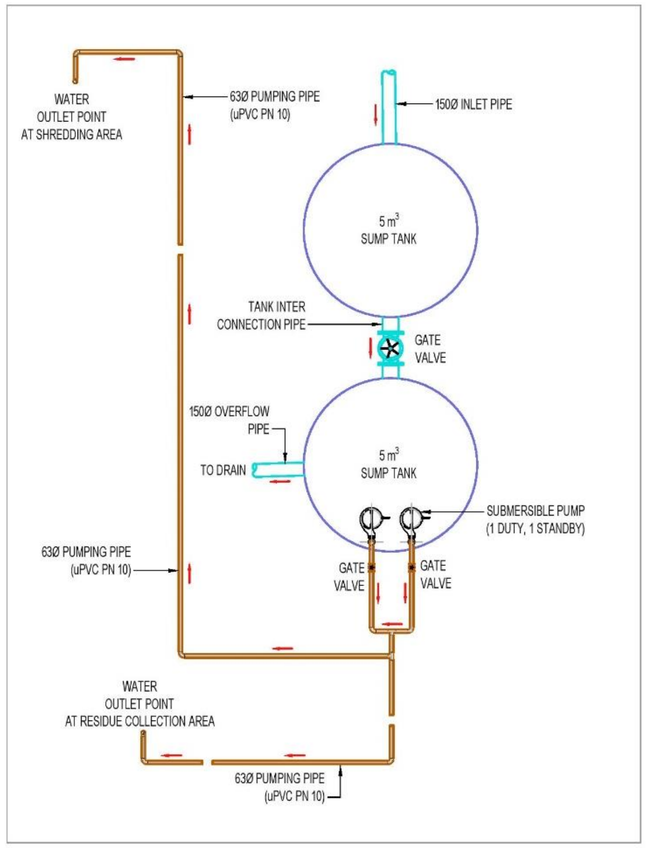
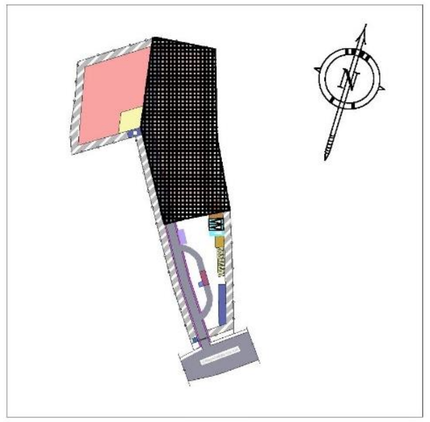


Figure A.12: Leachate collection system of the proposed ISWM facility

Annexure 4.7: Stormwater drainage system of the proposed ISWM facility



DETAILS OF THE STORMWATER COLLECTION AND RETICULATION SYSTEM
N.T.S.



KEY PLAN

ABBREVIATIONS	
ST	SILT TRAP
SMCT	STORMWATER COLLECTION TANK
SMDP	STORMWATER DOWN PIPE
SMP	STORMWATER PIPE
SMMH	STORMWATER MANHOLE

Figure A.13: Stormwater drainage system of the proposed ISWM facility (Part 1)

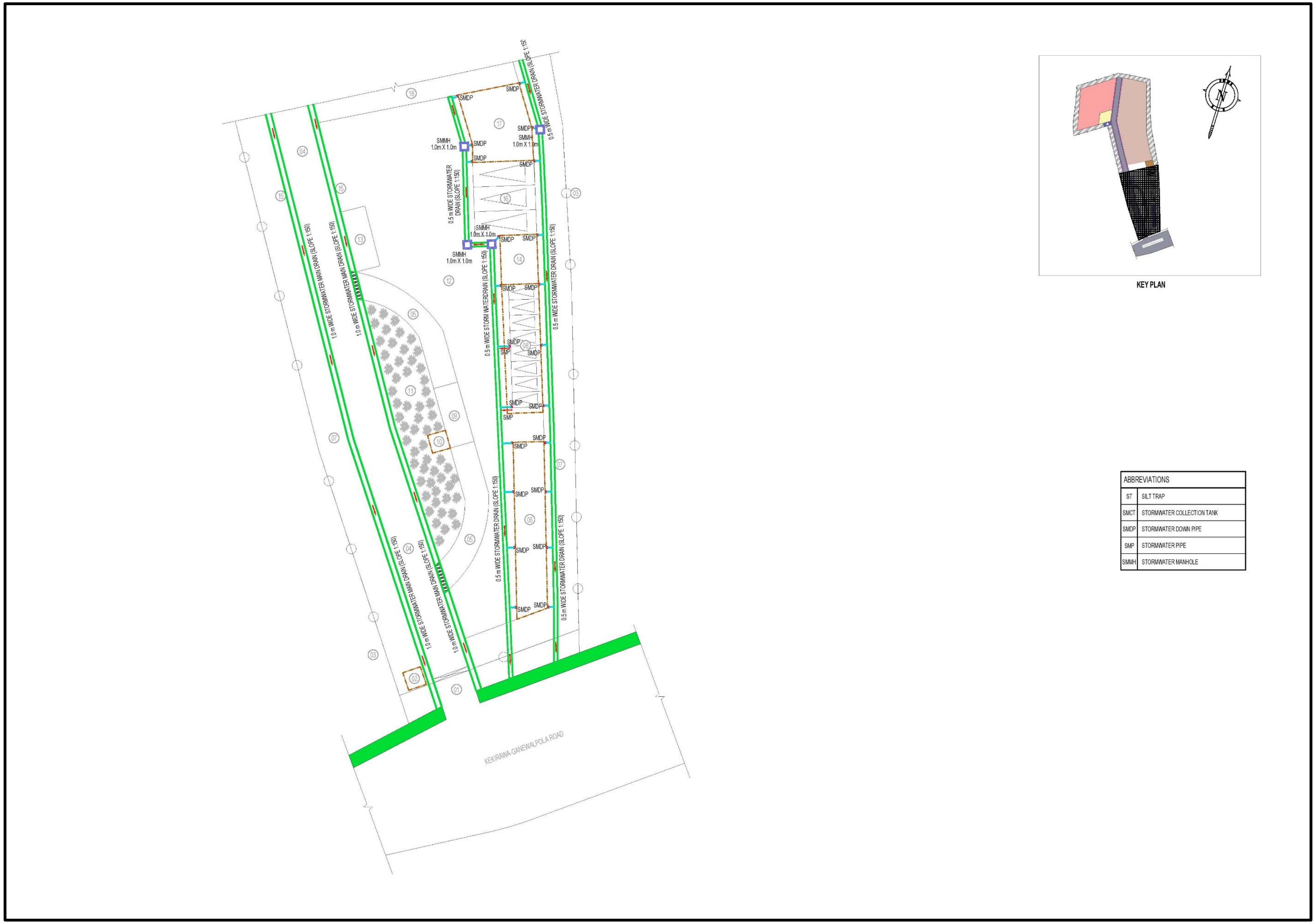


Figure A.14: Stormwater drainage system of the proposed ISWM facility (Part 2)

Annexure 4.8: Design, construction, and operation guidelines of the constructed wetland

Design and operation of constructed wetland

The leachate from the compost plant and controlled landfill is the influent for the wetland. The wetland is used as a polishing step for the leachate. The conceptual designing of the constructed wetland is to be used to remove BOD, COD, and TS in the resultant effluent. The conceptual design of the constructed wetland is given below.

