AN INTEGRATE SOLID WASTE MANAGEMENT PLAN (ISWM): MOHALI, PUNJAB

A

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of

Dr. RISHI RANA

Assistant Professor (Senior Grade)

by

ABHINAV CHOUDHARY (161652)

KARMA YANGZOM (161693)

to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT, SOLAN – 173234

HIMACHAL PRADESH, INDIA

June-2020

STUDENT'S DECLARATION

I hereby declare that the work presented in the Project report entitled **"AN INTEGRAED SOLID WASTE MANAGEMENT PLAN: MOHALI, PUNJAB"** submitted for fulfillment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Dr. Rishi Rana**. This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report.

Abhinav Choudhary

Abhinav Choudhary (161652)
Department of Civil Engineering
JUIT, Waknaghat
June, 2020

Karma Yangzom

Karma Yangzom (161693)
Department of Civil Engineering
JUIT, Waknaghat
June, 2020

CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"AN INTEGRATE SOLID WASTE MANAGEMENT PLAN (ISWM): MOHALI, PUNJAB"** in fulfillment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Abhinav Choudhary(161652)** and **Karma Yangzom(161693)** during a period from August, 2019 to June, 2020 under the supervision of **Dr. Rishi Rana** Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

Date: 1st June, 2020

Rishi Rana

Dr. Rishi Rana
Assistant Professor (Senior Grade)
Department of Civil Engineering
JUIT, Waknaghat

15/7/2020
HOD
CE DEPT

Dr. Ashok Kumar Gupta
Professor & Head of Department
Department of Civil Engineering
JUIT, Waknaghat

External Examiner

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Date: 1st June, 2020

Abhinav Choudhary (161652)

Karma Yangzom (161693)

ABSTRACT

The municipal solid waste (MSW) generation in Mohali has significantly increased due to increase in population. Until today there has been no proper waste management plan and this has given rise to major issues due of the threat imposed by MSW to the health of people, and the environment of the city. The major problems concerned with the mismanagement of the MSW are soil contamination, air pollution and water pollution. Hence to tackle this problem collection of waste from the source till it get disposed plays a major role hence to increase the collection efficiency an optimized waste collection route plan is necessary, therefore the optimized route for the collection of waste, and bin location plan is needed in Mohali city to increase the waste collection efficiency.

The objective of this study is to make Mohali, a tier-II city, a quintessence among the other tier-II cities in terms of its waste management system so we produced an effective bin location plan and the vehicle routing for Mohali city and the quantitative emission of methane gas from MSW using all available statistics, Geographic Information System (GIS), Remote Sensing (RS) and concept of Linear Programming. The capacity of the bin was determined using data like population, area, amount of waste generated from that particular place and bins were plotted using Google Earth (GE) considering the waste segregation into dry and wet fractions. And the bin plan for different areas that are residential area, industrial area, market and commercial area haves got different color coding and each location has got two bins each for dry and wet collection. This formulated strategy would help in overall cost reduction of solid waste collection system in Mohali city.

The MSW consist most of degradable solid waste which has produce greenhouse gas (GHG) under an aerobic or an anaerobic conditions and 50% of GHG generated is methane gas. The landfill is the main anthropogenic source of methane (CH_4) emission and actively contributing in global warming. The methane (CH_4) gas has greater ability than carbon dioxide (CO_2) in causing global warming and is becoming a threat to the ecosystem. Therefore, assessment for potential methane generation is necessary in consideration to stop the climate change which can ultimately stop the global warming. The Default Method (DM) of Intergovernmental Panel on Climate Change (IPCC) and Modified Triangular Method (MTM) are used in calculating the amount of methane gas emitted from the disposal site in the Mohali city. This study observed that the calculated quantity of methane gas generated from landfill is 25.89 Gg from IPCC default method and 1.620 from MTM in which the value calculated from IPCC DM is almost sixteen times that of calculated from MTM. Further the uncertainties of the two methods for methane assessment are also discussed in this study.

Keywords: Population, Municipal solid waste, Vehicle routing, Dumping point, Bin plan, Greenhouse gases, Methane emission.

CONTENTS

Chapter no.	Particulars	Page no.
	STUDENT’S DECLERATION	**ii**
	CERTIFICATE	**iii**
	ACKNOWLEDGEMENT	**iv**
	ABSTRACT	**V**
	LIST OF TABLES	**Xi**
	LIST OF FIGURES	**Xii**
	LIST OF ACRONYMS & ABBREVIATIONS	**Xiv**
1.	**Introduction**	**1**
	1.1 General	1
	1.2 Background	1
	1.3 World waste generation scenario	2
	1.4 Waste generation in India	2
	1.5 Municipal waste management system	4
	(a) Generation of waste	4
	(b) Collection and Storage	5
	(c) Transportation	6
	(d) Waste Treatment and Disposal	7

	1.6 Landfill Gas generation	8
	1.7 Need for the study	10
2.	**Literature review**	**12**
	2.1 General	12
	2.2 Review of Literature	12
	2.3 Summary of Literature review	15
	2.4 Objectives of the study	16
	2.5 Scope of study	16
3.	**Methodology**	**17**
	3.1 General	17
	3.2 Bin plan & Vehicle routing	**18**
	3.2.1 General	18
	3.2.2 Introduction	18
	3.2.3 Materials & methods	19
	(a) Description of study area – Mohali	19
	(b) Generation and characterization of waste	20
	(c) Collection and storage of MSW	21
	(d) Treatment and disposal of MSW	22
	3.2.4 Problems with existing MSWM practices in Mohali	23
	(a) Source segregation and treatment	23

