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Strategies for Integrated Municipal Solid Waste Management Plan for Sambalpur Municipal Corporation

Ankit Pradhan[1], Santosh Kumar[2], Samikshya Pradhan[3]
[1]*PG Scholar,* [2]*Assistant Professor,* [3]*Lecturer, School of Infrastructure and Planning, Odisha University of Technology and Research, Techno Campus, Ghatikia, Bhubaneswar*

Abstract: ***Rapid urban growth has increased the amount of municipal solid waste in cities like Sambalpur, creating challenges in collection, segregation, and disposal. At present, the waste management system faces issues such as lack of proper segregation at source, inefficient collection methods, and limited data on waste composition. This study focuses on developing a smart and data-driven solid waste management framework for Sambalpur, with special attention to household waste. The research includes field surveys to understand the type and quantity of waste generated, along with an analysis of existing waste management practices. Based on the waste composition, suitable treatment methods such as composting, recycling and waste-to-energy are identified. The study also explores the use of smart technologies like IoT-based bins and GIS-based route planning to improve efficiency and monitoring. By combining data analysis, resource recovery, waste to energy and technology, the study aims to create a more sustainable and efficient waste management system. The findings will help in better planning, reducing environmental impact, and promoting the concept of waste as a resource in urban areas.***
Keywords: Smart Solid Waste Management (SWM), Circular Economy, Urban Sustainability, Waste-to-Energy (WtE), Digital, Waste Monitoring.

I. INTRODUCTION

Urban India is confronted with a rapidly escalating solid waste crisis. The Central Pollution Control Board (CPCB, 2021) estimates that Urban India is dealing with a problem of solid waste. The Central Pollution Control Board says that cities in India produce over 1,50,000 tonnes of waste every day. A lot of this waste is not collected or separated properly and it is not disposed of in a safe way. This is an issue for smaller cities like the ones in Odisha. They do not have money their governments are not very strong and their populations are growing very fast. Sambalpur is a city in Odisha on the banks of the Mahanadi River. It is an example of the problems that smaller cities face. The population of Sambalpur has been growing steadily. From 2,13,003 in 2001 to 3,35,761 in 2011. By 2026 it is expected to have around 4,1,891 people. This means that the city is producing more solid waste. The Sambalpur Municipal Corporation is in charge of managing this waste. They have started collecting waste from people's homes. Have set up facilities to process it. However, there are still problems. Not many people separate their waste properly there are not vehicles or workers to collect the waste and the city does not use technology to monitor waste management. The city does not have a plan to manage its solid waste. This plan is necessary to improve the way waste is collected and to follow the rules set by the government.
The government has made rules for managing waste like separating it into three categories collecting it from people's homes and disposing of it safely. The Swachh Bharat Mission also requires cities to manage their waste. If Sambalpur does not improve its waste management it will not meet these requirements. The city needs to make some changes to the way it manages solid waste. Sambalpur needs to work on waste management to avoid problems. Solid waste management is an issue, for Sambalpur.

A. Aim and Objectives of the Study

This study is about creating a way to manage household waste in Sambalpur. We want to use data and technology to make it better. The main goal is to get the most out of the resources we have and make the whole process more efficient. The specific objectives are:

1) To assess the existing household solid waste generation quantity, composition, and spatial distribution across SMC wards.
2) To characterise and quantify the composition of household waste generated within the study area.
3) To evaluate the potential for resource recovery by comparing current practices against proven best practices from Indian and international contexts.

4) To propose an integrated and sustainable solid waste management strategy aligned with SWM Rules 2016 and SBM-U 2.0 for the case study area.

II. STUDY AREA

The Sambalpur Municipal Corporation is a city in western Odisha. It is the place for the Sambalpur district where all the important decisions are made. The city is near the Mahanadi River and the Hirakud Reservoir, which is one of the dams made of earth in the world. So it is very important to manage waste in Sambalpur Municipal Corporation not just for the city but also for the surrounding areas.

The city of Sambalpur Municipal Corporation is located at 21.47 degrees 83.97 degrees east. It is about 172 metres above the sea level.

The Sambalpur Municipal Corporation area is very big covering 303 square kilometres. This includes the Sambalpur city area, the Burla area, the Hirakud area and some villages around them. The Sambalpur Municipal Corporation is divided into 41 parts each with its own characteristics, such as business areas, old neighbourhoods, schools and areas that are becoming more urban.

In the year 2011 the population of Sambalpur Municipal Corporation was 3,35,761 people, living in 78,803 homes. By the year 2026 the population of Sambalpur Municipal Corporation is expected to be, around 4,51,891 people living in about homes. The economy of Sambalpur Municipal Corporation is driven by trade, education, small industries, healthcare and the handloom sector which supports people from all walks of life. They all generate waste in different ways.

