Smart Solid Waste Management: A Case Study of Ludhiana City

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ABSTRACT
The growing challenge of waste management in rapidly urbanizing cities calls for a shift toward more advanced and sustainable solutions. Traditional systems are no longer sufficient to cope with the increasing volume and complexity of waste. Smart waste management, driven by IoT, data analytics, and optimization techniques, offers a transformative approach that enhances operational efficiency, reduces environmental impacts, and promotes social and economic sustainability. This research paper addresses the mounting inefficient waste challenges and waste management system existing in Jalandhar and Chandigarh city so as to prioritize the implementation of these advanced systems in Ludhiana city, ensuring a cleaner, more efficient, and sustainable urban future.

Keywords: Generation, Collection, Disposal, Smart solid waste management, IoT (Internet of Things).

1. INTRODUCTION
Solid waste management (SWM) is indeed a fundamental service that municipalities provide to ensure public health, environmental sustainability, and overall urban cleanliness. However, despite its critical importance, SWM is often one of the most poorly rendered services in many urban centres, characterized by unscientific and outdated systems. These systems are inefficient, with low population coverage, and they tend to marginalize the poor. Waste is frequently littered, leading to unsanitary living standards. Municipal laws governing urban local bodies (ULBs) often lack comprehensive provisions to address the complexity of waste management effectively, exacerbating the issue. While urban centres expand, the systems designed to manage waste struggle to keep pace, leading to environmental and health problems. Effective waste management is essential not only to minimize the negative impacts on the environment and human health but also to support economic development and improve the overall quality of life. Effective SWM involves multiple processes, including monitoring, collection, transportation, processing, recycling, and disposal. The problems of municipal solid waste, involving both domestic and industrial, have become acute in large metropolises. Limited disposal facilities result in solid wastes being dumped haphazardly in various parts of cities, causing environmental issues and serious health problems. The rapid rise in the volume and changing composition of solid waste in India, from 6 million tons in 1947 to 48 million tons in 1997, highlights the challenges that urban centres face in managing waste effectively. The

growing population, shifting food habits, and increasing use of non-biodegradable products have added complexity to solid waste management systems. The statistics provided underscore the severe challenges faced by Indian cities in managing municipal solid waste (MSW). Despite rapid urbanization and increasing waste generation, municipal authorities are struggling with significant gaps in waste management systems. The data points from TERI (2003), indicating that more than 25% of municipal solid waste is not collected, 70% of cities lack adequate capacity to transport it, and there are no sanitary landfills for its disposal, highlights the scale of the issue and the need for urgent reforms.

Smart Waste Management represents a significant leap forward in addressing the complexities of urban waste management. Its multi-criteria approach involves a comprehensive system of technologies and strategies that enable municipalities to efficiently collect, transport, process, and dispose of waste. Key elements of this system include data collection, analytics, optimization, decision support, waste classification, and more. Among these, IoT enabled services stand out as a transformative force in smart waste management. By embracing IoT-enabled smart waste management systems, cities can address the complex issues of waste collection, processing, and disposal, ultimately contributing to more sustainable and liveable urban environments. The integration of IoT into waste management operations is not just a technological advancement, but a critical step toward creating more sustainable, resource-efficient, and cleaner cities.

The fundamental objectives of solid waste management are to reduce the impacts of solid waste on public health and to reduce pollution of the urban environment in a smarter approach. These goals should be achieved in a way that is financially sustainable, with waste being disposed of in a manner that is both financially and environmentally viable. This research article will focus upon the existing solid waste management practices in Ludhiana, a top-tier city in India, and suggesting remedies to some of the major problems faced by the current system.

2. Literature Survey

2.1. Different Types of Waste

The study conducted jointly by CHF International (now Global Communities) and Daily Dump categorizes household waste into four distinct categories: organic waste, recyclable waste, toxic waste, and rejects. Understanding these categories helps streamline the waste management process, ensuring that each type of waste is handled properly and efficiently.

Organic Waste: Organic waste, also known as wet waste, is biodegradable and primarily composed of natural materials that originate from plants or animals. This type of waste is typically decomposed by microorganisms, breaking it down into simpler organic compounds. Common examples of organic waste include food scraps involving leftovers from meals, vegetable peels, and fruit debris, garden waste and other biodegradable materials like bones, paper and human waste. Organic waste is generally quick to decompose and, if managed properly, can be converted into compost or biogas, making it an essential component of sustainable waste management practices. Composting or anaerobic digestion are common methods to handle organic waste, turning it into valuable resources like fertilizer or energy.

Recyclable Waste: Recyclable wastes are materials that can be processed and reused to create new products, reducing the need for raw materials and minimizing environmental impact. These materials are typically collected separately from organic waste to facilitate recycling. Common recyclable materials include glass, paper, metal, plastics, textiles and electronics. Recycling is often more sustainable than manufacturing new products from raw materials, as it requires less energy and produces fewer emissions.

However, some materials, especially plastics, are difficult or expensive to recycle, which can complicate the process. In many cases, recycled materials may be repurposed into new products rather than being converted back into the original material. For example, recycled paper may be used to make paperboard or other paper products.

Toxic Waste: Toxic waste includes materials that are harmful to human health and the environment due to their chemical composition. These materials can be hazardous in solid, liquid, or gas forms and may pose significant risks through inhalation, ingestion, or skin absorption. Proper disposal of toxic waste is critical to prevent contamination of the air, water, and soil, as well as to protect public health. These materials often require special handling and should be disposed of at designated collection points or recycling centres that are equipped to process them safely.

Rejects: Rejects are the types of waste that cannot be recycled, composted, or repurposed. These include materials that do not fall into any of the other categories and typically end up in landfills. Some examples of rejects are biomedical waste generated by healthcare facilities, including syringes, needles, cotton or bandages with body fluids, and expired medicines, sanitary waste items like used sanitary napkins, diapers, and incontinence products, non-recyclable plastics involving certain types of plastic that cannot be processed or reused and contaminated materials. Rejects, especially biomedical and sanitary waste, require specialized disposal methods. For instance, biomedical waste should be handed over to authorized biomedical waste vendors, who handle it according to strict safety protocols to prevent contamination and public health risks.

2.2. Stages of Solid Waste Management

Solid waste management (SWM) involves several key components that ensure waste is effectively managed from the moment it is generated until its final disposal. These components are interconnected, with each step playing an essential role in the overall process. Solid waste management is divided into five key components involving:

- Generation
- Storage
- Collection
- Transportation
- Disposal

2.2.1. Generation

The generation of solid waste is the initial stage, where materials become valueless or no longer useful to their owners. Waste is created as people discard items that they no longer need or want. It's important to note that what may be considered waste to one person might still have value to someone else. For example, tin cans might be discarded as waste, but they could be useful for children or hobbyists. Waste generation is influenced by several factors including lifestyle, consumption patterns, and urbanization.

Key Aspects of Generation:

- Waste is generated when items are no longer useful to the owner.
- Waste generation varies based on socio-economic factors, cultural habits, and lifestyle.
- The types of waste generated depend on individual and community behaviours, such as consumption and disposal habits.

2.2.2. Storage

Storage refers to how waste is kept between its generation and collection, before it is transported to a final disposal site. Proper storage is essential to prevent waste from becoming a health hazard or polluting the environment. In cases where waste is discarded directly into family pits or open areas, storage may not be required initially, but proper storage solutions should be put in place to handle waste more effectively.