(b) Collection 23

(c) Lack of financial and human resources 24

(d) Dumping site 24

3.2.5 Design and Planning of SWM system for Mohali 25

(a) Bin location plan and bin size 26

(b) Mythology used for planning bin locations 26

(c) Bin location plan 27

(d) Calculation of number of bins 28

3.2.6 Vehicle routing 29

(a) Assumptions and basic requirements for Vehicle routing 29

(b)Calculation of location served per trip to the collection point 30

(c)MSW collection from secondary collection point to dumping site 31

(d) Routes for collection of waste from collection points to dumping site 31

(e) Cost analysis 35

3.2.7 Manual Routing area wise 36

(a) Assumptions and basic requirements for hand-cart routing 39

(b)Calculations of time & distance for the selected areas 40

(c)Cost analysis for manual routing within different areas 46

3.2.8 Summary and discussion 48

	3.3 Assessment for potential methane generation from landfill site of municipal solid waste in Mohali city.	**49**
	3.3.1 General	49
	3.3.2 Introduction	49
	3.3.3 Materials and methods	50
	(a) Waste generation in Mohali city	50
	(b) Physical characterization of MSW in Mohali city	53
	(c) Methods for assessment of methane generation	54
	3.3.4 Results and discussion	57
	(a) Methane emission by default method	57
	(b)Methane emission by MTM	58
	3.3.5 Uncertainty incorporated in estimation of methane emission	61
4.	**Conclusions and Recommendations**	**63**
	4.1 General	63
	4.2 Conclusions drawn from two objectives	63
	4.3 Recommendations	64
	REFERENCES	

LIST OF TABLES

Table no.	Caption	Page no.
1.1	Typical Landfill Gas Components**.**	8
3.2.1	Sources of municipal solid waste in Mohali.	21
3.2.2	Number of bins required in specific area.	29
3.2.3	Time and distance of routes in Mohali city.	33
3.2.4	Cost analysis of collection of waste once in every third day.	36
3.2.5	Time & distance of routes for residential area.	41
3.2.6	Time & distance of routes for commercial area.	43
3.2.7	Time & distance of routes for institutional area.	45
3.2.8	Cost analysis for manual routing.	47
3.3.1	Calculation of per capita waste generation in Kg per day.	51
3.3.2	Amount of waste generation per year in Mohali from population and per capita waste generation.	52
3.3.3	Physical waste characterization of MSW in Mohali.	53
3.3.4	Methane emission in various years by Default method.	57
3.3.5	Methane emissions from MSW using Modified Triangular Method (MTM)	59
3.3.6	The uncertainty of empirical constants as documented by IPCC.	62

LIST OF FIGURES

Figure no.	Caption	Page no.
1.1	Functional elements of MSW system.	4
1.2	Composition of MSW in India.	5
1.3	Production phases of typical landfill gas.	9
1.4	Methane Emission by source.	10
3.1	Flow-chart showing methodology adopted for study.	17
3.2.1 (a)	Location of Punjab in India.	20
3.2.1 (b)	Location of Mohali city.	20
3.2.1 (c)	Mohali city.	20
3.2.1 (d)	Sector-wise map of Mohali.	20
3.2.2 (a)	Collection of waste from bin location	22
3.2.2 (b)	Stationary waste collection point.	22
3.2.3	Dumping site at Phase 8B, Mohali.	25
3.2.4	Step –wise flowchart for developing an ISWM plan for Mohali.	25
3.2.5	Bin Plan for Mohali city.	28
3.2.6	Route (R1), one time collection in every third day.	34
3.2.7	Route (R2).	35
3.2.8	Area layout of Phase (3B-1 & 3B-2).	37

3.2.9	Area layout of Phase 10.	38
3.2.10	Area layout of Sector 62.	39
3.2.11	Route R1 for residential area (Phase 3B-1& 3B-2).	42
3.2.12	Route R1 for commercial area (Phase 10).	44
3.2.13	Route R1 for institutional area (Sector 62).	46
3.3.1	Triangular form of gas production.	56
3.3.2	Methane emission profile.	58
3.3.3	Triangular form for gas production.	60
3.3.4	Emission profile of LFG.	61

LIST OF ACRONYMS & ABBREVIATIONS

C&D	Construction and Demolition Waste
CPCB	Central Pollution Control Board
DM	Default Method
GE	Google Earth
GHG	Green House Gas
GIS	Geographical Information System
GMADA	Greater Mohali Area Development Authority
GMI	Global Methane Imitation
HCS	Hauled Container System
IPCC	Intergovernmental Panel on Climate Change
ISWM	Integrated Solid Waste Management
IT	Information Technology
LFG	Landfill Gas
LP	Linear Programming
MSW	Municipal Solid Waste
MTM	Modified Triangular Method
MTPD	Metric Tons per Day
RCC	Reinforced Cement Concrete
RDF	Refuse Derived Fuel

RS	Remote Sensing
SCS	Stationary Container System
SWM	Solid Waste Management
TPD	Tons per Day
ULB	Urban Local Body