Table I: Socio-Demographic and Spatial Profile of Sambalpur Municipal Corporation

Parameter	Value / Details
Administrative Status	Municipal Corporation (SMC), Odisha Municipal Corporation Act, 2003
Total Jurisdiction Area	303 sq. km (41 wards)
Population (Census 2011)	3,35,761 persons | 78,803 households
Projected Population (2026)	4,51,891 persons | 1,00,420 households
Number of Municipal Wards	41 Wards
Geographic Location	21.47°N, 83.97°E | Mahanadi River Basin
Nearby Urban Centres	Jharsuguda, Rourkela, Bargarh
Economic Base	Trade, Education, Healthcare, Small Industry, Handloom

III.LITERATURE REVIEW

A. Regulatory and Policy Framework

The rules for managing waste in cities across India are mainly based on the Solid Waste Management Rules, 2016. These rules replaced the Municipal Solid Wastes Rules from 2000.

The 2016 Rules made some changes.

- They required households to sort waste into three categories: things that rot easily things that can be recycled and things that are hazardous.
- They mandated collection of waste from door-to-door in all cities.
- They suggested building waste processing units.
- They aimed to stop dumping waste in spaces and instead use proper landfills.

A study by Sharma and Chandel in 2017 looked at how cities were following these new rules. They found that many cities struggled with not having resources or money to implement the changes. These findings are also relevant to Sambalpur.

The Swachh Bharat Mission for cities started in 2014. Its second phase, started in 2021 have given a lot of money to cities to improve their waste management.

This mission has a rating system that checks how well cities are doing in terms of

- collecting waste from door-, to-door
- sorting waste,
- processing waste,
- and managing landfills.

This rating system encourages cities to do.

B. Waste Generation and Characterisation in Indian Cities

Accurate waste characterisation is very important for choosing the technology and planning how much treatment is needed.
Kumar and Gaikwad in 2004 found out that in Indian Class-II cities,

- 40 to 60 percent of waste is biodegradable by weight
- 15 to 25 percent is recyclable.

The National Environmental Engineering Research Institute did a study in 2019.

- They looked at waste in 35 cities.
- They found that on average 53.1 percent of waste is organic.
- Our study found results for Sambalpur.
- We found that 55 percent of waste is biodegradable.

This means that biological treatment is the way to handle waste in Sambalpur.

Sharholy and others in 2008 said that

- source segregation does not work well
- many cities still use dump sites that are not managed properly.

Our survey in Sambalpur showed the problems.

- These issues are common in Tier-II cities, like Sambalpur.
- They need to be fixed to manage waste properly.

C. Smart Technologies and Spatial Tools in SWM

The use of technologies in managing waste in cities has become really popular over the last ten years. Some people named Pardini and others did a review of forty-three projects that used internet connected devices to manage waste in sixteen countries. They found that knowing when bin is full tracking the trucks that collect waste using GPS and having a central place to see all the information are the things that make the biggest difference.
Using maps to find the best routes for the waste trucks has been shown to reduce how fuel they use by eighteen to thirty four percent in some cities in India. This is according to some people named Vijay and others and also Soneji and Bhatt. In India the city of Indore has used data to make their waste management and this has reduced their costs by twenty seven percent. They did this by making schedules and routes that change when they need to which's something that the city of Sambalpur might be interested, in.

D. Decentralised Processing and Resource Recovery

Rathi did a study in 2007. This study looked at composting models in Maharashtra. It found that composting at the ward level or zone level is better. These small composting units can handle waste and cost less to set up.
The CPHEEO Manual on Solid Waste Management from 2016 says that aerobic windrow composting is a way to handle organic waste. This is especially true when than 50 percent of the waste is organic. Sambalpurs waste stream meets this condition.
For the waste that is left over making refuse-derived fuel is a way to get energy from it. This is an idea for Indian cities especially since there are cement industries, near them. These industries can use derived fuel as an alternative fuel, which is what Joshi and Ahmed said in 2016.

IV. RESEARCH METHODOLOGY

A. Research Design

The study employs a mixed-methods research approach, combining structured quantitative primary data collection with secondary data analysis and spatial mapping. It collects numbers and facts from people. Also looks at information that is already available. The study is done in four steps.:

1) Study area profiling and secondary data compilation;
2) Primary household survey across sampled wards;
3) Waste generation and infrastructure gap analysis; and
4) Ward-level spatial priority mapping for targeted intervention planning.

B. Primary Survey Design and Sampling

A questionnaire was given to people in 26 out of 41 areas in SMC. We did not give it to people in areas 2, 3 4 5 7 8 9 10 11 12 20 38 39 40 and 41. We did this so we do not ask the questions as other people who are also asking questions in these areas. We also wanted to ask questions in areas where people are not getting the help they need.

We made sure to ask questions in areas where SMC said people were not getting enough help. This way we can see how things are going in areas where it's the most difficult to provide services. SMC areas that are not getting help are very important, to us. We want to know what is going on in these SMC areas.