Key Aspects of Storage:

- Small containers: Household bins, plastic bins, or small containers for personal waste.
- Large containers: Communal bins, oil drums, or larger receptacles for more significant amounts of waste.
- Shallow pits: Temporary or emergency waste storage that can be used in less developed or temporary areas.
- Communal depots: These can include fenced or walled areas where community members discard waste.

2.2.3. Collection

Waste collection is the process of gathering waste from storage locations and transporting it to the final disposal site. A collection system should be well-planned to prevent waste accumulation in storage areas and ensure timely removal. Collection intervals should be determined based on the volume of waste generated and the capacity of the storage facilities.

Key Aspects of Collection:

- Planning the collection system: This includes determining how often waste should be collected and ensuring that storage containers do not overflow.
- Collection intervals: The frequency of collection must be based on the amount of waste generated by the community.
- Efficiency: The system should ensure that waste collection is timely and prevents health hazards or environmental pollution.

2.2.4. Transportation

Once waste is collected, it needs to be transported to a final disposal site. The choice of transportation depends on the volume of waste, the distance to be covered, and the available resources. Several modes of transportation are used for this purpose.

Types of Transportation:

Human-powered: Open hand-carts, wheelbarrows, tricycles, or hand-carts with bins are typically used in areas where motorized transport is not feasible or where waste volumes are relatively low.

Animal-powered: In some areas, especially in less developed regions, animal-drawn carts (e.g., donkey carts) are used for waste transportation.

Motorized: Larger vehicles such as tractors, standard trucks, and tipper trucks are used for transporting larger volumes of waste over longer distances.

2.2.5. Disposal

The final stage of waste management involves the disposal of waste in a manner that minimizes environmental impact and risks to public health. There are several methods of disposal, with each having its benefits and limitations:

Main disposal methods:

Land application (Burial or Landfilling):

This is the most common disposal method, where waste is buried in the ground in designated landfills. Modern landfills are designed to minimize pollution by using liners and leachate treatment systems.

Composting:
Organic waste (e.g., food scraps, garden waste) is biologically decomposed into compost, which can be used as a soil conditioner. This method reduces the volume of waste sent to landfills and provides environmental benefits.
Burning or Incineration:
Incineration involves burning waste at high temperatures, converting it into ash, gas, and heat. This method can reduce waste volume significantly and can generate energy. However, it has environmental concerns related to air pollution.
Recycling (Resource Recovery):
Recycling involves reprocessing waste materials into new products. It helps conserve resources, reduces energy consumption, and decreases pollution by diverting materials from landfills. It is especially important for materials like paper, plastic, metals, and glass.
Key Considerations for Disposal:

- The environmental impact of the disposal method, particularly for landfills and incineration, which can contribute to pollution.
- The suitability of the method based on the type of waste (e.g., composting for organic waste, recycling for paper and plastic).
- Ensuring proper waste segregation to enable efficient resource recovery and minimize contamination.

2.3. Legal frameworks

2.3.1. SWM Rule 2015

The Solid Waste Management Rules (SWM) 2015, implemented by the Ministry of Environment, Forest and Climate Change (MoEFCC) in India, aim to address the growing challenge of solid waste management in urban and rural areas. These rules provide guidelines for municipal authorities, waste generators, and stakeholders to manage waste in an environmentally sustainable and efficient manner. The rules are meant to create an integrated system for solid waste management that minimizes the environmental footprint while promoting recycling and waste recovery. Following the guidelines, individuals and communities contribute to more effective and sustainable waste management, aligning with the broader goals of the Solid Waste Management Rules, 2015.

2.3.2. The Hazardous Wastes Rules, 2008

These rules aims to minimize the environmental and health risks associated with hazardous wastes through proper management practices, treatment technologies and regulatory oversights. Hazardous waste treatment and disposal must be carried out at authorized TSDF equipped with appropriate technologies. Treatment methods include incineration, chemical treatment, physical treatment and secured landfilling.

2.3.3. The Plastics Rule, 2009

These rules are designed to regulate the use of plastics in various purposes. Recycling of plastics are to be undertaken in accordance with the Beaureau of Indian Standards specification IS 1453: 1988.

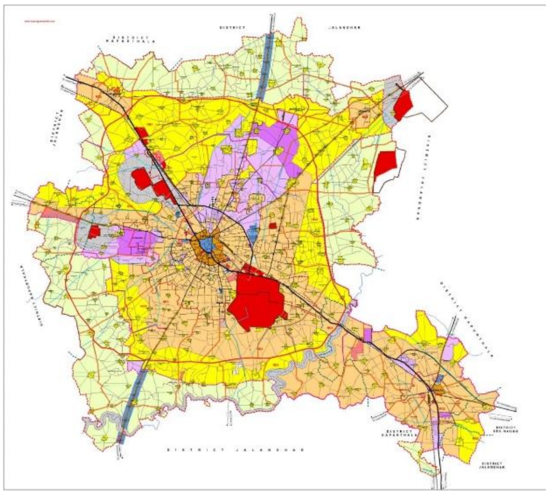
2.3.4. Waste Rules, 1998

It is the responsibility of the occupier to set-up requisite shall in accordance with the requisite biomedical waste treatment facility or to ensure requisite treatment of waste at a common waste treatment facility or any other waste treatment facility.

3. CASE STUDY OF JALANDHAR CITY

Jalandhar, formerly known as Jullundur during the British colonial period, is a historic and significant city located in the Doaba region of the northwestern state of Punjab, India. It is one of the oldest cities in Punjab, with a rich cultural and historical heritage. It is situated at latitude 31.3 and longitude 75.5. Jalandhar ranks 9th in terms of area among the districts in Punjab and 4th in terms of population in Punjab. 52.9% of the population of Jalandhar district resides in urban areas, reflecting its role as an important urban centre whereas 47.1% of the population lives in rural areas. The total area of Jalandhar is 3401 sq. km, and density of population is 836/sq.km (census2011). The land use map of Jalandhar city is shown in **Figure 1**.

Figure 1:- The land use map of Jalandhar city.



Jalandhar, with its approximately 2.34 lakh houses, faces challenges in solid waste management, as not all of its households have access to waste collection facilities. Among 2.34 lakh (234,000) houses. Only 1.50 lakh (150,000) houses have access to waste collection services. This implies that approximately 84,000 houses (around 35.9% of total households) still lack proper waste collection services. Approximately 0.5 kg of waste is produced per person per day, as per the Master Plan 2011-31. The total waste produced in Jalandhar city is estimated to be around 400-450 metric tons per day. It has been found that there are three broad groups into which waste generated by the city can be categorized. These include:-

1. Municipal solid waste
2. Hospital solid waste
3. Industrial solid waste

The municipal solid waste have further been divided into residential, commercial and industrial wastes as depicted in **Table 1**.