CHAPTER 1

INTRODUCTION

1.1 General:

This chapter consists of brief introduction to the waste generation scenario and the municipal solid waste management system in India and contribution of municipal solid waste to the greenhouse gases emission especially in methane generation. The generated MSW consist mostly of organic composition and the organic waste generates maximum landfill gas **[30].** About 3-19 % of world anthropogenic source of methane emission is MSW and that makes MSW as the major source of methane emission and global contributor to global warming **[14].** The 50% of landfill gas generated is methane gas and the amount of methane in the atmosphere increased 1-2 % per year **[14].**

1.2 Background:

One of the widespread realities of human presence is the age of waste. In ancient time, people were uncivilized, there were no developmental technologies, the resources and production at that time was self-sufficient and there was no excess amount to generate the waste that would cause negative impact on human health as well as on environment. Slowly people started to get more civilized introducing different methods of developmental activities, increased in population, and then urbanization and industrialization took place resulting in waste generation **[19, 21].**

Nowadays the word “solid waste” can be described as a non-fluid substance that can be produced from household, agricultural, commercial, industrial, public exercises **[36].**The composition of solid waste can be of different things like vegetables, papers, plastics, wood, glass, food waste, construction and demolition waste (C&D) waste, hazardous waste and the most important radioactive waste **[35]**. The improper management of such wastes leads to environmental problems. With the enhancing technologies many of these wastes can be reused and can be used as energy generation resources.

The MSW generally comprises of the waste generated by the domestic, commercial and institutional practices. MSW commonly refers to rejected materials generated from the daily activities the above mention areas. According to the Central Pollution Control Board the MSW is the leftover materials or garbage from houses including food waste, street sweeping and construction and demolition debris **[34]**. The MSW is categorized into three main categories –

i) Dry waste includes the waste consist of non-organic wastes like plastic, glass, tins, etc. ii) Wet waste which includes the organic waste generated basically form the house hold like food waste , garden trimmings, etc. iii) Inert waste like sand, dust, gravels, etc. which is usually collected from street sweeping **[38]**.

The major problem especially in the urban areas in most of the developing countries is associated with the adequate waste management as it is more efficient in the developed countries as the waste is managed either unscientifically or not attended properly **[36]**. To attain a better future it becomes important to understand the sources, composition, waste generation rates, collection, transportation and the disposal practices.

1.3 World waste generation scenario:

Around the globe, Waste generation rates are increasing quickly. MSW generation rates are influenced by the economic development, the level of industrialization, open propensities, and nearby atmosphere **[37]**. By and large, higher the financial turn of events and pace of urbanization, more prominent is the pace of waste delivered. Pay level and urbanization are exceptionally related and as expendable wages and expectations for everyday comforts expand, utilization of merchandise and enterprises correspondingly increments, as does the measure of waste produced. Urban occupants produce about twice as much waste as their rural partners **[16]**.

The world population in 2019 is about 7.7 billion and the majority of population is living in developing countries whereas, the global waste generation is 2.01 billion metric tons of MSWs are produced **[36].**

1.4 Waste generation in India:

India is getting covered under hills of trash since it is creating more than 1.50 lakh metric huge amounts of solid waste each day **[23]**. As there is an absence of appropriate sanitary landfill so around 55 lakh metric tons of solid waste is getting arranged in open territories consistently **[36].** The Central Pollution Control Board (CPCB) has sited that the maximum amount of the plastic waste are generated through metropolitan cities. While the Digital India is taking giant strides still there is no nationwide inventory of the e-waste generation [**34]**.

For an efficient solid waste management, there should be a proper relationship between waste generation, collection, storage, transportation and disposal. In India the municipal authorities are responsible for the collection of the waste till it gets disposed. But due to keep on dumping the waste openly it has become a problem as environmental and aesthetic point of view. The Central Pollution Control Board says that total MSW generation is 1, 27,486 TPD and the collection efficiency is only 70 percent that is 89,334 TPD and only 13 percent is processed which is 15,881 TPD of the total **[34]**. Due to lack of poor infrastructure and financial weakness plus weak laws and lack of awareness the MSW remains neglected **[16]**. In India the basic interrelation being followed is that the waste generation from the sources will be collected and will get stored in the storage hubs or secondary collection points from where they are taken to the dumping sites but only if the dumping site is less than 15 km range, if not then we have to provide a transverse station then it will be collected from the municipality vehicles and get disposed of weather in a secured landfill or can be an open dumping site. The functional element of MSW system is mentioned in the **Fig. 1.1**.