The questionnaire covered five thematic clusters:

1) Waste segregation practices and bin availability
2) Collection efficiency and service frequency
3) Vehicle infrastructure observation
4) Resident technology adoption willingness
5) Collection time preferences.

Responses were recorded at the household level and aggregated to the ward level for spatial analysis.

C. Secondary Data Sources

The secondary data that we looked at includes population projections for each ward in SMC from 2023 to 2026. We also got information about the number of vehicles and workers from the Solid Waste Management Department of SMC.

1) We found records about the infrastructure of Micro Composting Centres and Material Recovery Facilities.
2) The data on waste generation from 2021 to 2026 was also available.
3) The SMC has a system to find out what kind of waste is being generated. This is based on a 26-category waste characterisation framework.
4) This framework is compared to the SWM Rules 2016 and CPHEEO standards to see how well the SMC is doing in managing waste.

The secondary data includes all these things: SMC population projections, vehicle fleet and workforce inventories from SMCs Solid Waste Management Department, infrastructure records for Micro Composting Centres and Material Recovery Facilities, waste generation trend data and waste composition data, from the SMCs waste characterisation framework.

D. Gap Analysis and Spatial Priority Assessment

Infrastructure requirement calculations were done using CPHEEO benchmarks.

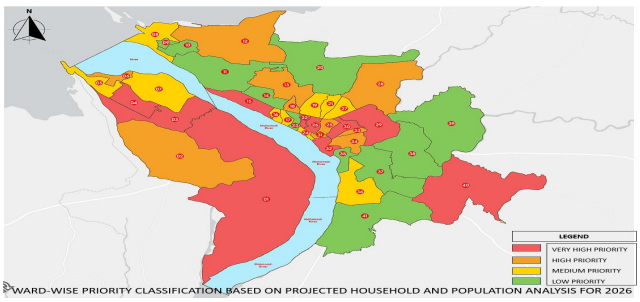
The benchmarks are as follows:

1) One door-to-door collection vehicle for every 2 tons of waste collected per day.
2) One door-to-door worker for 250 households.
3) One sweeper for 2.5 kilometres of road.

These benchmarks were applied to the 2026 household and population data. This helped to figure out the required workforce and vehicle fleet sizes. The required sizes were then compared to the existing ones to find gaps. The population and household data for each ward were mapped using QGIS. Shapefiles, from OUDA were used for this.

The maps classify wards into four priority tiers:

- High Priority
- High Priority
- Medium Priority
- Low Priority.



WARD-WISE PRIORITY CLASSIFICATION BASED ON PROJECTED HOUSEHOLD AND POPULATION ANALYSIS FOR 2026

E. Population and Household Growth Trends (2023–2026)

The city-level demographic analysis reveals a consistent upward trajectory in both population and household numbers across the study period, placing mounting pressure on SMC's waste collection and processing infrastructure. Table II presents the projected population and household data derived from SMC records.

Table II: Projected Population and Household Growth for SMC (2023–2026)

Year	Population	Households	Growth Rate (%)
2023	4,25,826	94,628	Base Year
2024	4,34,343	96,521	~2.0
2025	4,43,030	98,451	~2.0
2026 (Projected)	4,51,891	1,00,420	~2.0

The compound annual growth in households from 94,628 in 2023 to a projected 1,00,420 in 2026 represents an addition of 5,792 households within a three-year period. This incremental growth directly translates to increased daily waste generation and expanded demand for door-to-door collection services, underscoring the urgency of forward-looking infrastructure planning.

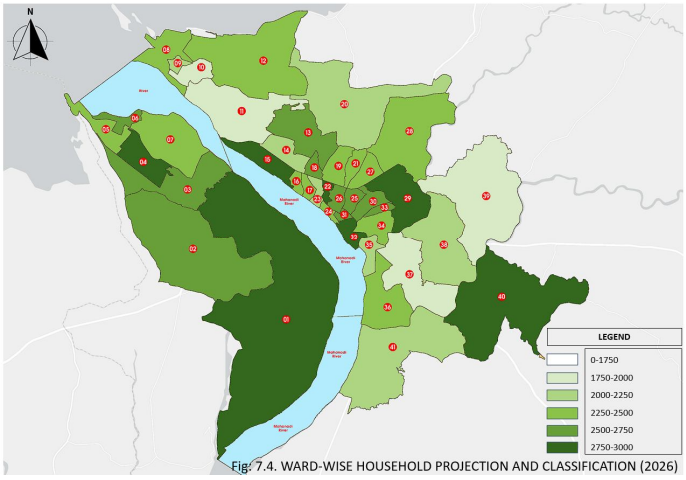


Fig: 7.4. WARD-WISE HOUSEHOLD PROJECTION AND CLASSIFICATION (2026)