In this study, a plug flow, continuous type Horizontal Flow Bed (HFB) system (submerged), was designed to remove the pollutants from the leachate. The theoretical considerations are the type of wetland plants, removal mechanism, and hydrology (water level estimation, hydraulic retention time, and contaminant dispersion). The design considerations are media size and hardness, slopes, Inlet and outlet piping, system depth, width, and length.

HBF systems have been used for polishing for a variety of wastewaters including, primary and septic tank effluents; pond effluent; and effluents from activated sludge, RBC, and trickling filter systems that don't consistently meet secondary standards. The primary mechanisms for BOD and TSS removal are flocculation, settling, and filtration of suspended and large colloidal particles. HBF systems are effective for the removal of TSS and BOD because of relatively low flow velocities and a high amount of media surface area. They typically do better at TSS removal, because TSS removal is a completely physical mechanism, while BOD removal is more complex. Larger biodegradable particles that have been quickly removed by physical mechanisms will be degraded over time and be converted into particles in the soluble and small colloidal size range. As such, they become an internal "source" of BOD as they degrade and reenter the water. Some material is also incorporated into microbial biomass. COD removal also follows the same trend as BOD.

The various models have been designed and tested for the removal of organic pollutants from the wastewater. The plug flow model seems to provide a reasonable approximation of performance in SF constructed wetlands (EPA 1993[1]). The various design models are principally derived from the basic plug-flow equation. A basic plug-flow equation is expressed in Equation 1.1.

$$C_e = C_o \exp(-K^T t) \qquad \text{[Equation 1.1]}$$

Where,

C_e = Effluent BOD_5, mg/L
C_o = Influent BOD_5, mg/L
K^T = Temperature dependent first-order reaction constant, d^{-1}
T = Hydraulic residence time, d

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[1] EPA, 1993, Subsurface Flow Constructed Wetlands for Wastewater Treatment: A Technology Assessment, Washington D.C.: Municipal Technology Branch, U.S. Environmental Protection Agency.

Determination of leachate rich stormwater runoff from the controlled landfill

As per the Table A.3, rainfall intensity (mm/hr) for a return period of 25 years can be calculated using Equation 1.2.

$$Y = 81.5\,X^{-0.76} \qquad \text{[Equation 1.2]}$$

Where,
Y = Rainfall intensity, mm/hr
X = Rainfall duration, hrs

The design leachate rich stormwater runoff from the controlled landfill can be calculated using Equation 1.3.

Table A.3: IDF curves - Anuradhapura 75% probability rainfall evaporation (Source: Hydrology Division, Irrigation Department, Colombo 07, Sri Lanka, October 2019)

T (Years)	**IDF Curves**	**R^2**
2	$Y = 48.056X^{-0.767}$	0.9940
5	$Y = 61.443X^{-0.764}$	0.9938
10	$Y = 70.304X^{-0.762}$	0.9937
25	$Y = 81.500X^{-0.760}$	0.9936
50	$Y = 89.805X^{-0.759}$	0.9935
100	$Y = 98.048X^{-0.759}$	0.9934
200	$Y = 106.26X^{-0.758}$	0.9933
X = Rainfall Duration in hrs		
Y = Rainfall Intensity in mm/hr		

Rainfall intensity of the Kekirawa PS area considering a return period of 25 years and rainfall duration of 24 hrs can be determined as 7.28 mm/hr (Equation 1.2)

$$Q = CIA/360 \qquad \text{[Equation 1.3]}$$

Where,

Q = The design peak runoff rate, m^3/s
C = The constant runoff co-efficient
I = The rainfall intensity, mm/hr
A = The drainage area, ha

For a ground cover of Lawns C can be taken as 0.2, the area of the drainage area is 0.239 ha (as per the design), and rainfall intensity of 7.28 mm/hr (using equation 1.2), leachate rich stormwater runoff from the controlled landfill can be calculated as 9.67×10^{-4} m^3/s by using Equation 1.3.

Consider the peak condition where the rainfall intensity of 7.28 mm/hr is recorded for 24 hours to the controlled landfill area in a given day,

The volume of the leachate rich stormwater to the constructed wetland

$$= 9.67 \times 10^{-4} \ m^3/s \times 24 \times 3600 \ s/day$$
$$= 83 \ m^3/day$$

Note: Amount of leachate generated is negligible compared to the stormwater quantity.

Determination of treated effluent quality

$$A_s = Q_d (\ln C_i - \ln C_e)/K_{BOD} \qquad \text{[Equation 1.4]}$$

Where,

A_s = Surface area of bed (m^2) = L × W
Q_d = average daily flow rate (m^3/d)
K_{BOD} = Areal removal rate constant at T (°C)
d = depth of the water column (m)
n = porosity of the substrate medium (%)

An appropriate value of K_{BOD} can be selected from Figure A.14 for HFB, and thus, the surface area required to treat leachate can be obtained from Equation 1.5.

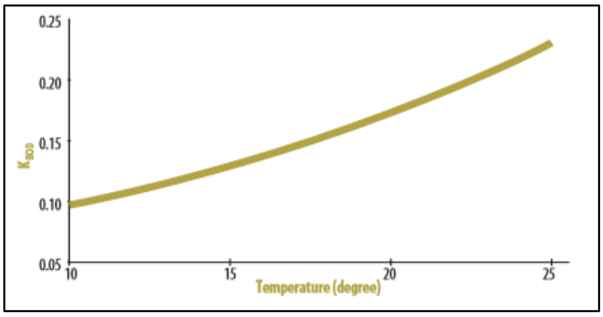

Figure A.15: K_{BOD} for HFB plotted against temperature for Substrate depth of 40 cm and porosity of 40% (UN-HABITAT 2008[2])

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[2] UN-HABITAT, 2008, Constructed Wetlands Manual, Kathmandu, Nepal: Water for Asian Cities Program, United Nations Human Settlements Program.

Q_d = 83 m^3/day

Assuming C_i = 400 mg/L; C_e = 100 mg/L; d = 0.4 m; n = 40% and using Equation 1.4 and Figure A.14, treated effluent quality can be calculated as depicted in Table A.4. The area of the surface bed (A_s) is 2388 m^2 and the depth of the substrates is 0.4 m.