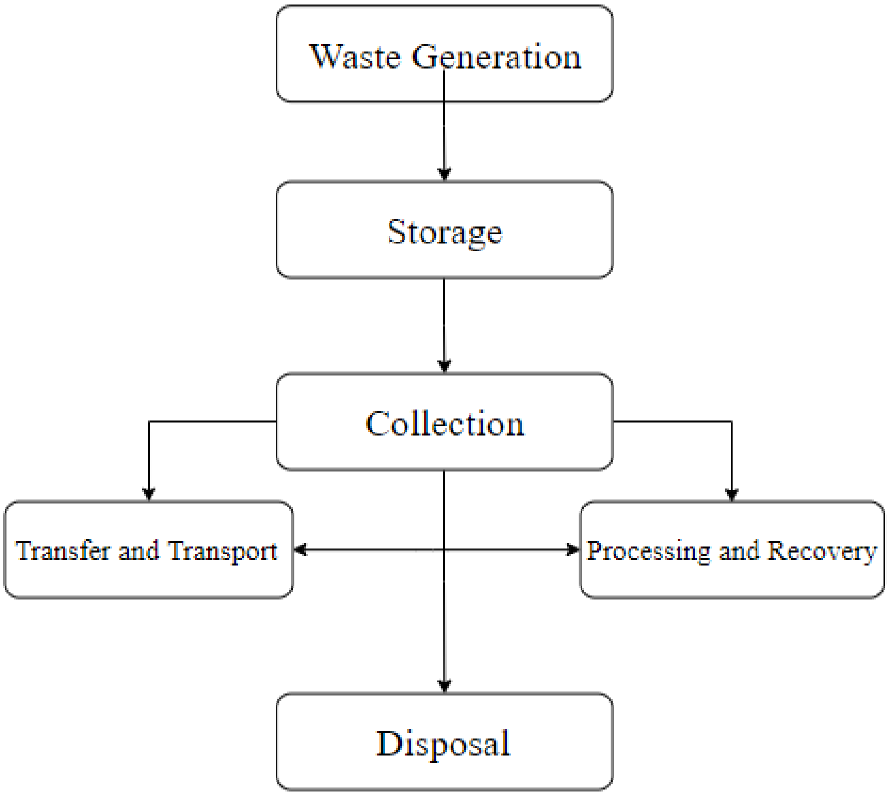


Figure 1.1 Functional elements of MSW system **[36].**

Over a previous year India has seen a high development in population; individuals have relocated to urban territory which is prompting a gigantic increment in the waste creation just as it is putting a weight on the current assets **[16]**. As per Census of India, 2011; the 31 percent of the all out population lives in the urban zones **[5]**. The information required for a compelling waste management plan incorporates the amount; composition and quality which is further rely on different factors, for example, occasional varieties, food propensities, age source, expectations for everyday comforts and the financial state of that specific spot **[19]**.

1.5 Municipal waste management system:

a) Generation of waste:

The age of solid waste is bearing corresponding to the number of inhabitants in that specific spot, the expectations for everyday comforts, pay of individuals, the travel industry, and so on. India is developing at a quicker rate as is the age of solid waste, as should be obvious a heap of piles of waste lying in the edges of urban areas and towns **[1]**. The significant interesting point is the waste organization, which can be extremely useful for making a proficient MSW the executives plan. **Figure 1.2** shows the average physical composition of MSW in India.

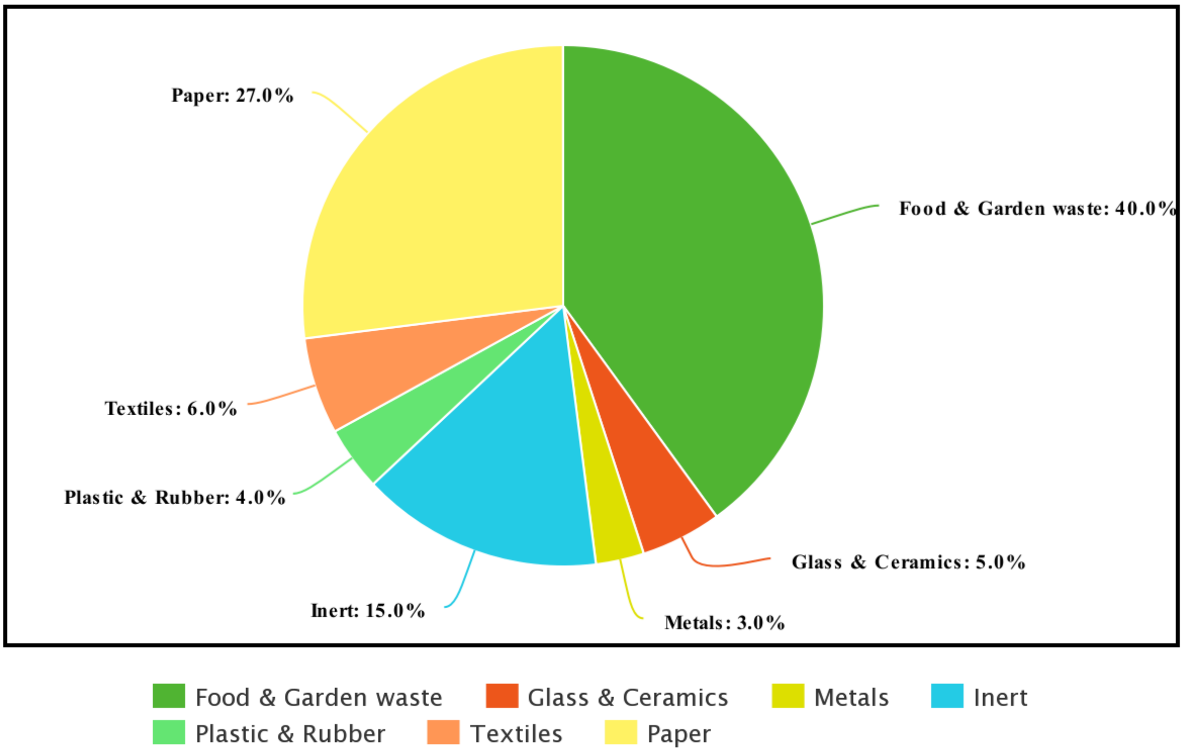


Figure 1.2 Composition of MSW in India **[36].**

As per the above mentioned figure the organic waste production in India most because of the rising population, the organic fraction contains food waste, wood, textiles, yard waste, plastics, papers, etc. The amount of organic waste produced by India is equivalent to the total waste production by some developed countries [**36]**.

b) Collection and Storage:

To make a MSW management system, the executives framework should be viable, the waste assortment proficiency ought to be high or can even be more than the waste generation rate. The solid waste collection is very important for maintain the public health of towns and cities **[39]**. The solid waste collection includes the pickup of the waste from its source of generation like residential, commercial and institutional to the disposal site. There are numerous methods developed for the collection of waste on the basis of their classification type and the mode of operation **[42]**.