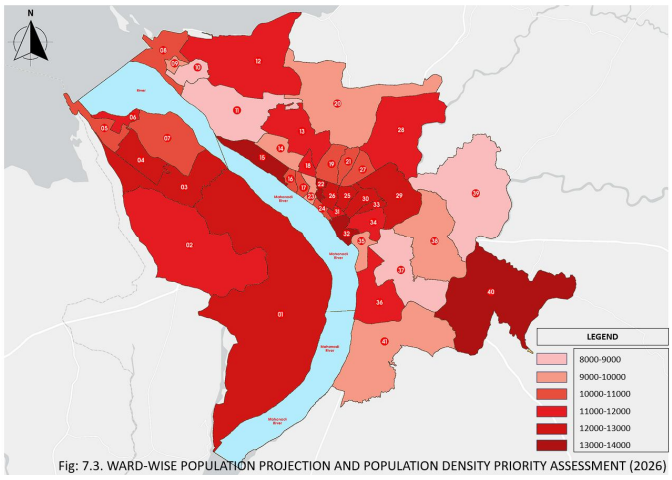


Fig: 7.3. WARD-WISE POPULATION PROJECTION AND POPULATION DENSITY PRIORITY ASSESSMENT (2026)

F. Current and Projected Waste Generation

The city gets a lot of solid waste. We are talking about 196 tons per day. This is like 0.58 kilograms of waste per person per day. If we look at how many people will be living in the city in 2026, which's 4,51,891 people we can guess that the total household waste will be around 262 tons per day. This is a problem because we do not have the ability to handle this much waste right now. We can only handle 196 tons per day. So, there is a shortfall of 66 tons per day.

The reason for this shortfall is that more and more people are living in the city. Also, the city is getting more crowded. We are getting better at collecting waste from all areas. If we look at the data from 2021 to 2026, we can see that the total waste generation is increasing fast. In 2021 we had 110 tons per day of waste. Now we have 196 tons per day. That is a 78 percent increase in five years. This is happening because people are consuming more things and we are getting better, at collecting waste.

Table III: Waste Generation Trend for SMC (2021–2026)

Year	Waste (TPD)	Per Capita (kg/person/day)
2021	110	~0.46
2022	120	~0.49
2023	130	~0.51
2024	150	~0.55
2025	170	~0.57
2026	196	0.58

G. Ward-wise Waste Generation (2026 Projection)

The amount of waste generated at the ward level was figured out by using the rate of 0.58 kilograms per person per day. The population data for each ward in 2026. This shows that there is a difference in the amount of waste generated in each ward. For example, Ward 10 generates around 4.88 tons per day while Wards 15 and 40 generate around 7.74 tons per day.

The top five wards that generate the waste are Wards 15, 40 32 22 and 1. These wards generate around 38.2 tons per day which's about 14.6 percent of the total waste generated in the city. This is significant because these wards only make up 12.2 percent of the total wards in the city. This shows that we need to have plans for collecting waste in each ward.

Some wards like Wards 10 37 and 11 do not generate much waste. They generate around 4.88, 5.02 and 5.11 tons, per day. This is because these wards have populations and are located on the outskirts of the city. Even though they do not generate much waste we still need to make sure they have the right equipment to collect waste so we can provide services to the entire city.

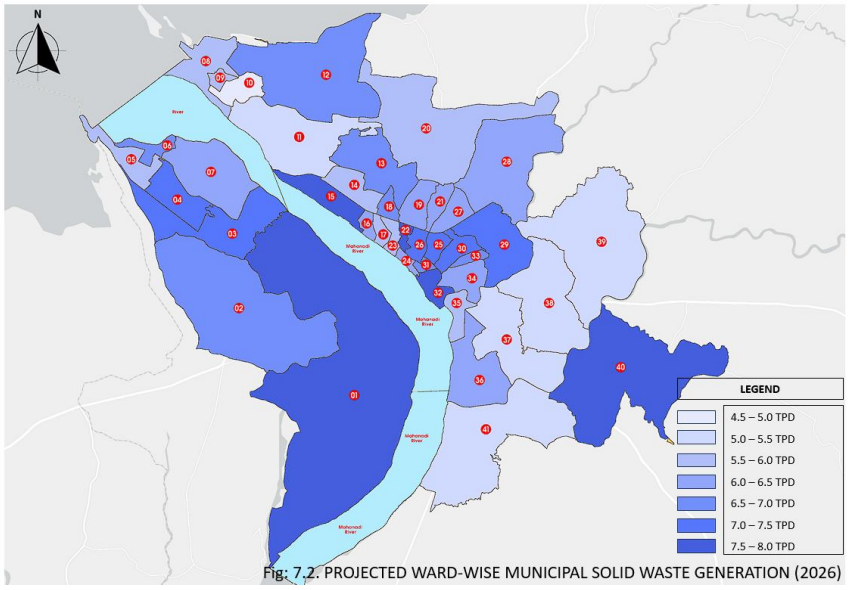


Fig: 7.2. PROJECTED WARD-WISE MUNICIPAL SOLID WASTE GENERATION (2026)

VI. WASTE COMPOSITION ANALYSIS

The waste characterisation framework applied in this study draws on a 26-category classification system derived from the SWM Rules 2016, CPHEEO operational standards, and SMC's own operational classification practices. The composition data for the 2026 period is presented in Table IV below.