K_{BOD} at 25°C = 0.24 (Figure A.14)

Table A.4: Influent and effluent levels

	Influent Quality (C_i)	**Treated Quality (C_e)**	**Tolerance Limit**
BOD	400 mg/L	186 mg/L	250 mg/L
COD	800 mg/L	372 mg/L	400 mg/L
TSS	200 mg/L	93 mg/L	-

Notes: Tolerance limits are given for waste discharged on land for irrigation purpose as per the Gazette Extraordinary dated 2008.02.02.

It is clear from the design, given the area fixed to an approximately 267 m^2, final BOD, COD and TSS levels could be reduced with the introduction of the wetland so that final levels of BOD, COD, and TSS would be 186, 372 and 93 mg/l, respectively. The original average levels of BOD, COD, and TSS are 400, 800, and 200 mg/L, respectively. The treated wastewater from the construction wetland will be stored in 10,000 m^3 underground tanks and used for irrigation purposes.

It is of utmost importance to adhere to the following conditions in the construction and operation procedures.

Construction guidelines

(i) Excavation work should commence only in the dry season, where no sheet flow is present in the area of construction.

(ii) Preliminary approval should be obtained from the relevant authorities to commence the proposed work.

(iii) The entire vegetation covering the proposed wetland should be cleared, and they should be disposed of in an environmentally safe manner.

(iv) Proper drainage plan should be worked out for draining the stormwater rich leachate into the wetland.

(v) No worker should be allowed to stay overnight within the development area. Once the construction work is over for a given day they should leave the site. This is to ensure that no additional BOD and COD loading be generated. Also, no waste arising from sewage, food, or any other material brought from outside should contribute to the canal flow.

(vi) Sediment loading to the canal should be completely stopped by having a couple of pits to which the dewatering be done. Only the clear water devoid of sediment should be released to the canal.

(vii) Excavated material should not be brought outside the site but ensure to make use of it for bund construction, perhaps mixing with other materials.

(viii) If the dewatering process generates, the acidic water (pH less than 6.0) neutralization, must be done before releasing the water to the canal.

(ix) The bottom of the wetland must be laid with a geotextile so as not to percolate water into the deeper layers.

(x) The depth and height of the wetland must be as indicated in the design, and no deepening should be done without the approvals from the relevant authorities.

(xi) Only the proposed vegetation type should be grown, and under no circumstances, invasive species be planted.

(xii) As indicated inlet zone must be worked out, and no free water column is developed. This effort is to control the mosquito breeding within site.

(xiii) The outlet from the wetland should be directed to the nearby natural wetland.

During operation

(i) Thick vegetation cover should be maintained within the wetland, and excess cover should be harvested from time to time. No litter should be allowed to remain in the wetland as it yields extra oxygen for mineralization.

(ii) Periodic maintenance should be undertaken to keep the wetland in good working conditions.

(iii) No other wastewater line should be diverted into this wetland without permission from the relevant authorities.

(iv) Environmental Protection License should be obtained even for the wetland, and conditions laid down in the EPL should be adhered to.

Annexure 4.9: Detailed financial analysis

Year	1. Capital cost														
	1.1 Preliminary investigations	1.2 Promoting source segregation	1.3 Collection and transport	1.4 Compost plant	1.5 Recycling and reusing waste	1.6 Controlled landfill	1.7 Contingencies (5%)	1.8 VAT (8%)	2.1 Environmental monitoring	2.2 Promoting source segregation	2.3 Collection and transport				
											2.3.1 Preventive maintenance of all vehicles involved in the collection	2.3.2 Corrective maintenance of all vehicles involved in the collection	2.3.3 Major repair for vehicular fleet	2.3.4 Management of GPS-assisted garbage-carrying vehicular tracking system	2.3.5 Fueling for the vehicular fleet (Assuming eight vehicles running 40 km on average for a day)
2020	3,730,000.00	500,000.00	15,250,000.00	183,672,500.00	500,000.00	20,794,000.00	11,222,325.00	18,853,506.00							
2021									60,000.00	500,000.00	3,600,000.00	3,600,000.00	1,000,000.00	120,000.00	2,920,000.00
2022									63,096.00	525,800.00	3,785,760.00	3,785,760.00		126,192.00	3,070,672.00
2023									66,351.75	552,931.28	3,981,105.22	3,981,105.22		132,703.51	3,229,118.68
2024									69,775.50	581,462.53	4,186,530.25	4,186,530.25		139,551.01	3,395,741.20
2025									73,375.92	611,466.00	4,402,555.21	4,402,555.21	1,222,932.00	146,751.84	3,570,961.44
2026									77,162.12	643,017.65	4,629,727.05	4,629,727.05		154,324.24	3,755,223.06
2027									81,143.68	676,197.36	4,868,620.97	4,868,620.97		162,287.37	3,948,992.56
2028									85,330.70	711,089.14	5,119,841.81	5,119,841.81	1,422,178.28	170,661.39	4,152,760.58
2029									89,733.76	747,781.34	5,384,025.65	5,384,025.65		179,467.52	4,367,043.03
2030									94,364.02	786,366.86	5,661,841.37	5,661,841.37		188,728.05	4,592,382.45
2031									99,233.21	826,943.39	5,953,992.39	5,953,992.39	1,653,886.77	198,466.41	4,829,349.38
2032									104,353.64	869,613.67	6,261,218.40	6,261,218.40		208,707.28	5,078,543.81
2033									109,738.29	914,485.73	6,584,297.26	6,584,297.26		219,476.58	5,340,596.67
2034									115,400.78	961,673.19	6,924,047.00	6,924,047.00	1,923,346.39	230,801.57	5,616,171.46
2035									121,355.46	1,011,295.53	7,281,327.83	7,281,327.83		242,710.93	5,905,965.91
2036									127,617.41	1,063,478.38	7,657,044.35	7,657,044.35		255,234.81	6,210,713.75
2037									134,202.46	1,118,353.87	8,052,147.83	8,052,147.83	2,236,707.73	268,404.93	6,531,186.58
2038									141,127.31	1,176,060.93	8,467,638.66	8,467,638.66		282,254.62	6,868,195.80
2039									148,409.48	1,236,745.67	8,904,568.82	8,904,568.82		296,818.96	7,222,594.71
2040									156,067.41	1,300,561.75	9,364,044.57	9,364,044.57	2,601,123.49	312,134.82	7,595,280.59
2041									164,120.49	1,367,670.73	9,847,229.27	9,847,229.27		328,240.98	7,987,197.07
2042									172,589.10	1,438,242.54	10,355,346.30	10,355,346.30		345,178.21	8,399,336.44
2043									181,494.70	1,512,455.86	10,889,682.17	10,889,682.17	3,024,911.71	362,989.41	8,832,742.20
2044									190,859.83	1,590,498.58	11,451,589.77	11,451,589.77		381,719.66	9,288,511.70