On the basis of the mode of operations it is categorized into two – hauled container system (HCS) and stationary container system (SCS). The containers which can be easily hauled from one place to the disposal site and get it back to its place again are the hauled container, they are designed with the two cabinets for the purpose of waste segregation and a hauling mechanism is provided in it **[19]**. Whereas the container which are fixed at one spot in which the waste is collected and when the municipal vehicle comes to gets the waste, it is transferred from that container to the vehicle and then it went to empty it in the disposal point that type of bin are the stationary containers. There is always a benefit of hauled containers over the stationary with respect to time and one more major benefit is that the stationary containers lags in the waste segregation **[19, 43]**.

The major collection of the waste is done with the help of bins. In India, the types of bins used for the collection of waste are either made of plastic, steel, reinforced concrete, masonry, etc. The collection bins if not properly designed then it will lead to poor collection efficiency **[42]**.

c) Transportation:

If we see in context to the MSW the function of transportation refers to the facilities that are used to transfer the waste from one point to the disposal point. The vehicles that can be used are trailers, semi-trailers, tippers, dumpers, compactors, hand carts, tri-cycles, electric-carts, trucks and trolleys **[43]**. The factors which should be considered for the transportation of waste are the density of waste, cost, route followed and the capacity of the vehicle. Only 30 percent of the cities in India are having adequate transportation facilities. Most studies have said that the vehicles used in transportation of waste are either outdated or not having a proper design **[42]**. The effect of using an inadequate transportation will lead to increase in operation and maintenance costs, reduction in transportation efficiency, leads to noise and air pollution. To overcome this problem, proper maintenance of the vehicles is required. In some cities, the municipality gives transportation contracts to the private parties at a reasonable contract rate. The collection and transportation budget of the waste comprises about 80 to 90 percent of the total budget allocated for the solid waste management hence it leaves very less budget for the treatment of the waste **[36]**.

d) Waste Treatment and Disposal:

The most economical and feasible practice of waste disposal is land filling, which is being followed in most parts of the world. When we talk about land filling, it is basically of either a non-engineered landfill or it can be an engineered landfill **[19]**. The difference between both the type of landfills are that the engineered landfill are the secured landfills which doesn't allow the leachate to gets inside the soil, whereas in the open landfill there is no kind of safety provided hence the leachate can easily percolate inside the soil and contaminate the ground water **[19, 36].**

In India the MSW is generally dumped on non-engineered land fill sites or open landfills. Treatment process like segregation, recycling, composting and incarnation are used but still the most preferable way to dump waste is using a landfill **[42]**. The more waste disposed on the open grounds, more will be the pollutants gets mixed up into the soil and create environmental misbalance. The unmanaged dumping of solid waste will lead to environmental hazards like soil, air and ground water pollution will cause adverse effect on the public health **[39]**. Contamination of groundwater by the leachate generated in the unlined landfill sites is a predominant problem in the developing countries. Contamination from the groundwater by leachate is a serious environmental hazard as it can stay undetected for long duration **[36]**.

The major part in the disposed waste is organic which in future will get decomposed and generates the greenhouse gasses like methane, leading to global warming **[41]**. Also no single technology is sufficient to attain sustainable management of waste because of the diverse composition of the waste hence a combination of sanitary land filling, composting, recycling, and incineration and refuse derived fuel (RDF), etc. must be adopted to attain sustainable solid waste management **[42]**. But as we know that the major waste portion in India is organic containing food waste, wood, paper, etc. therefore, composting should be adopted like vermin-composting, aerobic and anaerobic composting and gasification, bio-methanation can be used to convert the waste into energy [**36]**.

1.6 Landfill Gas generation:

Solid waste deposited in the landfill generated the gases such methane, carbon dioxide, hydrogen sulfide, sulfide, nitrogen. Landfill gases are produce because of anaerobic deterioration of natural solid waste, for example, kitchen squander, garden squander, papers and so on. The MSW is the major anthropogenic source of emission of greenhouse gases and contributes 11% of global methane gas emission **[46].** Methane gas **(CH_4)** which is of 20% of green house (GHG) emitted from the landfill waste is contributing to the cause of global warming **[50].** A study conducted on landfill in Delhi **[46]** mentioned that methane generated from the MSW was 31.06 Giga grams per year in 1999 and it has doubled to 65.16Giga grams per year from 2000 to 2015.Municipal solid waste landfill gases are made of different constituents of gases as shown in **Table 1.1**.