Table IV: Waste Composition by Category – Sambalpur Municipal Corporation (2026)

Waste Category	Proportion (%)	Quantity (TPD)	Primary Treatment Route
Wet / Biodegradable Waste	55%	108	Micro Composting
Dry Recyclable Waste	20%	39	Material Recovery Facility
Low-Value Plastic / RDF Waste	5%	10	Refuse-Derived Fuel / Co-processing
Sanitary Waste	7%	14	Incinerator
Domestic Hazardous Waste	3%	6	Authorised Hazardous Recycler
Inert / Reject Waste	10%	19	Landfill
Total	100%	196	–

Wet biodegradable waste makes up a part of the total waste at 55 percent, which is 108 tons per day. This type of waste includes things like food waste, old vegetables and fruits garden cuttings and coconut shells. The fact that so much of the waste is organic is similar to what we see in Indian cities that are similar in size and economy. This means that the best way to deal with the waste in Sambalpur is to use methods like composting and anaerobic digestion.

Dry things that can be recycled make up 20 percent of the waste which's 39 tons per day. This includes things like paper, cardboard, plastic bottles, hard and soft plastics and glass. There are people in Sambalpur who collect waste informally which means they pick out the things before the formal waste collection system kicks in. So the amount of recyclables we see is what is left after these informal collectors have done their job.

Sanitary waste is a problem that is getting bigger it makes up 7 percent of the waste which is 14 tons per day. This type of waste includes things like diapers, sanitary pads and medical cotton. The problem is that we do not have a system in place to collect and treat this type of waste. Then there is hazardous waste, which makes up 3 percent of the total waste it includes things like batteries, paint containers and electronic waste. We need to make sure this type of waste is sent to the people who can recycle it like the companies that made the products in the first place.

The rest of the waste 10 percent is made up of things like dust, silt and ash. This type of waste needs to be put in a kind of landfill that is designed to handle it. Wet waste and dry recyclables and sanitary waste and domestic hazardous waste all need to be handled in different ways. Wet biodegradable waste and dry recyclables are the parts of the waste, in Sambalpur.

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VII. PRIMARY SURVEY FINDINGS

A. Waste Segregation Practices

The household survey results reveal a near-total breakdown of source segregation practice across surveyed wards. Table V summarises the key segregation-related indicators.

Table V: Household Waste Segregation and Bin Usage – Survey Results

Parameter	Yes (%)	No (%)	Operational Inference
Separate food from non-food waste	1%	99%	Source segregation virtually non-existent
Separate bins available at home	1.5%	98.5%	Critical infrastructure gap at household level
Use available bins properly	10%	90%	Behavioural resistance compounded by awareness gap
Find waste segregation difficult	99%	1%	Training and system design required urgently

The fact that ninety nine percent of people who answered the survey do not keep food waste and non-food waste separate is a problem. This is surprising because ninety nine percent of them also said that they have a time keeping these things separate. This shows that there are two reasons for this problem. First people do not have a way to separate their waste at home. Second people are not aware of how to do it. They need to change their behaviour.

One and a half percent of households has separate bins for different kinds of waste. This makes it very hard for people to follow the Solid Waste Management Rules from 2016. These rules say that people have to separate their waste into three categories.

These results are similar, to what other people have found out. For example, Sharholy and others found out the thing in 2008. This shows that Sambalpur needs a plan to separate waste from the source. This plan should include giving people the tools they need and also teaching them about the importance of separating waste.

B. Collection Efficiency and Service Delivery

Survey data on waste collection service performance shows a picture.

- The service covers a lot of areas. Does not work well all the time.
- Most people, 95% say they give their waste to the collector who comes to their door.
- This shows that most citizens are following the rules.
- Only 60% of people get their waste collected every day.
- The other 40% have to wait or have days when no collection happens.

Table VI summarises the collection service indicators.

Table VI: Collection Efficiency and Service Delivery Indicators

Parameter	Yes (%)	No (%)	Operational Inference
Daily waste collection	60%	40%	Service skipping; operational inconsistency
Waste handed to collector	95%	5%	High citizen compliance with collection
Vehicle has separate compartments	2%	98%	Mixed waste transport; defeats segregation efforts
Alarm / announcement system available	60%	40%	Partial coverage; fringe wards under-served

The high percentage of non-daily collection being 40% results from lack of workforce and improper routing strategy, but not an overall lack of intentions on the part of the organization to serve. Most devastating of all is the information that less than 2% of the collection trucks have segregated compartments for segregate waste: this means that any efforts made on the part of the source will be futile at the time of collection.