Year	2. Operational and maintenance cost													
	2.4 Compost plant, Recycling and reusing waste, Controlled landfill													
	2.4.1 Training for employees	2.4.2 Machinery and equipment maintenance	2.4.3 Fuel cost for machinery	2.4.4 Electricity, water, telecommunication	2.4.5 Cost of bacterial solutions for odor control (bacterial solution will be sprayed to the landfill and compost plant, if necessary)	2.4.6 Packaging of finished compost (Two workers for packaging finished compost product - 3 MT per day)	2.4.7 Packaging of finished liquid fertilizer (Two workers for packaging finished liquid fertilizer product - 500 L/day)	2.4.8 Quality enhancement	2.4.9 Main office/administration cost, including stationery	2.4.10 Building maintenance cost	2.4.11 CCTV network maintenance	2.4.12 Approval renewals (EPL)	2.4.13 Cost for personal protective gears for employees	2.4.14 Welfare and medical expenses for employees (for 57 employees)
2020														
2021	50,000.00	1,200,000.00	365,000.00	3,600,000.00	1,200,000.00	912,500.00	912,500.00	912,500.00	600,000.00	1,200,000.00	40,000.00	50,000.00	1,200,000.00	1,710,000.00
2022	52,580.00	1,261,920.00	383,834.00	3,785,760.00	1,261,920.00	959,585.00	959,585.00	959,585.00	630,960.00	1,261,920.00	42,064.00	52,580.00	1,261,920.00	1,798,236.00
2023	55,293.13	1,327,035.07	403,639.83	3,981,105.22	1,327,035.07	1,009,099.59	1,009,099.59	1,009,099.59	663,517.54	1,327,035.07	44,234.50	55,293.13	1,327,035.07	1,891,024.98
2024	58,146.25	1,395,510.08	424,467.65	4,186,530.25	1,395,510.08	1,061,169.12	1,061,169.12	1,061,169.12	697,755.04	1,395,510.08	46,517.00	58,146.25	1,395,510.08	1,988,601.87
2025	61,146.60	1,467,518.40	446,370.18	4,402,555.21	1,467,518.40	1,115,925.45	1,115,925.45	1,115,925.45	733,759.20	1,467,518.40	48,917.28	61,146.60	1,467,518.40	2,091,213.72
2026	64,301.76	1,543,242.35	469,402.88	4,629,727.05	1,543,242.35	1,173,507.20	1,173,507.20	1,173,507.20	771,621.18	1,543,242.35	51,441.41	64,301.76	1,543,242.35	2,199,120.35
2027	67,619.74	1,622,873.66	493,624.07	4,868,620.97	1,622,873.66	1,234,060.18	1,234,060.18	1,234,060.18	811,436.83	1,622,873.66	54,095.79	67,619.74	1,622,873.66	2,312,594.96
2028	71,108.91	1,706,613.94	519,095.07	5,119,841.81	1,706,613.94	1,297,737.68	1,297,737.68	1,297,737.68	853,306.97	1,706,613.94	56,887.13	71,108.91	1,706,613.94	2,431,924.86
2029	74,778.13	1,794,675.22	545,880.38	5,384,025.65	1,794,675.22	1,364,700.95	1,364,700.95	1,364,700.95	897,337.61	1,794,675.22	59,822.51	74,778.13	1,794,675.22	2,557,412.18
2030	78,636.69	1,887,280.46	574,047.81	5,661,841.37	1,887,280.46	1,435,119.51	1,435,119.51	1,435,119.51	943,640.23	1,887,280.46	62,909.35	78,636.69	1,887,280.46	2,689,374.65
2031	82,694.34	1,984,664.13	603,668.67	5,953,992.39	1,984,664.13	1,509,171.68	1,509,171.68	1,509,171.68	992,332.06	1,984,664.13	66,155.47	82,694.34	1,984,664.13	2,828,146.38
2032	86,961.37	2,087,072.80	634,817.98	6,261,218.40	2,087,072.80	1,587,044.94	1,587,044.94	1,587,044.94	1,043,536.40	2,087,072.80	69,569.09	86,961.37	2,087,072.80	2,974,078.74
2033	91,448.57	2,194,765.75	667,574.58	6,584,297.26	2,194,765.75	1,668,936.46	1,668,936.46	1,668,936.46	1,097,382.88	2,194,765.75	73,158.86	91,448.57	2,194,765.75	3,127,541.20
2034	96,167.32	2,308,015.67	702,021.43	6,924,047.00	2,308,015.67	1,755,053.58	1,755,053.58	1,755,053.58	1,154,007.83	2,308,015.67	76,933.86	96,167.32	2,308,015.67	3,288,922.33
2035	101,129.55	2,427,109.28	738,245.74	7,281,327.83	2,427,109.28	1,845,614.35	1,845,614.35	1,845,614.35	1,213,554.64	2,427,109.28	80,903.64	101,129.55	2,427,109.28	3,458,630.72
2036	106,347.84	2,552,348.12	776,339.22	7,657,044.35	2,552,348.12	1,940,848.05	1,940,848.05	1,940,848.05	1,276,174.06	2,552,348.12	85,078.27	106,347.84	2,552,348.12	3,637,096.06
2037	111,835.39	2,684,049.28	816,398.32	8,052,147.83	2,684,049.28	2,040,995.80	2,040,995.80	2,040,995.80	1,342,024.64	2,684,049.28	89,468.31	111,835.39	2,684,049.28	3,824,770.22
2038	117,606.09	2,822,546.22	858,524.48	8,467,638.66	2,822,546.22	2,146,311.19	2,146,311.19	2,146,311.19	1,411,273.11	2,822,546.22	94,084.87	117,606.09	2,822,546.22	4,022,128.36
2039	123,674.57	2,968,189.61	902,824.34	8,904,568.82	2,968,189.61	2,257,060.85	2,257,060.85	2,257,060.85	1,484,094.80	2,968,189.61	98,939.65	123,674.57	2,968,189.61	4,229,670.19
2040	130,056.17	3,121,348.19	949,410.07	9,364,044.57	3,121,348.19	2,373,525.19	2,373,525.19	2,373,525.19	1,560,674.09	3,121,348.19	104,044.94	130,056.17	3,121,348.19	4,447,921.17
2041	136,767.07	3,282,409.76	998,399.63	9,847,229.27	3,282,409.76	2,495,999.09	2,495,999.09	2,495,999.09	1,641,204.88	3,282,409.76	109,413.66	136,767.07	3,282,409.76	4,677,433.90
2042	143,824.25	3,451,782.10	1,049,917.06	10,355,346.30	3,451,782.10	2,624,792.64	2,624,792.64	2,624,792.64	1,725,891.05	3,451,782.10	115,059.40	143,824.25	3,451,782.10	4,918,789.49
2043	151,245.59	3,629,894.06	1,104,092.78	10,889,682.17	3,629,894.06	2,760,231.94	2,760,231.94	2,760,231.94	1,814,947.03	3,629,894.06	120,996.47	151,245.59	3,629,894.06	5,172,599.03
2044	159,049.86	3,817,196.59	1,161,063.96	11,451,589.77	3,817,196.59	2,902,659.91	2,902,659.91	2,902,659.91	1,908,598.29	3,817,196.59	127,239.89	159,049.86	3,817,196.59	5,439,505.14