Table 1.1 Typical Landfill Gas Components **[51]**

Components	Percent by Volume	Characteristics
Methane	45-60	Naturally occurring gas, colorless, odorless.
Carbon dioxide	40-60	Only 0.03% is found in the atmosphere, Colorless, odorless, slightly acidic in nature.
Nitrogen	2-5	Colorless, odorless, tasteless, about 79% is found in the atmosphere.
Oxygen	0.1-1	Odorless, tasteless, colorless, and approximately comprise 21 % in the atmosphere.
Ammonia	0.1-1	Colorless, pungent odor.
Non-methane organic compound	0.01-0.6	Are organic compounds, mostly found in landfills including hexane, toluene, vinyl chlorides, benzene etc.
Sulfides	0-1	Unpleasant odor (rotten egg smell).
Hydrogen	0-.2	Colorless and odorless gas.
Carbon monoxide	0-.2	Colorless and odorless gas.

The above mentioned table shows the landfill gases, their volume by percent and their characteristics, the most abundant landfill gases are methane and carbon dioxide.

Anaerobic decomposition of organic wastes and converted into the byproducts is as shown in the following equation **1.**

Equation 1

$$C_aH_b\,O_cN_d + H_2O \rightarrow nC_wH_xO_yN_z + CH_4 + CO_2 + H_2O + NH_3 + other\ gases$$

(Organic waste) **(Decomposed organic waste)**

Where, the expression ‘$C_aH_bO_cN_d$’ and ‘$nC_wH_xO_yN_z$’ indicate the composition of the substances present at the start and end of the decomposition processes.

The more measure of natural waste stored in the landfill site, the more landfill gas will be created during bacterial disintegration of squanders and there are a few factors that is influencing in landfill gases discharges, for example, temperature, moisture content, nearness of oxygen in landfill and so forth.

The landfill waste undergoes the four phases of bacterial decomposition as shown in **Fig.1.3** to produce the landfill gases. And the methane gas (CH_4) generation from different source is shown in **Fig1.4**.