C. Technology Adoption Willingness and Collection Timing

Residents were highly ready for service improvements using digital innovations. The survey respondents showed a willingness to utilize a mobile application for reporting waste management information as well as filing grievances. It is therefore conclusive that the integration of the smart system via mobile technology into the overall integrated MSWM model was highly appropriate. Also, 80% of respondents showed a willingness to pay for a user charge for waste management services, hence the economic viability of introducing a user charge mechanism for cross subsidization of expenses.

In regards to the optimal time of waste collection, 67% of respondents expressed a preference for morning waste collection at 6:00AM – 8:00 AM, whereas 33% were keen on evening collection at 7:00PM - 8:00 PM. None of the respondents were interested in afternoons as an optimal time of waste collection.

D. Existing Vehicle Fleet and Gap Assessment

SMC's collection vehicle fleet consists of a total of 180 vehicles, which include 30 battery operated vehicles (BOVs), 120 light commercial vehicles (LCVs), 27 tractors, and 3 compactors. The total number of collection vehicles based on the CPHEEO recommendation of one primary collection vehicle for each 2 TPD of waste generation for 2026 projected waste generation of 262 TPD would be about 131. There is a moderate shortage of primary collection vehicles since there are 120 LCVs in service presently. However, the shortage of compactors is critical as there are only 3 compactors available against 10 needed.

Table VII: Vehicle Fleet – Existing Inventory, Requirement, and Gap (2026)

Vehicle Type	Existing	Required (2026)	Gap	Priority
Battery-Operated Vehicles (BOVs)	30	N/A	–	Supplementary
Light Commercial Vehicles (LCVs)	120	131	11	Moderate
Tractors	27	–	–	Adequate
Compactors (Secondary Transport)	3	10	7	SEVERE

E. Workforce Deployment and Gap

The total number of staff involved in SMC's SWM is 1,135 employees working in SWM collection, supervision, running health centres, and administration. The number of door-to-door (D2D) workers required based on CPHEEO standards of 1 worker per 250 houses, for the projected 1,00,420 household figure in 2026, is roughly 402 employees. There are only 150 D2D workers employed, making the shortage of 252 workers, which shows how critical the shortage is as indicated by the 40% non-daily collection rate found in the first survey.

The sweeping staff is higher at 416 staff members compared to the 432 staff estimated from a total road network length of 1,081.02 km at 1 sweeper per 2.5 km. However, optimally deploying sweepers based on specific routes is necessary.

Table VIII: Workforce Gap Analysis for Door-to-Door Collection and Road Sweeping (2026)

Workforce Component	Existing	Required	Gap	Severity
D2D Collectors (LCV Helpers)	150	402	252	Severe
Sweepers / Dust Collectors	416	432	16	Moderate
Ward Officers	41	41	0	Adequate
Swachha Sathis (Supervisors)	92	92	0	Adequate

F. Processing Infrastructure Gap

The findings from the infrastructure analysis point to serious deficiencies which will be made worse by increased amounts of waste being produced. There are currently 9 Micro Composting Centres (MCC) and 9 Material Recovery Facilities (MRF) in place in SMC. However, there are guidelines by the government that stipulate that there should be 22 MCCs in operation; based on projections, the number required would be 29 MCCs, leaving 20 more to be created – high priority – for the year 2026.

Table IX: Processing Infrastructure Gap Analysis

Facility Type	Existing	Requirement (Govt. Data)	Projected Need (2026)	Gap Level
Micro Composting Centres (MCCs)	9	22	29	HIGH
Material Recovery Facilities (MRFs)	9	9	12	CRITICAL

VIII. PROPOSED INTEGRATED MSWM FRAME WORK

A. Framework Principles

The suggested framework for integrated management system of MSWM at SMC includes the following four guiding principles:

1) Waste Hierarchy – giving preference to the principle of avoidance/reduction, reusing and recycling as compared to disposal of wastes;
2) Circular Economy – looking upon waste as a resource by producing compost from organic wastes, biogas/biomass, recycling of recyclable waste into resources, residual waste into energy;
3) Integration of Smart Technology – use of IoT technology for continuous monitoring, GIS route optimization technology, mobile applications for citizen participation;
4) Staged Implementation – implementation of interventions on priority wards.

B. Source Segregation Roll-out

A city-wide segregation program in three color-coded streams—Green (wet/biodegradable); Blue (dry recyclable); and Red (domestic hazardous and sanitary)—is proposed for all residential homes, businesses, and institutional bulk generators. The implementation is planned over a period of three years, starting with very high priority wards (year one), followed by high and medium priority wards (year two), and then covering all remaining fringe and low priority wards (year three).

The ward-level segregation program will be driven by an Information-Education-Communication (IEC) drive conducted by SHGs, school children, and RWAs using Odia-language material. The willingness of 80% respondents to pay user charges and 100% mobile app preparedness is an encouraging behavioural basis for this project.