Year					Total cost	3. Direct revenue						Total revenue	Gross return
		2.5 Controlled landfill		2.6 Salaries and wages (including new recruitments) 57 personnel both permanent and temporary		3.1 Collection tariff from commercial establishments (A tariff from 200 commercial establishments that have the capability to pay tariff under the "Polluter Pays Principle" are expected to be collected.)	3.2 Selling of recyclables	3.3 Selling of construction and demolition waste for filling	3.4 Selling of final compost product (3,000 kg per day)	3.5 Selling of liquid fertilizers (The expected quantity of value-added liquid fertilizer was 400 L/day)	3.6 Accepting MSW under emergency case (1 MT at a rate of SLR 1,500); Anticipating 120 MT per month		
	2.4.15 Cost of maintaining security	2.5.1 Supply of soil for daily cover, temporary roads, bunds, etc.)	2.5.2 Tipping fee of SLR 3,000 per day to the Waste-to-Energy plant by Kekirawa Pradeshiya Sabha										
2020					**254,522,331**	-	-	-	-	0	-	**0**	**-254,522,331**
2021	1,200,000.00	1,095,000.00	9,855,000.00	10,260,000.00	**48,162,500**	2,400,000.00	144,000.00	120,000.00	27,375,000.00	5,840,000.00	2,160,000.00	**38,039,000**	**-10,123,500**
2022	1,261,920.00	1,151,502.00	10,840,500.00	10,789,416.00	**50,073,067**	2,523,840.00	151,430.40	126,192.00	30,112,500.00	6,424,000.00	2,271,456.00	**41,609,418**	**-8,463,649**
2023	1,327,035.07	1,210,919.50	11,924,550.00	11,346,149.87	**53,181,517**	2,654,070.14	159,244.21	132,703.51	33,123,750.00	7,066,400.00	2,388,663.13	**45,524,831**	**-7,656,686**
2024	1,395,510.08	1,273,402.95	13,117,005.00	11,931,611.20	**56,502,832**	2,791,020.16	167,461.21	139,551.01	36,436,125.00	7,773,040.00	2,511,918.15	**49,819,116**	**-6,683,716**
2025	1,467,518.40	1,339,110.54	14,428,705.50	12,547,282.34	**61,276,173**	2,935,036.80	176,102.21	146,751.84	40,079,737.50	8,550,344.00	2,641,533.12	**54,529,505**	**-6,746,668**
2026	1,543,242.35	1,408,208.65	15,871,576.05	13,194,722.11	**63,850,338**	3,086,484.70	185,189.08	154,324.24	44,087,711.25	9,405,378.40	2,777,836.23	**59,696,924**	**-4,153,414**
2027	1,622,873.66	1,480,872.21	17,458,733.66	13,875,569.77	**67,913,199**	3,245,747.31	194,744.84	162,287.37	48,496,482.38	10,345,916.24	2,921,172.58	**65,366,351**	**-2,546,849**
2028	1,706,613.94	1,557,285.22	19,204,607.02	14,591,549.17	**73,684,702**	3,413,227.87	204,793.67	170,661.39	53,346,130.61	11,380,507.86	3,071,905.09	**71,587,227**	**-2,097,475**
2029	1,794,675.22	1,637,641.14	21,125,067.72	15,344,473.10	**76,920,772**	3,589,350.43	215,361.03	179,467.52	58,680,743.67	12,518,558.65	3,230,415.39	**78,413,897**	**1,493,124**
2030	1,887,280.46	1,722,143.42	23,237,574.49	16,136,247.91	**81,912,338**	3,774,560.92	226,473.65	188,728.05	64,548,818.04	13,770,414.52	3,397,104.82	**85,906,100**	**3,993,762**
2031	1,984,664.13	1,811,006.02	25,561,331.94	16,968,878.31	**88,917,600**	3,969,328.26	238,159.70	198,466.41	71,003,699.85	15,147,455.97	3,572,395.43	**94,129,506**	**5,211,906**
2032	2,087,072.80	1,904,453.93	28,117,465.14	17,844,472.43	**93,003,689**	4,174,145.60	250,448.74	208,707.28	78,104,069.83	16,662,201.56	3,756,731.04	**103,156,304**	**10,152,615**
2033	2,194,765.75	2,002,723.75	30,929,211.65	18,765,247.20	**99,163,564**	4,389,531.51	263,371.89	219,476.58	85,914,476.81	18,328,421.72	3,950,578.36	**113,065,857**	**13,902,292**
2034	2,308,015.67	2,106,064.30	34,022,132.82	19,733,533.96	**107,700,725**	4,616,031.34	276,961.88	230,801.57	94,505,924.49	20,161,263.89	4,154,428.20	**123,945,411**	**16,244,687**
2035	2,427,109.28	2,214,737.21	37,424,346.10	20,751,784.31	**112,882,162**	4,854,218.55	291,253.11	242,710.93	103,956,516.94	22,177,390.28	4,368,796.70	**135,890,887**	**23,008,724**
2036	2,552,348.12	2,329,017.65	41,166,780.71	21,822,576.38	**120,518,220**	5,104,696.23	306,281.77	255,234.81	114,352,168.64	24,395,129.31	4,594,226.61	**149,007,737**	**28,489,517**
2037	2,684,049.28	2,449,194.97	45,283,458.78	22,948,621.33	**130,966,140**	5,368,098.56	322,085.91	268,404.93	125,787,385.50	26,834,642.24	4,831,288.70	**163,411,906**	**32,445,766**
2038	2,822,546.22	2,575,573.43	49,811,804.66	24,132,770.19	**137,563,591**	5,645,092.44	338,705.55	282,254.62	138,366,124.05	29,518,106.46	5,080,583.20	**179,230,866**	**41,667,276**
2039	2,968,189.61	2,708,473.02	54,792,985.12	25,378,021.13	**147,072,763**	5,936,379.21	356,182.75	296,818.96	152,202,736.46	32,469,917.11	5,342,741.29	**196,604,776**	**49,532,013**
2040	3,121,348.19	2,848,230.22	60,272,283.64	26,687,527.02	**159,914,822**	6,242,696.38	374,561.78	312,134.82	167,423,010.10	35,716,908.82	5,618,426.74	**215,687,739**	**55,772,917**
2041	3,282,409.76	2,995,198.90	66,299,512.00	28,064,603.41	**168,348,264**	6,564,819.51	393,889.17	328,240.98	184,165,311.11	39,288,599.70	5,908,337.56	**236,649,198**	**68,300,934**
2042	3,451,782.10	3,149,751.17	72,929,463.20	29,512,736.95	**180,243,930**	6,903,564.20	414,213.85	345,178.21	202,581,842.22	43,217,459.67	6,213,207.78	**259,675,466**	**79,431,536**
2043	3,629,894.06	3,312,278.33	80,222,409.52	31,035,594.17	**196,099,215**	7,259,788.11	435,587.29	362,989.41	222,840,026.45	47,539,205.64	6,533,809.30	**284,971,406**	**88,872,191**
2044	3,817,196.59	3,483,191.89	88,244,650.47	32,637,030.83	**206,919,702**	7,634,393.18	458,063.59	381,719.66	245,124,029.09	52,293,126.21	6,870,953.86	**312,762,286**	**105,842,584**
												NPV 10%	**(175,134,998.98)**
												IRR	**4%**