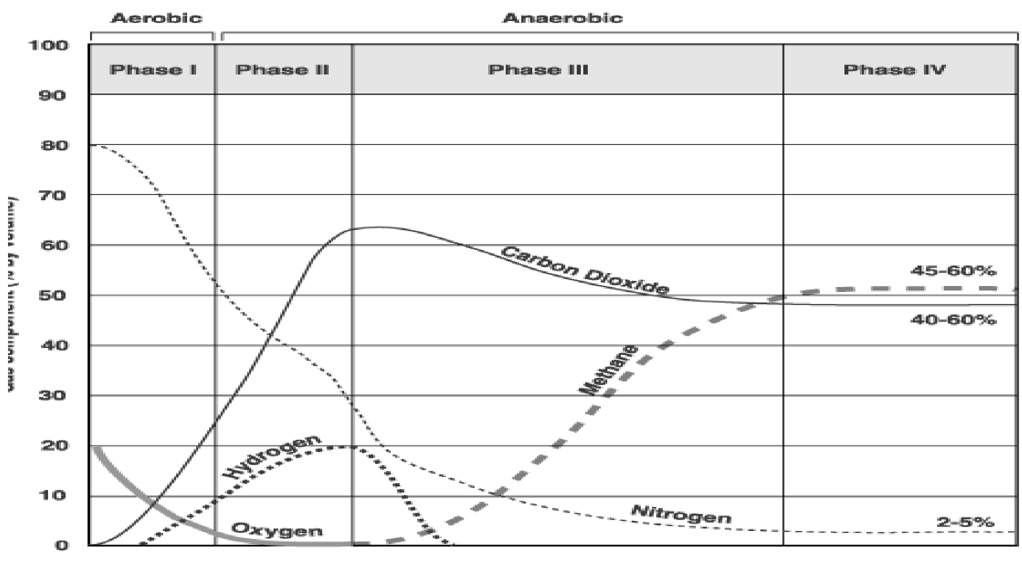


Figure1.3. Production phases of typical landfill gases **[41, 43].**

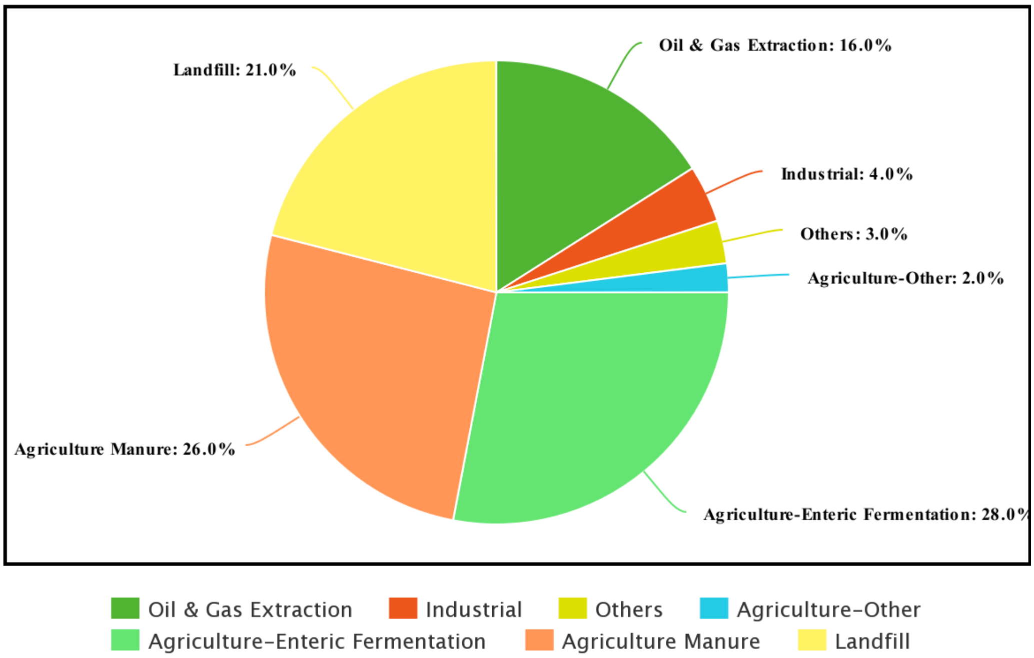


Figure 1.4 Methane Emission by source **[4].**

1.7 Need for the Study:

- Generation of MSW is increased instantly and the lack of proper waste management system has led cities to become a wasteland. Therefore, deficiencies associated with existing MSW management system need to be root out and have to adopt the effective solid waste management system to improve the efficiency of overall system.
- Optimization of collection routes will ensure to maximize the waste collection keeping minimum resource allocation. This will helps to lower the cost in terms of fuel & vehicle maintenance and improve service experience.
- The major anthropogenic source of methane generation are MSW or landfills which is having high potential of causing global warming, so it's should be evaluated and further used as a subsidiary fuel.

CHAPTER-2

LITERATURE REVIEW

2.1 General:

This chapter discusses the reviews related to literature both in terms of theoretical and experimental research on municipal solid waste and quantitative analysis of methane generation from landfill which was done by the great scholars.

2.2 Review of Literature:

The literature review helps in understanding about the waste generation, solid waste management problems and generation of harmful gas (methane) from the deposited waste and it also helps in framing the better MSW management plan for sustainable, healthy and eco-friendly city with a vision to move towards the cleaner city.

As population is increasing day by day, the world is attracting an excessive number of prodigies with scientific knowledge and experts in digital and leading the world towards the peak of development. Along with the developmental activities, the world is slowly turning into the state of wasteland.

In an investigation **[17]** directed it is referenced that from the World Bank Group, each year 2.01 billion tons of MSW is produced from overall contributing 5% to worldwide emanations and the examination additionally referenced that many creating nations like USA and Canada gives just 16% to the total population development yet contributes 34% to world waste generation. And a study [**17**] is also stated that the world is expected to generate 3.40 billons tonnes of waste by 2050**.** The world solid waste management cost is predicted to be increase from USD 205.4 billion to nearly 375.5 billion in the year 2050 in the World Bank Report **[18, 53].**

Similarly in India, MSW generation is increasing due to increased in population, urbanization, industrialization and more of commercial activities taking place **[41].** According to Central Pollution Control Board (CPCB), the MSW generated per day is 143449 tonnes in India during the period of 2014-2015 with an average waste generated was 0.11kg/capita/day**[49]** and approximately 150,000 tonnes of waste is generated per day in the year 2016-2017**[23]**, while 90 % of total waste is collected and 80% of collected waste is going to dumping sites and rest of the waste is taken to the treatment area.

The MSW generated every day is unloaded in our surrounding and piled up on our mother earth is a byproduct of human misbehave activities and the increased in solid waste production has become a burden to the existing MSW management system and needed a strategic plan for better SWM system in India **[43, 47, 52],** however it is a challenging task for the government because huge amount of waste generated is to be collected, transported, disposed in the dumping sites and some have to send it to the treatment area**[22]** and the average collection efficiency of MSW in India as per study**[12]** is ranges from 22% to 60%.And the study also mentioned that MSW in India is mainly comprises of organic wastes (51%), 17% recyclable wastes, hazardous wastes(11%) and inert wastes(21%). A large portion of the wastes are produced from local location, modern zone, business zone, market region, institutional region and road clearing **[21, 35].**

Solid waste is just a byproduct and it is useless and worthless but it has got intense strength to harm our mother earth and human being too. Insufficient capacity of bins and poor collection practices will lead to littering of wastes in the surroundings disturbing traffics activities, and hampering the aesthetic view of the places **[43]**. Irresponsibility of mankind is causing endangering the source and quality of our natural resources like water quality, air quality, and soil quality. The municipal solid waste generated the green house greenhouse gases (GHG) which are affecting the temperature and causing climate change and it is major factor contributing to global warming.

A study **[46]** shown that the municipal solid waste (organic waste) collected from the residential building is the third largest human-made source of methane (CH_4) emission contributing 11% to global methane emissions. The study **[46]** also discovered that the net emission of CH_4 from dumping sites in India is increased from 404 Giga grams in 1999-2000 to 990 Giga grams in2011 and 1084 Giga grams in 2015. The emissions of methane gas from the landfills are prime contributor of greenhouse gas emission to the atmosphere. In study **[48]**, the methane is considered as one of important GHG because it has got potential to cause global warming which is 28 times higher than the carbon dioxide (CO_2) in 100 years. Ambient air quality is affected by the landfill gas emissions **[45].**

In study **[9],** the Global Methane Initiative made estimation that the concentration of methane emission is presumed to be 8.59Giga tonnes CO_2 Equivalent (CO_2-eq) by 2020 and noted as 6.88 Giga tonnes CO_2 Equivalent in 2010. The researchers and scholars have adopted some methods to study and determine the concentrations of methane gas emitted from the dumping sites **[13, 29]**. In case of study **[26],** the first–order kinetic model was used to calculate the estimated methane generation and was compared with the modified triangular model. The study conducted in the past shown that methane gas emission will be controlled by covering the landfill with soils.