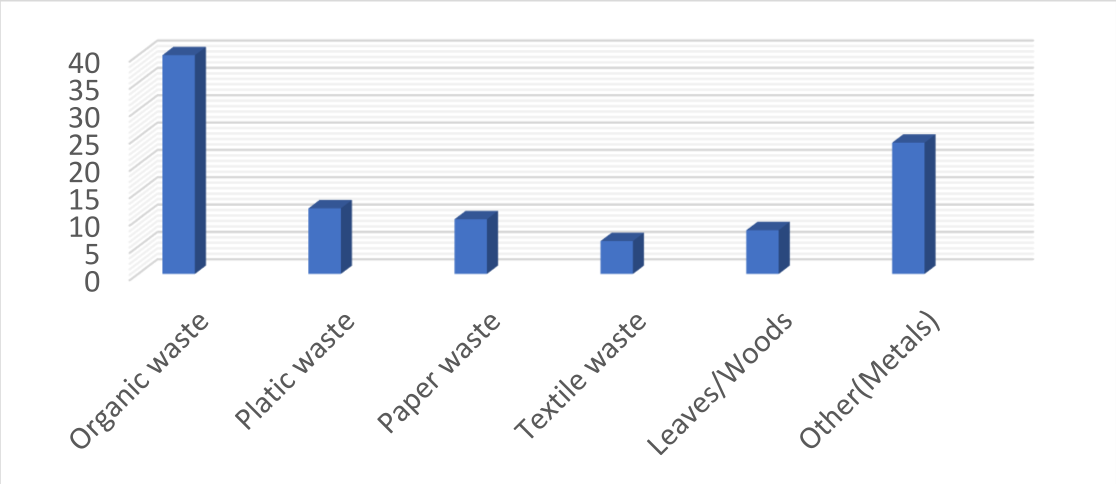
Table 1: Types of municipal solid wastes

S.No	Sources	Typical facilities, activity and location	Type of MSW
1	Residential & Open areas (90%)	Single & multi family dwelling, streets, parks, bus stand.	Food waste, street waste, Rubbish, Ashes.

2	Commercial including sweeping. (5%) street	Offices, Institution, markets, Hotels, restaurants, stores auto repair shop, medical facilities, streets etc.	Food waste, rubbish ashes, street waste occasionally hazardous waste.
3	Industrial (5%)	Small/medium scale industry, Offices, canteen	Office waste, food waste, packaging material.

58% waste is organic and biodegradable, hence can be treated easily to generate economy and reduce landfill by manufacturing of manures by various means. 18% waste is recyclable and 24% is inert waste as illustrated in **Graph 1**. There is potential to use 76% of waste but currently all the waste collected, is dumped into Wariana dump.

Graph 1:- Graphical representation of composition of solid waste generated in Jalandhar city.

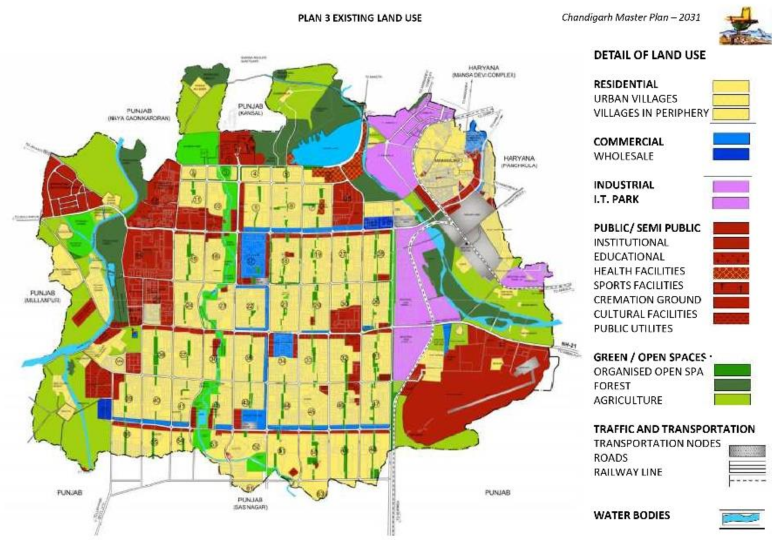


Solid waste generated from various sources is different hence the composition is different. Therefore there should be different mechanisms dealing with each type of waste. It should be segregated at source only. So that it's treatment can be done according to the requirements. The residential waste comprises of the organic waste which can be converted into manure, while waste from commercial sources has a greater potential for recycling.

4. CASE STUDY OF CHANDIGARH

Chandigarh, one of India's most modern cities, is indeed a remarkable example of urban planning and architectural design. Planned by the renowned French architect Le Corbusier in the 1950s, it stands out as a vision of modernity, function, and beauty. Nestled at the foothills of the Shivalik range, the city's layout follows a grid pattern, making it one of the best-planned cities in India. The name "Chandigarh" is derived from the nearby *Chandi Mandir*, a temple dedicated to Goddess Chandi, whose name represents power. The word "garh," meaning fort, symbolizes strength, and the combination reflects the city's cultural and historical significance. The name *Chandigarh-The City Beautiful* aptly captures the essence of the city's aesthetic appeal, which is enhanced by its green spaces, wide avenues, and well-maintained architecture. The Master Plan of UT Chandigarh covers a total area of approximately 114 square kilometres. Out of the total 114 sq. km, about 70 sq. km are dedicated to the area originally planned and developed by Le Corbusier and his team. An area of 26 sq. km is excluded from the master plan as it falls within the boundaries of the Sukhna Wildlife Sanctuary, which is a protected area. The remaining 44 sq. km refers to the periphery-controlled area, which is part of a 16 km radius around the city. This area is under specific planning regulations, and Chandigarh has a 3% share of that larger zone, influencing its growth and land-use policies. As per the Census 2011, the population of Chandigarh is 10.54686 lakh (or 1,054,686 people). This is the total population residing in the city at that time. Additionally, Chandigarh is known for its high population density of 9,252 persons per square kilometre, which indicates that it is a relatively compact and densely populated city. The population of Chandigarh is predominantly urban, with approximately 97.01% of households located in urban areas, while only 2.98% of households are in rural areas. This indicates that Chandigarh is a highly urbanized city with a dense population living in planned urban spaces. 10,672.16 acres are designated for residential purposes. This area includes spaces for both low and high-density housing, ensuring adequate accommodation for the urban population. About 1,339.73 acres are allocated to commercial activities such as markets, offices, shopping complexes, and retail spaces, 2,046.1 acres are dedicated to transport infrastructure including roads, highways, public transportation systems, and parking areas, 1,326.5 acres are reserved for industrial use, 2,968.79 acres are designated as public or semi-public areas including government buildings, institutions, schools, hospitals, and other public service facilities, 2,428.47 acres are set aside for recreational use including parks, playgrounds, and sports facilities, 302.33 acres are allocated for public utilities, 136.29 acres are dedicated to railway land, supporting transportation and logistics infrastructure, 1,573 acres are designated as defence land, 2,113.97 acres are allocated as forest land, contributing to Chandigarh's green cover and environmental sustainability, 2,046.1 acres are marked as vacant land, which could potentially be used for future development, expansion, or urbanization, 277.29 acres are designated as green belts and 302.33 acres are allocated for water treatment plants and sewage treatment facilities, ensuring that the city has proper infrastructure for water supply and waste treatment. The land use map of Chandigarh is depicted in **Figure 2**.

Figure 2. The land use map of Chandigarh.



Chandigarh, recognized as a model for sustainable urban development, has also been an example in terms of its waste management practices. According to the **City Development Plan** for Chandigarh, the waste generated from different locations in the city is categorized into four main categories namely residential, commercial, institutional and miscellaneous that is shown in **Table 2**.