Annexure 4.10: Detailed economic analysis

Year	1. Capital cost															
	1.1 Preliminary investigations	1.2 Promoting source segregation	1.3 Collection and transport	1.4 Compost plant	1.5 Recycling and reusing waste	1.6 Controlled landfill	1.7 Contingencies (5%)	2.1 Environmental monitoring	2.2 Promoting source segregation	2.3 Collection and transport						
										2.3.1 Preventive maintenance of all vehicles involved in the collection	2.3.2 Corrective maintenance of all vehicles involved in the collection	2.3.3 Major repair for vehicular fleet	2.3.4 Management of GPS-assisted garbage-carrying vehicular tracking system	2.3.5 Fueling for the vehicular fleet (Assuming eight vehicles running 40 km on average for a day)	2.4.1 Training for employees	2.4.2 Machinery and equipment maintenance
2020	3,730,000.00	500,000.00	15,250,000.00	183,672,500.00	500,000.00	20,794,000.00	11,222,325.00									
2021								60,000.00	500,000.00	3,600,000.00	3,600,000.00	1,000,000.00	120,000.00	2,920,000.00	50,000.00	1,200,000.00
2022								63,096.00	525,800.00	3,785,760.00	3,785,760.00		126,192.00	3,070,672.00	52,580.00	1,261,920.00
2023								66,351.75	552,931.28	3,981,105.22	3,981,105.22		132,703.51	3,229,118.68	55,293.13	1,327,035.07
2024								69,775.50	581,462.53	4,186,530.25	4,186,530.25		139,551.01	3,395,741.20	58,146.25	1,395,510.08
2025								73,375.92	611,466.00	4,402,555.21	4,402,555.21	1,222,932.00	146,751.84	3,570,961.44	61,146.60	1,467,518.40
2026								77,162.12	643,017.65	4,629,727.05	4,629,727.05		154,324.24	3,755,223.06	64,301.76	1,543,242.35
2027								81,143.68	676,197.36	4,868,620.97	4,868,620.97		162,287.37	3,948,992.56	67,619.74	1,622,873.66
2028								85,330.70	711,089.14	5,119,841.81	5,119,841.81	1,422,178.28	170,661.39	4,152,760.58	71,108.91	1,706,613.94
2029								89,733.76	747,781.34	5,384,025.65	5,384,025.65		179,467.52	4,367,043.03	74,778.13	1,794,675.22
2030								94,364.02	786,366.86	5,661,841.37	5,661,841.37		188,728.05	4,592,382.45	78,636.69	1,887,280.46
2031								99,233.21	826,943.39	5,953,992.39	5,953,992.39	1,653,886.77	198,466.41	4,829,349.38	82,694.34	1,984,664.13
2032								104,353.64	869,613.67	6,261,218.40	6,261,218.40		208,707.28	5,078,543.81	86,961.37	2,087,072.80
2033								109,738.29	914,485.73	6,584,297.26	6,584,297.26		219,476.58	5,340,596.67	91,448.57	2,194,765.75
2034								115,400.78	961,673.19	6,924,047.00	6,924,047.00	1,923,346.39	230,801.57	5,616,171.46	96,167.32	2,308,015.67
2035								121,355.46	1,011,295.53	7,281,327.83	7,281,327.83		242,710.93	5,905,965.91	101,129.55	2,427,109.28
2036								127,617.41	1,063,478.38	7,657,044.35	7,657,044.35		255,234.81	6,210,713.75	106,347.84	2,552,348.12
2037								134,202.46	1,118,353.87	8,052,147.83	8,052,147.83	2,236,707.73	268,404.93	6,531,186.58	111,835.39	2,684,049.28
2038								141,127.31	1,176,060.93	8,467,638.66	8,467,638.66		282,254.62	6,868,195.80	117,606.09	2,822,546.22
2039								148,409.48	1,236,745.67	8,904,568.82	8,904,568.82		296,818.96	7,222,594.71	123,674.57	2,968,189.61
2040								156,067.41	1,300,561.75	9,364,044.57	9,364,044.57	2,601,123.49	312,134.82	7,595,280.59	130,056.17	3,121,348.19
2041								164,120.49	1,367,670.73	9,847,229.27	9,847,229.27		328,240.98	7,987,197.07	136,767.07	3,282,409.76
2042								172,589.10	1,438,242.54	10,355,346.30	10,355,346.30		345,178.21	8,399,336.44	143,824.25	3,451,782.10
2043								181,494.70	1,512,455.86	10,889,682.17	10,889,682.17	3,024,911.71	362,989.41	8,832,742.20	151,245.59	3,629,894.06
2044								190,859.83	1,590,498.58	11,451,589.77	11,451,589.77		381,719.66	9,288,511.70	159,049.86	3,817,196.59