C. Smart Collection System

In order to cater to these deficits, the recommended approach towards the implementation of the collection system includes incremental addition in terms of 11 more LCVs, 7 more compactors, and deployment of D2D collectors to account for 402 workers in total. All the vehicles involved would incorporate GPS units in their operations, along with the use of a GIS-based routing platform that would facilitate dynamic routing depending on the fill level data obtained through IoT devices.

The 67% to 33% split for mornings/afternoons reflects a dual shift system that will help increase involvement of residents and avoid road conflict issues. Six collections zones corresponding to ward cluster would be established for which dedicated vehicle fleets, zone-wise supervisors, and links to the SMC Central Command Centre would be arranged.

D. Processing Infrastructure Scale-up

In order to fill the gaps in the MCCs and MRFs, phased infrastructure development needs to take place. Priority MCCs would be developed in Very High Priority wards (Wards 1, 15, 22, 32, and 40) during Phase 1. The rollout of MCCs would continue in subsequent phases until all the wards get an MCC each. MCCs would sort the wet, organic waste that can be processed using aerobic composting, thus generating compost for urban and regional agricultural practices. The MRF expansion would allow for better sorting of recyclables under the Sambalpur Waste Workers Cooperative system.

E. Smart Monitoring Architecture

Three-tier architecture of smart monitoring system is proposed, which consists of three layers: the first one is known as perception layer that will include IoT level sensor, GPS device, and RFID bins; the second layer will be called network layer which will use 4G/NB-IoT technology; and third will be application layer which will provide users with the GIS command dashboard as well as a mobile app. This type of architecture can solve all smart infrastructure problems that have been listed in Table X, taking into consideration that all people are willing to use mobiles.

IX. RESULTS

A. Overall Gap Summary

The gap analysis done comprehensively highlights several gaps in the operation of the solid waste management process in Sambalpur, all of which pertain to all five operational dimensions. Source separation is practically non-existent (<1%), while collection involves only 60% of daily activity. Transport involves mixed waste transportation because less than 1% of transporters segregate their compartments for the different wastes collected. Processing is undersized, with 9 MCCs compared to the necessary 29, while monitoring is practically nil.

The overall gap analysis summary is presented in Table XII.

Table XII: Overall SWM Gap Analysis Summary

Dimension	Existing Condition	Required Condition	Gap Level	Urgency
Segregation	Minimal (<1%)	Universal (100%)	Critical	Immediate
Collection	60% daily	Optimised daily (100%)	High	Immediate
Transportation	Mixed waste	Segregated transport	Critical	Phased (1–3 yr)
Processing	9 MCCs, 9 MRFs	29 MCCs, 12 MRFs	Severe	Phased
Smart Monitoring	Partial/Absent	Full digital system	Severe	Year 1

B. Significance of the 66 TPD Waste Generation Gap

A shortfall in 66 TPD between the existing capacity of 196 TPD and the estimated total waste generated by 2026 at 262 TPD is expected, which is a rise by 33.7%. This shortage will have to be addressed through the development of more infrastructure. In the absence of pre-emptive investments in collection vehicles, processing facilities, and manpower, it will lead to increased dumping, late collection, degradation of the environment, and violation of the SWM Rules 2016.

C. Strategic Significance of Segregation Failure

The lack of source segregation in most cases (only 1% compliance from households) impacts all other areas within the waste management value chain. The presence of mixed waste affects the quality of composts, makes recyclables dirty, hinders MRF processes, and makes the process more dependent on landfills. Source segregation cannot be addressed only as a way to meet legal requirements since it is an imperative that needs to be fulfilled if further activities, such as composting and recycling, are expected to have economic sense.

X. CONCLUSION

This study looks at the solid waste generation in Sambalpur Municipal Corporation. It checks the composition of the waste how it is collected and what is missing in terms of infrastructure. The study then creates a plan to manage the waste in a way keeping in mind the specific needs of Sambalpur Municipal Corporation and the amount of waste it will generate by 2026.

Several things are clear from this study.

First Sambalpur Municipal Corporation generates a lot of solid waste about 196 tonnes per day. This is 0.58 kilograms of municipal solid waste per person per day. By 2026 this number is expected to increase to 262 tonnes per day which's a big jump. This means that Sambalpur Municipal Corporation needs to improve its infrastructure to handle the municipal solid waste.

Second most of the solid waste in Sambalpur Municipal Corporation is wet and can be broken down. This type of solid waste is about 55% of the total municipal solid waste generated. This means that Sambalpur Municipal Corporation should focus on composting and using biogas units to manage the solid waste. However, Sambalpur Municipal Corporation does not have enough of these facilities. It needs Micro Composting Centres to manage the municipal solid waste.

Third people in Sambalpur Municipal Corporation are not separating their solid waste. 99% Of households do not separate their municipal solid waste, which is a big problem. This is because they do not have the bins and they are not aware of the importance of separating municipal solid waste. Sambalpur Municipal Corporation needs to educate people about the importance of separating solid waste and provide them with the right bins.