Table 2. Categories of primary waste collection in Chandigarh

Category	Sub-Category
Residential	Urban, rural and informal settlements
Institutional	Educational institutions, health institutions, transportation hubs
Commercial	Various produce markets, shopping complex, hotels and restaurants
Miscellaneous	Roads, open spaces, parks, places of fairs and festival celebration

The Ward map of Chandigarh is depicted in **Figure 3**.

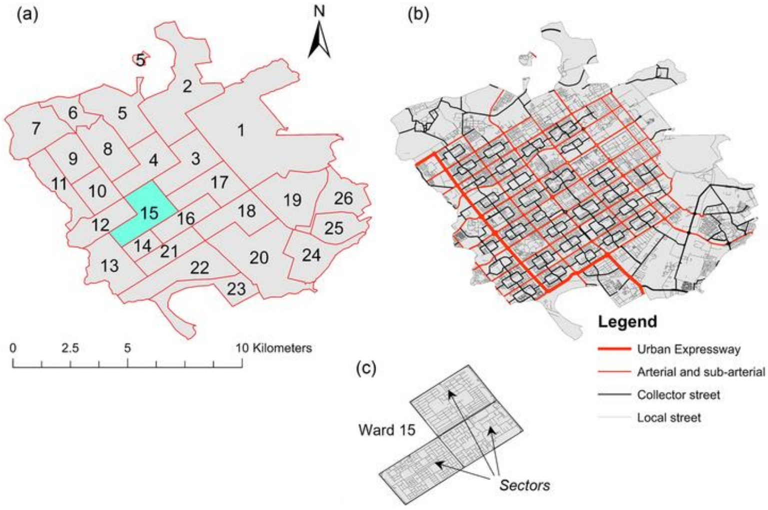


Figure 3. Ward map of Chandigarh.

Chandigarh's solid waste management system focuses on the collection, transportation, and disposal of municipal waste generated from households, commercial areas, and other sources. The waste generated includes wet, dry, and horticultural waste, and the Municipal Corporation (MCC) has implemented several strategies to handle these categories effectively. The current status of solid waste management as per census 2011 is depicted in **Table 3**.

Table 3. Current status of solid waste management in Chandigarh as per census 2011.

S.No.	Urban Local bodies	No of Wards	No of Households	Population	Solid Waste Generated per day
1	Municipal corporations (Nagar Nigam or Mahanagar Palika)	26	234033 (Census 2011 urban)	1055450 as per 2011 census	500 TPD

To gain a comprehensive understanding of the waste management practices, challenges, and impacts in Chandigarh, particularly around the Dadumajra dumping site, multiple stakeholder engagement methods were employed. These included interviews, focus group discussions, observations, and consultations with key officials. Here's a detailed breakdown of the process:

Key Insights and Findings from the Engagement:

1. **Health and Environmental Concerns**:
   - Residents near the Dadumajra site reported significant health problems such as respiratory issues, skin conditions, and water contamination, primarily due to the open dumping of waste and the absence of proper waste management systems at the site for many years.
   - There were concerns about the leachate (liquid that drains from landfills) and methane emissions from the decomposing waste, which could lead to contamination of the surrounding environment, including soil and groundwater.
2. **Challenges Faced by Waste Workers**:
   - Formal workers expressed concerns about the lack of protective gear (e.g., gloves, masks), inadequate training, and poor working conditions in handling waste.
   - Informal workers working in the sorting of recyclable materials or collecting waste from households face the dual challenge of low wages and unsafe working conditions, exposing them to hazardous materials like sharp objects and harmful chemicals.
3. **Effectiveness of Waste Segregation**:
   - While the color-coded bin system is in place in commercial areas and many residential zones, there is a lack of awareness and compliance in some sectors, especially in informal settlements.
   - Residents' feedback suggested that while many understand the importance of waste segregation, the system is not consistently followed across all areas. Behavioral change campaigns and better enforcement are needed.
4. **MCC's Role and Future Directions**:
   - According to the CMO, MCC has been actively working on improving the city's waste management system, with particular focus on:
     - Upgrading the Dadumajra processing plant.
     - Bio-remediation of the legacy waste site, which is expected to reclaim 20 acres of land once completed.
     - The launch of educational campaigns to promote waste segregation and reduce plastic waste.

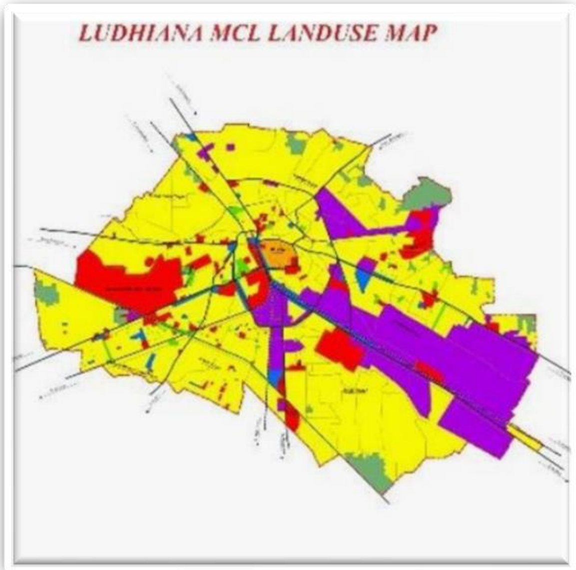
The comprehensive engagement with various stakeholders—residents, waste workers and municipal officials—has highlighted both successes and challenges in Chandigarh's waste management system. Key challenges include lack of awareness about waste segregation, unsafe working conditions for waste workers, and environmental concerns surrounding the legacy waste site. However, the ongoing initiatives such as the bio-remediation of legacy waste and the upgradation of the Dadumajra plant show a positive direction towards achieving a cleaner, more sustainable city. Further improvements in public awareness, worker safety, and waste processing capacity will be critical for Chandigarh to address its waste management challenges and promote a healthier and more sustainable urban environment.

5. SOLID WASTE MANAGEMENT IN LUDHIANA CITY

Ludhiana, located in the Indian state of Punjab, is the most populous city in the state and holds a prominent position in both industrial and agricultural sectors. Known as the "Manchester of India" due to its large hosiery and textile industry, the city has earned a reputation as a major hub for garment manufacturing. The Punjab Agricultural University (PAU), established in the 1960s, is a key institution in Ludhiana. It is renowned as one of India's leading agricultural universities and has played a crucial role in advancing agricultural practices and research. Historically, Ludhiana was a significant town along the Grand Trunk Road, one of Asia's oldest and most important trade routes, linking the eastern and western parts of the

Indian subcontinent. The city stands on the southern bank of the Sutlej River, with a strategic location that has contributed to its growth as a major trade and transportation centre. Ludhiana is a city in the Indian state of Punjab, and is the largest city north of New Delhi, with an estimated population of 1,693,653 as of the 2011 census and area of 159.37 sq. km. It is located at 30.9°n 75.85°e. It has an average elevation of 244 meters (798 ft).L udhiana is strategically located 98 kilometres (61 miles) west of Chandigarh, the capital of Punjab and Haryana. It is easily accessible via National Highway 95 (NH 95), which connects the city to Chandigarh. Moreover, Ludhiana is centrally positioned on National Highway 1 (NH 1), one of India's most important roads, which runs from New Delhi to Amritsar. The World Bank ranked Ludhiana as the city in India with the best business environment in 2009 and 2014.It is a major industrial center of northern India, and was referred to as India's Manchester by the BBC. Ludhiana district is geographically located in the central part of Punjab, with distinct boundaries. It is bordered by the Sutlej River to the north, which provides the district with fertile land and irrigation opportunities. To the west, it is bordered by Ferozepur and Moga districts. On the southern side, it borders the Sangrur district, while to the east, it touches Fatehgarh Sahib and Ropar districts. The district has an almost rectangular shape, with a length of 96 kilometres along the northern side, where it runs parallel to the Sutlej River, and a breadth of 39 kilometres from north to south. This geographical positioning contributes to the region's agricultural and industrial importance. The land use map of Ludhiana city is depicted in **Figure 4**.