Year	2. Operational and maintenance cost															
	2.4 Compost plant, Recycling and reusing waste, Controlled landfill													2.5 Controlled landfill		2.6 Salaries and wages (including new recruitments) - 57 personnel both permanent and temporary
	2.4.3 Fuel cost for machinery	2.4.4 Electricity, water, telecommunication	2.4.5 Cost of bacterial solutions for odor control (bacterial solution will be sprayed to the landfill and compost plant, if necessary)	2.4.6 Packaging of finished compost (Two workers for packaging finished compost product - 3 MT per day)	2.4.7 Packaging of finished liquid fertilizer (Two workers for packaging finished liquid fertilizer product - 500 L/day)	2.4.8 Quality enhancement	2.4.9 Main office/administration cost, including stationery	2.4.10 Building maintenance cost	2.4.11 CCTV network maintenance	2.4.12 Approval renewals (EPL)	2.4.13 Cost for personal protective gears for employees	2.4.14 Welfare and medical expenses for employees (for 57 employees)	2.4.15 Cost of maintaining security	2.5.1 Supply of soil for daily cover, temporary roads, bunds, etc.)	2.5.2 Tipping fee of SLR 3,000 per day to the Waste-to-Energy plant by Kekirawa Pradeshiya Sabha	
2020																
2021	365,000.00	3,600,000.00	1,200,000.00	912,500.00	912,500.00	912,500.00	600,000.00	1,200,000.00	40,000.00	50,000.00	1,200,000.00	1,710,000.00	1,200,000.00	1,095,000.00	9,855,000.00	10,260,000.00
2022	383,834.00	3,785,760.00	1,261,920.00	959,585.00	959,585.00	959,585.00	630,960.00	1,261,920.00	42,064.00	52,580.00	1,261,920.00	1,798,236.00	1,261,920.00	1,151,502.00	10,840,500.00	10,789,416.00
2023	403,639.83	3,981,105.22	1,327,035.07	1,009,099.59	1,009,099.59	1,009,099.59	663,517.54	1,327,035.07	44,234.50	55,293.13	1,327,035.07	1,891,024.98	1,327,035.07	1,210,919.50	11,924,550.00	11,346,149.87
2024	424,467.65	4,186,530.25	1,395,510.08	1,061,169.12	1,061,169.12	1,061,169.12	697,755.04	1,395,510.08	46,517.00	58,146.25	1,395,510.08	1,988,601.87	1,395,510.08	1,273,402.95	13,117,005.00	11,931,611.20
2025	446,370.18	4,402,555.21	1,467,518.40	1,115,925.45	1,115,925.45	1,115,925.45	733,759.20	1,467,518.40	48,917.28	61,146.60	1,467,518.40	2,091,213.72	1,467,518.40	1,339,110.54	14,428,705.50	12,547,282.34
2026	469,402.88	4,629,727.05	1,543,242.35	1,173,507.20	1,173,507.20	1,173,507.20	771,621.18	1,543,242.35	51,441.41	64,301.76	1,543,242.35	2,199,120.35	1,543,242.35	1,408,208.65	15,871,576.05	13,194,722.11
2027	493,624.07	4,868,620.97	1,622,873.66	1,234,060.18	1,234,060.18	1,234,060.18	811,436.83	1,622,873.66	54,095.79	67,619.74	1,622,873.66	2,312,594.96	1,622,873.66	1,480,872.21	17,458,733.66	13,875,569.77
2028	519,095.07	5,119,841.81	1,706,613.94	1,297,737.68	1,297,737.68	1,297,737.68	853,306.97	1,706,613.94	56,887.13	71,108.91	1,706,613.94	2,431,924.86	1,706,613.94	1,557,285.22	19,204,607.02	14,591,549.17
2029	545,880.38	5,384,025.65	1,794,675.22	1,364,700.95	1,364,700.95	1,364,700.95	897,337.61	1,794,675.22	59,822.51	74,778.13	1,794,675.22	2,557,412.18	1,794,675.22	1,637,641.14	21,125,067.72	15,344,473.10
2030	574,047.81	5,661,841.37	1,887,280.46	1,435,119.51	1,435,119.51	1,435,119.51	943,640.23	1,887,280.46	62,909.35	78,636.69	1,887,280.46	2,689,374.65	1,887,280.46	1,722,143.42	23,237,574.49	16,136,247.91
2031	603,668.67	5,953,992.39	1,984,664.13	1,509,171.68	1,509,171.68	1,509,171.68	992,332.06	1,984,664.13	66,155.47	82,694.34	1,984,664.13	2,828,146.38	1,984,664.13	1,811,006.02	25,561,331.94	16,968,878.31
2032	634,817.98	6,261,218.40	2,087,072.80	1,587,044.94	1,587,044.94	1,587,044.94	1,043,536.40	2,087,072.80	69,569.09	86,961.37	2,087,072.80	2,974,078.74	2,087,072.80	1,904,453.93	28,117,465.14	17,844,472.43
2033	667,574.58	6,584,297.26	2,194,765.75	1,668,936.46	1,668,936.46	1,668,936.46	1,097,382.88	2,194,765.75	73,158.86	91,448.57	2,194,765.75	3,127,541.20	2,194,765.75	2,002,723.75	30,929,211.65	18,765,247.20
2034	702,021.43	6,924,047.00	2,308,015.67	1,755,053.58	1,755,053.58	1,755,053.58	1,154,007.83	2,308,015.67	76,933.86	96,167.32	2,308,015.67	3,288,922.33	2,308,015.67	2,106,064.30	34,022,132.82	19,733,533.96
2035	738,245.74	7,281,327.83	2,427,109.28	1,845,614.35	1,845,614.35	1,845,614.35	1,213,554.64	2,427,109.28	80,903.64	101,129.55	2,427,109.28	3,458,630.72	2,427,109.28	2,214,737.21	37,424,346.10	20,751,784.31
2036	776,339.22	7,657,044.35	2,552,348.12	1,940,848.05	1,940,848.05	1,940,848.05	1,276,174.06	2,552,348.12	85,078.27	106,347.84	2,552,348.12	3,637,096.06	2,552,348.12	2,329,017.65	41,166,780.71	21,822,576.38
2037	816,398.32	8,052,147.83	2,684,049.28	2,040,995.80	2,040,995.80	2,040,995.80	1,342,024.64	2,684,049.28	89,468.31	111,835.39	2,684,049.28	3,824,770.22	2,684,049.28	2,449,194.97	45,283,458.78	22,948,621.33
2038	858,524.48	8,467,638.66	2,822,546.22	2,146,311.19	2,146,311.19	2,146,311.19	1,411,273.11	2,822,546.22	94,084.87	117,606.09	2,822,546.22	4,022,128.36	2,822,546.22	2,575,573.43	49,811,804.66	24,132,770.19
2039	902,824.34	8,904,568.82	2,968,189.61	2,257,060.85	2,257,060.85	2,257,060.85	1,484,094.80	2,968,189.61	98,939.65	123,674.57	2,968,189.61	4,229,670.19	2,968,189.61	2,708,473.02	54,792,985.12	25,378,021.13
2040	949,410.07	9,364,044.57	3,121,348.19	2,373,525.19	2,373,525.19	2,373,525.19	1,560,674.09	3,121,348.19	104,044.94	130,056.17	3,121,348.19	4,447,921.17	3,121,348.19	2,848,230.22	60,272,283.64	26,687,527.02
2041	998,399.63	9,847,229.27	3,282,409.76	2,495,999.09	2,495,999.09	2,495,999.09	1,641,204.88	3,282,409.76	109,413.66	136,767.07	3,282,409.76	4,677,433.90	3,282,409.76	2,995,198.90	66,299,512.00	28,064,603.41
2042	1,049,917.06	10,355,346.30	3,451,782.10	2,624,792.64	2,624,792.64	2,624,792.64	1,725,891.05	3,451,782.10	115,059.40	143,824.25	3,451,782.10	4,918,789.49	3,451,782.10	3,149,751.17	72,929,463.20	29,512,736.95
2043	1,104,092.78	10,889,682.17	3,629,894.06	2,760,231.94	2,760,231.94	2,760,231.94	1,814,947.03	3,629,894.06	120,996.47	151,245.59	3,629,894.06	5,172,599.03	3,629,894.06	3,312,278.33	80,222,409.52	31,035,594.17
2044	1,161,063.96	11,451,589.77	3,817,196.59	2,902,659.91	2,902,659.91	2,902,659.91	1,908,598.29	3,817,196.59	127,239.89	159,049.86	3,817,196.59	5,439,505.14	3,817,196.59	3,483,191.89	88,244,650.47	32,637,030.83