Fourth Sambalpur Municipal Corporation does not have workers to collect the municipal solid waste from people's homes. This means that not all households get their municipal solid waste collected every day.

Fifth people in Sambalpur Municipal Corporation are willing to use their phones to help manage the municipal solid waste. They are also willing to pay for the services. This is a thing because it means that Sambalpur Municipal Corporation can use technology to manage the municipal solid waste in a better way.

The study identifies some areas in Sambalpur Municipal Corporation that need attention. These areas are Wards 1, 15, 22, 32, and 40. They generate a lot of solid waste and need better infrastructure to manage it.

The plan proposed in this study can help Sambalpur Municipal Corporation manage its solid waste in a better way. It suggests a step-by-step approach to separate solid waste use technology to collect it and build more facilities to process it. This plan can help Sambalpur Municipal Corporation follow the rules and regulations for managing solid waste.

This study is important because it provides a plan for managing municipal solid waste in Sambalpur Municipal Corporation. It can also be used as a model for cities in India that are facing similar problems, with municipal solid waste management.

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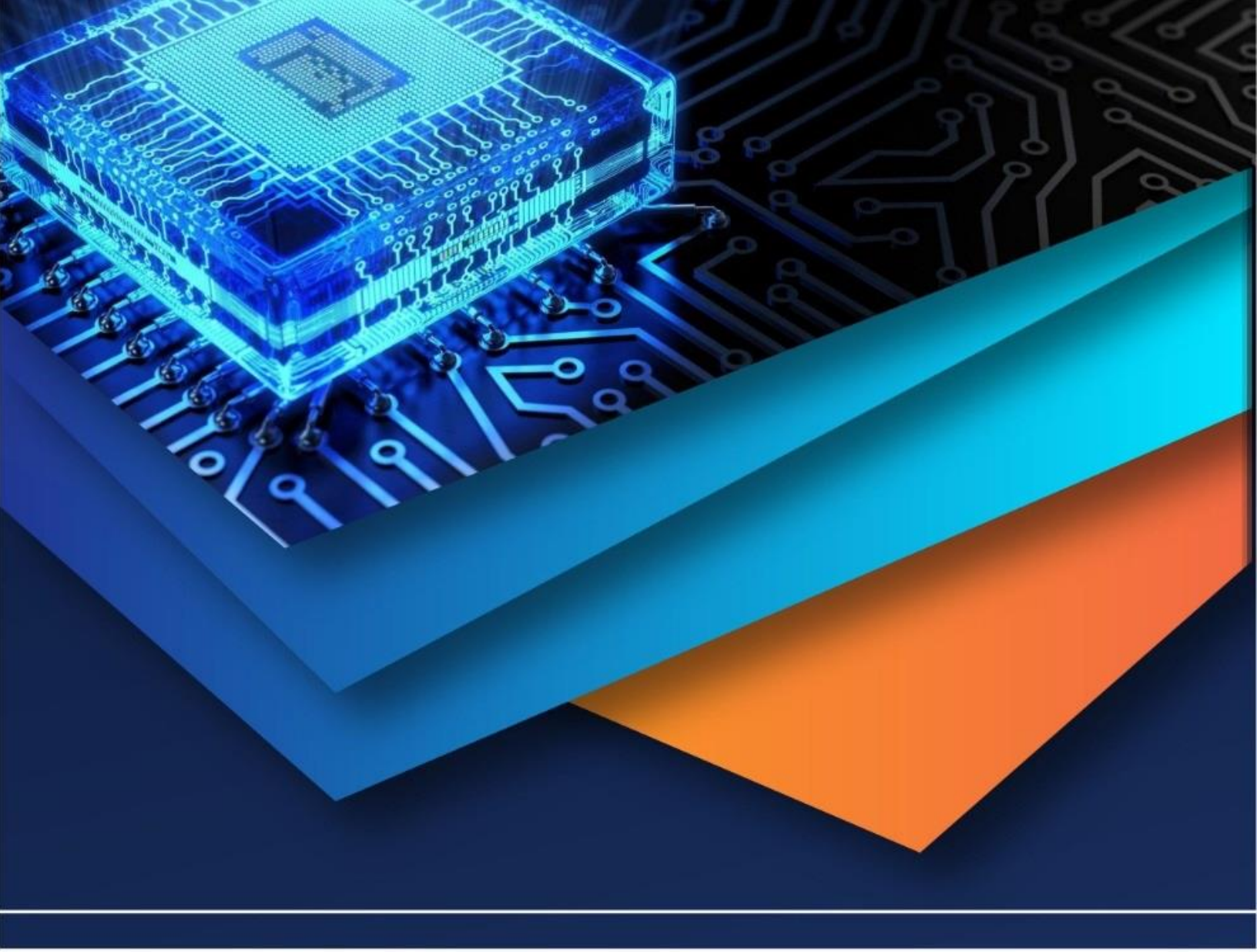

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