Figure 4. The land use map of Ludhiana city.



5.1. STAGES OF SOLID WASTE MANAGEMENT IN LUDHIANA

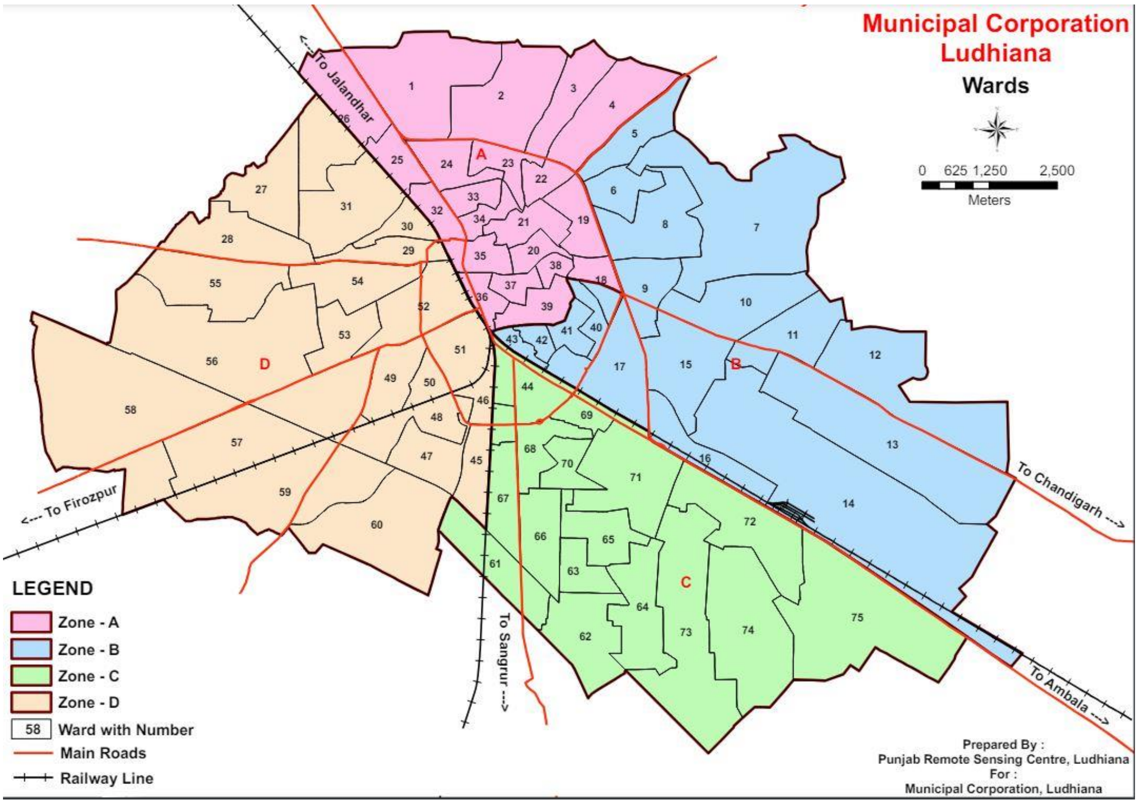
5.1.1. Generation stage

This is the first stage of the solid waste management process. The study areas initial focus over the generation sources, types of solid waste generated and its ward wise analysis.

Ward wise Generation of waste

Ludhiana generates 850 MT of waste per day and per capita waste generated is 535 gms per day. The waste generated by wards is direct proportional to the population of ward. Maximum number of waste generated by wards ranges from 8 to 11 MT. Only 7 wards ranges from 15 to 22 MT and only 5 wards from 3 to 5 MT. This area lies on the urban fringe of Ludhiana and away from the city centre. So this is the low density part of the city. The solid waste generation in this part of city ranges from 3 to 11 MT. This part shows the high density zone of Ludhiana city. The city centre and high density residential development of this region leads to generation of more solid waste in this area. The solid waste generation in this region ranges from 8 to 22 MT of solid waste. The wards near the city centre that are 3,5,6,7,18 are the highest waste generating wards and the wards away from centre that are 51,58,61,62 are among lowest waste generator. The ward map of Ludhiana is shown in **Figure 5**.

Figure 5. The ward map of Ludhiana.



Waste generated through littering

Littering is a significant environmental issue, even though its exact waste generation is not systematically recorded by the government. The harmful effects of littering, however, can be clearly observed through visual surveys, and its consequences are far-reaching. Carelessly discarded garbage affects every member of society, posing risks to both people and animals, damaging ecosystems, and negatively impacting the aesthetic and health of communities. Littering leads to various problems: it contaminates our waterways, harms wildlife who may ingest or become entangled in the waste, and results in the accumulation of non-biodegradable materials. Research and experience have shown that littering is often the result of individual behaviour. A clean environment not only discourages littering but also improves the overall appearance of the community and enhances the quality of life for its residents. Communities that invest in cleanliness and proper waste management can promote a sense of civic pride, encourage responsible waste disposal, and foster a culture of environmental stewardship.

Sources of littering

- Pedestrians dropping garbage in streets and roadways.
- Uncovered loads. Items that are not secure can easily be blown out trucks and cause roadside littering.
- Household refuse disposal and collection.

- Animal scavengers and the wind can dislodge unsecured items placed out on the corner for collections.
- Commercial refuse and disposal.
- Construction projects

Problems caused by littering

Littering has a wide array of negative effects, impacting both the environment and public well-being. Here are some of the primary issues caused by litter:

- **Environmental Harm**: Litter discarded in streets, parks, or other public spaces can easily travel through the stormwater system into rivers, creeks, and other waterways. Once there, it can cause significant harm to wildlife, as animals may ingest or become entangled in the waste. The accumulation of plastic and other non-biodegradable materials in aquatic environments also disrupts ecosystems.
- **Economic Costs**: Removing litter from public areas requires significant financial resources. Local governments, municipalities, and sometimes communities must allocate funds for litter cleanup, diverting money from other essential services. This means that everyone pays for the consequences of littering, often in the form of higher taxes or community-based programs.
- **Public Health Threats**: Litter poses serious health risks, as it can attract vermin such as rats, mice, and insects. These pests often carry diseases and can contribute to the spread of infections. Moreover, items like broken glass, discarded syringes, or food waste can become breeding grounds for harmful bacteria, creating unhygienic conditions in public spaces and posing health hazards to those who come into contact with them.
- **Fire Hazards**: Accumulated litter, especially dry leaves, paper, or other flammable materials, can pose a significant fire risk. Carelessly discarded cigarette butts or matches can easily ignite the litter, leading to fires in urban or rural areas. These fires can be destructive, endanger lives, and require costly emergency responses.
- **Aesthetic Impact**: Litter significantly detracts from the appearance of a community, making public spaces look unkempt and unattractive. This negative visual impact can lower the quality of life for residents and discourage visitors, potentially affecting local tourism and the community's overall image.
- **Encourages More Littering**: Littering creates a cycle where discarded waste attracts more litter. Seeing trash in an area sends the message that people don't care about the cleanliness of the environment and that it's acceptable to add more waste. This can foster a culture of negligence, making it harder to maintain clean and healthy public spaces.