Year	Total cost	3. Direct revenue						4. Indirect revenue	Total revenue	Gross return
		3.1 Collection tariff from commercial establishments (A tariff from 200 commercial establishments that have the capability to pay tariff under the "Polluter Pays Principle" are expected to be collected.)	3.2 Selling of recyclables	3.3 Selling of construction and demolition waste for filling	3.4 Selling of final compost product (3,000 kg per day)	3.5 Selling of liquid fertilizers (The expected quantity of value-added liquid fertilizer was 400 L/day)	3.6 Accepting MSW under emergency case (1 MT at a rate of SLR 1,500); Anticipating 120 MT per month	Reduced cost from global warming		
2020	**235,668,825**	-	-	-	-		-		**0.00**	**-235,668,825.00**
2021	**48,162,500**	2,400,000.00	144,000.00	120,000.00	27,375,000.00	5,840,000.00	2,160,000.00	16,376,021.85	**54,415,021.85**	**6,252,521.85**
2022	**50,073,067**	2,523,840.00	151,430.40	126,192.00	30,112,500.00	6,424,000.00	2,271,456.00	17,401,160.82	**59,010,579.22**	**8,937,512.22**
2023	**53,181,517**	2,654,070.14	159,244.21	132,703.51	33,123,750.00	7,066,400.00	2,388,663.13	18,490,473.49	**64,015,304.48**	**10,833,787.02**
2024	**56,502,832**	2,791,020.16	167,461.21	139,551.01	36,436,125.00	7,773,040.00	2,511,918.15	19,647,977.13	**69,467,092.66**	**12,964,260.68**
2025	**61,276,173**	2,935,036.80	176,102.21	146,751.84	40,079,737.50	8,550,344.00	2,641,533.12	20,877,940.50	**75,407,445.98**	**14,131,272.82**
2026	**63,850,338**	3,086,484.70	185,189.08	154,324.24	44,087,711.25	9,405,378.40	2,777,836.23	22,184,899.57	**81,881,823.48**	**18,031,485.74**
2027	**67,913,199**	3,245,747.31	194,744.84	162,287.37	48,496,482.38	10,345,916.24	2,921,172.58	23,573,674.29	**88,940,025.00**	**21,026,825.56**
2028	**73,684,702**	3,413,227.87	204,793.67	170,661.39	53,346,130.61	11,380,507.86	3,071,905.09	25,049,386.30	**96,636,612.80**	**22,951,911.27**
2029	**76,920,772**	3,589,350.43	215,361.03	179,467.52	58,680,743.67	12,518,558.65	3,230,415.39	26,617,477.88	**105,031,374.58**	**28,110,602.15**
2030	**81,912,338**	3,774,560.92	226,473.65	188,728.05	64,548,818.04	13,770,414.52	3,397,104.82	28,283,732.00	**114,189,831.99**	**32,277,494.43**
2031	**88,917,600**	3,969,328.26	238,159.70	198,466.41	71,003,699.85	15,147,455.97	3,572,395.43	30,054,293.62	**124,183,799.23**	**35,266,199.67**
2032	**93,003,689**	4,174,145.60	250,448.74	208,707.28	78,104,069.83	16,662,201.56	3,756,731.04	31,935,692.40	**135,091,996.44**	**42,088,307.61**
2033	**99,163,564**	4,389,531.51	263,371.89	219,476.58	85,914,476.81	18,328,421.72	3,950,578.36	33,934,866.74	**147,000,723.61**	**47,837,159.12**
2034	**107,700,725**	4,616,031.34	276,961.88	230,801.57	94,505,924.49	20,161,263.89	4,154,428.20	36,059,189.40	**160,004,600.77**	**52,303,876.12**
2035	**112,882,162**	4,854,218.55	291,253.11	242,710.93	103,956,516.94	22,177,390.28	4,368,796.70	38,316,494.66	**174,207,381.17**	**61,325,218.97**
2036	**120,518,220**	5,104,696.23	306,281.77	255,234.81	114,352,168.64	24,395,129.31	4,594,226.61	40,715,107.22	**189,722,844.59**	**69,204,624.47**
2037	**130,966,140**	5,368,098.56	322,085.91	268,404.93	125,787,385.50	26,834,642.24	4,831,288.70	43,263,872.94	**206,675,778.78**	**75,709,638.57**
2038	**137,563,591**	5,645,092.44	338,705.55	282,254.62	138,366,124.05	29,518,106.46	5,080,583.20	45,972,191.38	**225,203,057.70**	**87,639,467.11**
2039	**147,072,763**	5,936,379.21	356,182.75	296,818.96	152,202,736.46	32,469,917.11	5,342,741.29	48,850,050.56	**245,454,826.34**	**98,382,063.13**
2040	**159,914,822**	6,242,696.38	374,561.78	312,134.82	167,423,010.10	35,716,908.82	5,618,426.74	51,908,063.73	**267,595,802.37**	**107,680,980.61**
2041	**168,348,264**	6,564,819.51	393,889.17	328,240.98	184,165,311.11	39,288,599.70	5,908,337.56	55,157,508.52	**291,806,706.55**	**123,458,442.92**
2042	**180,243,930**	6,903,564.20	414,213.85	345,178.21	202,581,842.22	43,217,459.67	6,213,207.78	58,610,368.55	**318,285,834.49**	**138,041,904.07**
2043	**196,099,215**	7,259,788.11	435,587.29	362,989.41	222,840,026.45	47,539,205.64	6,533,809.30	62,279,377.62	**347,250,783.81**	**151,151,568.85**
2044	**206,919,702**	7,634,393.18	458,063.59	381,719.66	245,124,029.09	52,293,126.21	6,870,953.86	66,178,066.66	**378,940,352.24**	**172,020,650.33**
									NPV 10%	**66,522,276.75**
									EIRR	**12%**