  Addressing littering requires collective action, including raising awareness, improving waste disposal infrastructure, enforcing litter laws, and encouraging individuals to take responsibility for their actions. A cleaner, litter-free environment benefits everyone, improving the quality of life, reducing health risks, and protecting the natural world.

Sources of generation

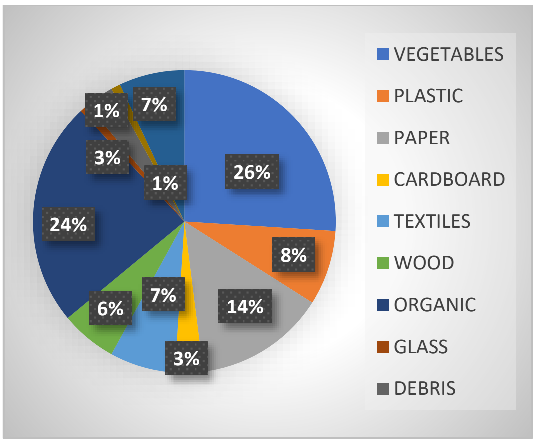
The waste generation in residential, commercial and industrial region in Ludhiana is shown in **Table 4**.

Table 4. Sources of Generation of Waste

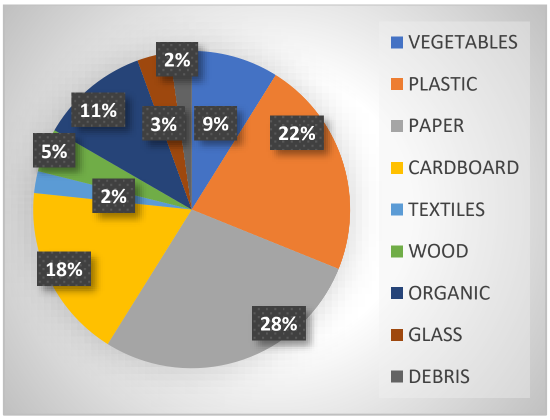
S. No.	Sources	Typical facilities, activity and location	Type of MSW
1	Residential & Open areas (56.31%)	Single & multi family dwelling, streets, parks, bus stand.	Food waste, street waste, Rubbish, Ashes.
2	Commercial including sweeping (24.95%) street	Offices, Institution, markets, Hotels, restaurants, stores auto repair shop, medical facilities, streets etc.	Food waste, rubbish ashes, street waste occasionally hazardous waste.
3	Industrial (19.74%)	Small/medium scale industry, Offices, canteen	Office waste, food waste, packaging material.

Furthermore, the waste incorporated in various regions include vegetable waste, plastic, textile, wood, organic waste and many more. Categorizing each type of waste in these regions is shown through pie chart representation as depicted in **Figure 6**.

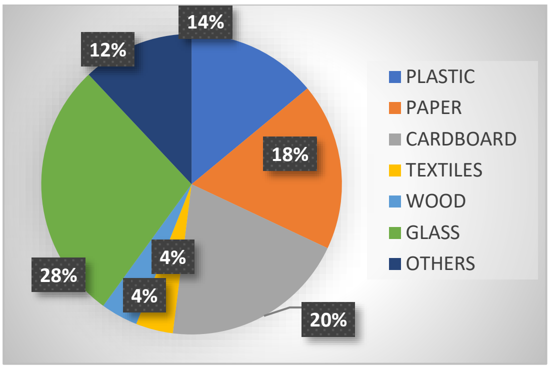
Figure 6. Pie chart representation of various type of waste in (a) Residential, (b) Commercial and (c) Industrial region.



(a) Residential



(b) Commercial



(c) Industrial

Out of 850 MT waste generated in the whole city the major part is of the biodegradable waste which is very good indication for the environment point of view, so it is 44.67 % that is 371.2 MT. The recyclable and reusable waste generated per day is of 264.5 MT which is again a g0od sign but of no use if not segregated. And best to be segregated at the generation level itself. The non-biodegradable waste is quite low but can have great environment impact if not treated properly.

5.1.2. Collection Stage

This is the second and most important stage of the solid waste management process. As per available data the parameters on the base on which collection system is praised is the type of the collection system, manpower and vehicles, zonal distributions and routing and scheduling. Type of collection system adapted involved:-

Household Waste

The process of waste management at the individual level in many areas is characterized by significant gaps in proper disposal practices. Typically, solid waste generated at individual premises is either removed by the property owner or their employee, who then transports the waste to designated collection points, which are identified by the local municipal corporation or other governing bodies. These collection points include community bins, designated open sites, and portable bins. However, despite these designated collection points, the waste is often not disposed of properly. In many cases, people do not dump the waste directly into the community bins. Instead, the waste is often discarded outside the bins, in nearby open areas, or even on the roadside. This improper disposal of waste is an indication of the low level of awareness about the importance of solid waste management and the negative consequences it can have on public health, the environment, and the community's overall cleanliness.

Road Side Waste

Roadside Waste refers to the waste that is discarded improperly on the sides of roads, including trash thrown out of vehicles or littered by pedestrians. This kind of waste is a major contributor to urban pollution, causing environmental and aesthetic issues. To address this problem, municipal corporations employ workers, commonly known as Safai Sewaks, who are responsible for maintaining cleanliness in public spaces, including roadsides.

Sweeping

Sweeping is a critical aspect of maintaining cleanliness in urban areas, particularly in municipal roads and public spaces. Municipal corporations typically employ Safai Sewaks (sanitation workers) who are responsible for sweeping roads, collecting solid waste, and ensuring that public spaces remain free of litter. This process helps in keeping the streets clean, reducing pollution, and promoting better public health.

Primary Collection

The major vehicle used for primary household collection is tricycle and wheel barrows, which collect solid waste from each household and put it at collection points which can be containerized and paved. The truck trippers, tractor trolleys and mini tata basically transfer the waste directly to the dumping sites so as to reduce pressure over the collection points and save time. The quantity of waste handled by vehicles per metric tone is represented by **Table 5**.

Table 5. the quantity of waste handled by vehicles in Ludhiana

Vehicle type	No.	Capacity	A.V Trip	Quantity handled (metric tone)
Tricycle	600	0.6	1	360
Wheelbarrow	465	0.2	1	93
Tractor trolley	8	2	2	32
Mini tata	15	1.2	6	108
Truck trippers	14	5.5	4	252

The average trips made by the collection vehicle such as truck trippers and the mini Tata are quite higher up to 4 and 6.The maximum desired trips to be made by any vehicle is to be 3 so as to do primary collection work before 10 and avoid traffic problems and save time. So there is shortage of 5 truck trippers and 15 mini Tata as per desired trips.

Routing and Scheduling

The MC has divided city into 4 zones depending upon separation by physical barriers and the nature of land use. The zone A has 21 wards and 95 points, zone B has 16 wards and 72 points, zone C has 16 wards and 63 points and zone D has 22 wards and 39 points. The capacity of each point is about 4 MT, whose total came out to be 1092 MT which is242 MT higher than the total waste generated per day.

Manpower

The standard for the Safai Sewak is one Safai Sewak for the 625 population. So the standard Safai Sewak for Ludhiana is 2284 and available is 894 so there is shortage of 390 Safai Sewaks. The standard for the jamadar is one jamadar for 25 Safai Sewaks. So the standard Jamadar for Ludhiana is 91, available is 71 and shortage is of 20. Overall the shortage of manpower leads to many problems like inefficiency, mismanagement etc.

5.1.3. Disposal stage

- The waste is lied openly on unpaved area leads to the leaching effect and is also anesthetic and breeding ground for mosquitoes. The segregation is done manually without any dress or precautions by the workers.
- The disposal facility like landfilling, incineration, and compositing is not done in a scientific way and very slow due to lack of infrastructure.
- The inert waste segregated is not used properly and just openly at the place.
- Also the biodegradable waste, organic waste and compositing waste are not scientifically used so as to create the funds from manure or other use. Also the ash generated from the incinerators is not used for productive practices like brick making etc. It is just dumped or released in drain.

Landfill sites

This is the most economic way to dispose of the waste. Certain kinds of problems are arised due to landfills. Landfills, particularly in urban areas like Ludhiana, can lead to a number of serious environmental and infrastructural problems if not managed properly. Infrastructure disruption, in which heavy vehicles damaged accessed roads, may occur. Pollution of local roads and water courses from wheels on vehicles when they leave the landfill can be significant and can be mitigated by wheel washing systems. Pollution of the local environment, such as contamination of groundwater or aquifers or soil contamination may occur as well. The following is listing of various landfills in Ludhiana:-

- Jamalpur (Land area 25 acre)
- Jainpur (Land area 10 acre)
- Noorpur Bet (Land area 20 acre)

5.2. FINDINGS

There are certain findings being drawn from the conceptual framework as well as from the study area regarding Ludhiana city. The findings as per the different stages are also mentioned but some specific to people behaviour and visual survey are listed as follows:

- In Ludhiana, the scientific and systematic storage of waste at the source is often not implemented in many places which causes several problems.
- The practice of throwing waste in vacant areas, government land, drains, and streets is a significant problem. This contributes to environmental degradation, poor hygiene, and persistent cleanliness challenges. Even if municipal workers regularly clean the streets, the city remains dirty because waste continues to be improperly disposed of.
- People often fail to arrange proper dustbins or waste storage containers, which leads to a range of environmental problems, including clogged drains, reduced capacity in large drains, and litter in public spaces. In case of open drains and large drains passing across the city, people throw waste due to which these drains are clogged as a result width of large drains are reduced because of continuous dumping.
- People avoiding designated waste disposal points and instead dumping waste on nearby roads, railway tracks, open plots, etc. is a common issue. This behaviour exacerbates environmental pollution, creates public health risks, and significantly hinders effective waste management.
- Sweepers generally restrict themselves only to the sweeping of the streets and cleaning of drains.
- The practice of private sweepers collecting waste from households but then depositing it at collection points instead of following the proper waste management process, including door-to-door waste collection by municipal authorities, creates several issues.
- Lack of initiatives to monitor and encourage community and citizen cooperation with municipal sweepers is a significant challenge especially in areas where waste management practices are poorly coordinated or where residents are disengaged from the process. If citizens are not encouraged or incentivized to bring their household and commercial waste to designated collection points or community bins, it can result in inefficient waste collection, overflowing bins, and increased environmental pollution.

5.3. STRATEGIES AND PROPOSALS

The certain strategies are drawn from the conceptual framework for the Ludhiana city for betterment of solid waste management. The most of the strategies strategies again are regarding the people behaviour oriented.

- Educating and raising awareness among the community is the foundation of effective waste management. Without public participation and a change in individual behaviours, even the best systems and infrastructures may fail. The solution to many waste-related challenges such as improper storage, unsegregated disposal, and non-compliance with municipal guidelines lies in shifting people's habits and encouraging them to actively cooperate with municipal authorities.
- Guidelines relating to the kind of storage receptacles, segregation of waste etc. should be cleared and offenders should be penalized.
- Segregation of recyclable / non-biodegradable waste should be done using appropriate methods.
- The need for waste segregation at the city level and ensuring the proper disposal of recyclable waste and hazardous waste is essential for creating a sustainable and efficient waste management system. Segregation at both the source level (households, commercial establishments, etc.) and the municipal level is crucial for reducing landfill burden, increasing recycling rates, and mitigating environmental and health risks associated with improper waste disposal.
- The proper storage and disposal of dry, recyclable, and hazardous waste are critical to ensuring that waste management systems are effective, reduce environmental impact, and safeguard public health. Dry and recyclable waste should be stored in bags made of plastic /paper / cloth etc. whereas the domestic hazardous waste, electronic equipment waste should be should be disposed in notified safe areas.
- Providing separate community bins for dry (recyclable) and wet (organic) waste is a fundamental step in improving waste management at the community and commercial levels. Properly designed and appropriately sized bins, especially in commercial areas like hotels, markets, and business districts, can greatly contribute to more efficient waste segregation, reduction of contamination, and overall cleanliness.
- In case of vegetable markets large containers complementing the transportation system should be provided. For waste in meat and fish markets the containers should be non corrosive and not more than 1001ts.
- To enhance the efficiency of street cleaning and waste collection operations in urban areas, it is essential to synchronize sweeping operations with the time of waste generation. This ensures that waste is collected promptly, before it accumulates excessively or causes environmental hazards. Dividing the city into sweeper beats and using appropriate tools, like shovels, to transfer waste to containers are critical components of an effective waste management strategy.
- In the case of community bins and temporary storage, transitioning from traditional infrastructure (such as cylindrical cement bins and masonry tanks) to more modern, metal mobile containers offers several benefits. These metal containers, typically ranging from 3 to 10 cubic meters in capacity, can enhance both the cleanliness and practicality of waste management systems.
- In order to reduce waste at dumping site appropriate composting methods can be used.
- Active participation of the community and the design and development of an appropriate system for the primary collection of waste. This system must be well-coordinated with storage at source as well as temporary storage collection points. Synchronizing these elements ensures that waste is efficiently collected, transported, and processed, ultimately contributing to cleaner and healthier urban environments.
- For effective waste disposal while minimizing negative impacts appropriate criteria for selection of

dumping sites should be followed. Every dumping site should be away from residential area or habitation.

- Dumping sites should have provision for workers shelter stay, tools, equipment electronic weigh bridge etc private initiative in proper manner required in treatment and disposal solid waste.
- Biomedical waste from hospitals and nursing homes should be treated as per the provisions laid down by government of India in which specific regulations for the safe handling, treatment, and disposal of biomedical waste are made so as to minimize its risks to human health and the environment. (Ministry of environment and forest biomedical waste rules 1998)
- Waste from construction sites, demolition waste should be within the premises and should not obstruct the road.
- Doorstep collection of waste by municipal workers and commercial are should be ensured.
- All waste should be segregated between biodegradable and non-biodegradable waste before primary collection.

5.4. ELEMENTS OF SMART SOLID WASTE MANAGEMENT

5.4.1. Key elements of Smart Solid Waste Management

Smart solid waste management refers to the application of innovative technologies, data-driven strategies, and collaborative approaches to optimize the collection, processing, disposal, and recycling of solid waste in urban areas. It integrates digital solutions, IoT (Internet of Things) devices, data analytics, and automation to improve efficiency, reduce environmental impact, and enhance overall waste management practices. Smart SWM involves several key elements:

(a) IoT-enabled Waste Bins: Utilizing sensors and IoT devices in waste bins to monitor fill levels, optimize collection routes, and reduce unnecessary pickups, thereby saving costs and minimizing carbon footprint.

(b) Data Analytics: Analyzing data collected from waste management operations to identify trends, patterns, and areas for improvement. This data-driven approach helps in making informed decisions, optimizing resources, and enhancing operational efficiency.

(c) RFID and Barcode Technology: Implementing RFID (Radio-Frequency Identification) tags or barcodes on waste containers to track waste streams, improve sorting at recycling facilities, and enable traceability throughout the waste management process.

(d) Waste-to-Energy Technologies: Exploring innovative waste-to-energy solutions such as anaerobic digestion, incineration, or gasification to convert organic waste into renewable energy sources, reducing landfill dependency and contributing to sustainable energy production.

(e) Public Engagement and Education: Leveraging digital platforms, mobile apps, and community outreach programs to educate and engage citizens in responsible waste disposal practices, recycling initiatives, and promoting a culture of waste reduction and sustainability.

(f) Smart Contracts and Blockchain: Utilizing blockchain technology and smart contracts for transparent and secure transactions within the waste management ecosystem, including waste collection services, recycling partnerships, and waste disposal agreements.

(g) Collaborative Partnerships: Fostering collaborations between government agencies, private waste management companies, technology providers, research institutions, and community stakeholders to develop innovative solutions, share best practices, and address challenges in SWM collectively.

5.4.2. IoT based waste management for smart city

Waste management is a critical aspect of environmental sustainability and urban planning. It involves the systematic handling of waste from its generation to its final disposal or recovery, ensuring that the processes involved reduce the negative impacts on public health, the environment, and the economy. In essence, waste management is about reducing waste, properly collecting, recovering, transporting, and eventually disposing of waste materials in a way that aligns with environmental and societal goals. Get live notifications of filled bins and their locations. Various elements of IoT based waste management for smart city are shown in **Figure 7.**

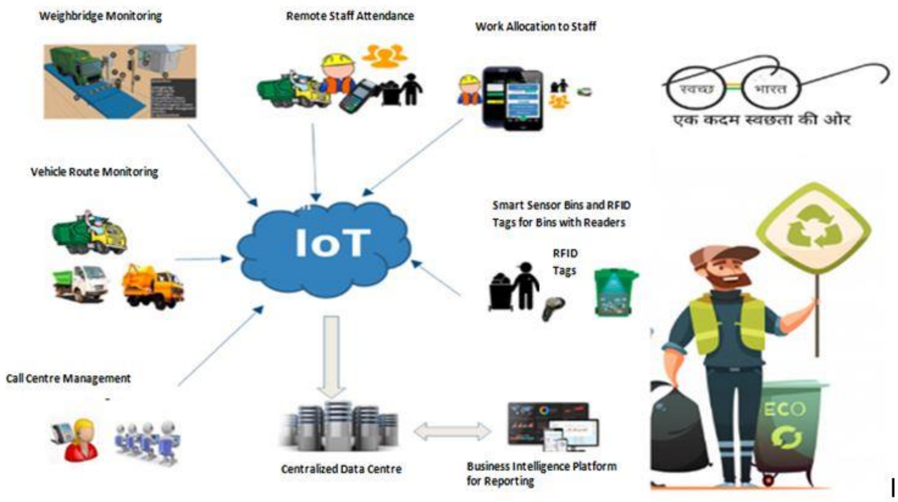


Figure 7. Elements of IoT based waste management for smart city

The use of smart containers is revolutionizing waste management systems worldwide by IoT technology, which allows for more efficient, real-time monitoring and management of waste. This innovation offers numerous advantages, especially in terms of fuel savings, labour efficiency, maintenance costs, and overall operational management. The example of the American textile company illustrates how smart container technology can bring substantial improvements in both yield and cost-effectiveness. It saved 43% in labour costs and 25% in fuel costs. Both private waste management companies and municipalities can benefit from intelligent waste management technology. With the reduction of the costs of sensor and the widespread use of sensors; all waste-management services can manage waste in cities with operational efficiency and lower costs.

Trash fill Sensor

Trash fill sensor as depicted in **Figure 8** involved a technology to transform a normal trash bin into a smart one with the ability to measure waste levels accurately, provide real-time notifications, and track the bin's location, in which integrate sensors and a communication system helps to monitor and manage the waste bin more efficiently. There are ultrasonic sensors placed on the lid of the trash bin and a weight sensor under the bottom panel. A combined reading is used to get an accurate measurement of the weight of the trash stored.

Figure 8: Trash fill sensor

Truck fill Sensor

In modern logistics and transportation, managing truck load capacity effectively is crucial for maximizing operational efficiency, ensuring safety, and preventing unnecessary wear and tear on vehicles. By integrating sensor technology into trucks, fleet operators can better monitor and control truck load capacities in real-time, receiving immediate notifications when the truck reaches its maximum capacity. Whenever the truck is filled with the maximum level of trash loading capacity this sensor technology notifies the operator and driver resulting in better handling of trash as shown in **Figure 9**.

Figure 9: Truck fill sensor

Route Optimization

One of the most effective ways to improve waste management operations is by optimizing garbage truck routes. With smart technology, waste management systems can minimize fuel consumption, reduce operational costs, and ensure that garbage trucks only visit filled containers, thus saving valuable time and resources.

Data & Analytics

Learning waste disposal trends and habits of the residents, can be used to further enhance the operational efficiency of the system. By leveraging data collected from smart bins and analysing resident behaviour, the waste management system can be fine-tuned for better time-to-pick-up, improved scheduling, and more effective resource allocation.

CONCLUSION

As urban populations continue to grow and waste generation accelerates, traditional waste management systems are increasingly proving to be insufficient. These conventional systems often struggle with inefficiency, inadequate infrastructure, and the inability to adapt to the evolving needs of rapidly expanding cities. The rising complexity of waste generation, both in terms of volume and composition, further underscores the urgency of finding innovative solutions. Smart waste management, leveraging IoT technologies, data analytics, and optimized systems, provides a promising solution to these challenges. By improving operational efficiency, reducing environmental impacts, and increasing social and economic sustainability, smart waste management systems can significantly improve urban living conditions and contribute to a more sustainable future. As such, municipal authorities need to prioritize the adoption of these advanced systems to address the growing problem of waste in cities effectively.

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