Beside the cause of air pollution, the landfills also cause land degradation and degrades water quality. Especially the organic solid waste deposited on the land contains an excessive amount of chemicals and nutrients that can disturb the natural soil nutrients and runoff over the landfill will wash away the chemicals and top soil making the land infertile **[45].** The landfill waste also contaminates the groundwater. Therefore proper slope must be considered while excavating the landfill site. And the appropriate slope is be considered is between 0% to 12% and greater than 12% slope is not considered as the steep slope will increase the runoff which will degraded the land and affect the life and quality of groundwater **[7].** A study **[43]** pronounced that the improper garbage disposal on the open land will generate the foul smell that will disturb the resident living near that landfill and also affect mood of travelers passing through that area. Moreover the heaped of garbage accumulation will leave bad impression and causes threat to the life of people and the surrounding environments.

Poor MSW management practices is due to absence of integrated plan for assortment, segregation, transportation, stockpiling, removal and treatment process and it is also due to lack of financial resources that resulted in providing insufficient number of collecting and transporting vehicles and equipments, number of sanitation workers are insufficient to works, no proper or secure disposal area and no treatment plants as mentioned in study **[43].**This huge amount of waste can be turn into electricity source if there is sufficient budget allocated for the purpose and if people are taking the responsibility.

It is responsibility for the Municipal Corporation to create the better future accounts to waste free cities and must adopt the effective MSW management plan for supportable and natural well disposed turn of events. Deficiencies in existing MSW management plan have been replaced by the new formulated strategic plan to enhance the waste management system. A study **[43]** conducted in Kharagpur District; West Bengal has formed an integrated MSW management plan for the Kharagpur area using techniques like Geographic Information System (GIS), Remote Sensing (RS) and Linear Programming. Using GIS and RS satellite image, features of places and information and data can be obtained. The significance of using GIS and remote sensing is that we can obtain the necessary data freely from the internet, simple and easy to use and operate, and it is easily available from the internet **[6, 49]**.

The several studies were conducted on the methods for estimating the methane emission and the validation of some methods was done in paper **[30].**The default method and modified triangular method are the mostly used method because they are applicable even when there is lack of detailed data and the information **[15,20,30].** The methane emission from the MSW is the one of the prime source of anthropogenic methane emission **[14]** and the study **[30]** mentioned that almost 60% of organic carbon is converted into landfill gas. As the world population increases, it is certain that their byproducts have also increases and will increase exponentially as the population increases by. Therefore, population forecasting is necessary in order to study the situations on methane emission and there are a few techniques to conjecture the population yet the geometric increased strategy gives the most exact worth **[8].**

Methane gas has got potential to cause global warming and its potential is almost 20 times more than that of the carbon dioxide and the methane concentration in the atmosphere is increasing in the range of 1-2 % per year **[15].** With rapid increase in population and waste production, the world is experiencing the major threat since few decades due to global warming which is mainly triggered by emission of greenhouse gas mostly consist of methane gas **[3].**

Solid Waste Management (SWM) is a core part of Human health and has the control of environment. The issues related to SWM are mostly arising in highly populated area. In study **[50],** the waste management plan is organized and formulated using GIS technique to increase the efficiency of waste management practices helps in reducing the work load and will save cost and time. From a study **[1]** it is mentioned that GIS and RS are supporting and assessing in formulating the strategic waste management plan. In study **[43]** GIS and remote sensing are use for obtaining data, mapping of study area, for bin size calculation and location of bin plan, size and location of landfill and transfer station and for manual vehicle routing. Route optimization was done using linear programming and optimized route is obtained on the basis of route length, time take by collecting vehicle and on the basis of cost-benefit analysis.

2.3 Summary of Literature Review:

From the literature review, it is affirmed that the gigantic measure of waste is created each year and the current waste management framework isn't reasonable for taking care of the immense amounts of waste being produced each year. Major sources from which the MSW are being generated are residential area, markets and commercial area, institutional area, and street sweeping. The solid wastes generated are kitchen wastes, plastics, papers, glass, clothes, inert wastes etc.

Most of the wastes generated are disposed in the landfill and only less amount of waste are being treated. MSW management is solely responsible for the local urban bodies and the local municipality. Low efficiency of management system is an indication of lacking a sense of responsibility and indicates the failure of concern authority and every individual.

Many study conducted mentioned that the improper management of MSW is due to lack of financial budget resulting in insufficient number of collecting and transporting vehicles, lack of sanitation workers and insufficient of protective equipments.

From the review of literature, Landfill is considered as one of the significant wellsprings of greenhouse gas outflow (GHG) that has potential to alter the climatic conditions resulting in global warming. Methane gas transmitted from the landfill is the most potential greenhouse gas having 28 times higher potential in causing an unnatural weather change than the carbon dioxide.

The literature reviews summarized that with increased in population and continuous developmental activities carried out, the amount of solid waste generated is also increases. So, for the better future, the municipal corporation authority must adopt the effective waste management system in the society.

Therefore, the present study of an Integrated Solid Waste Management plan for Mohali city using the techniques like Google Earth Pro, Remote Sensing and the concepts of linear programming has been carried out to root out the deficiencies present in existing municipal solid management system, to understand the occupational health risks of municipal waste workers and to provide better working facilities with sufficient protective equipments, to estimate the methane generation and to suggest the controlling measures and over all to increase the efficiency of MSW management system in Mohali city in Punjab.

2.4 Objectives of the Study:

The main objectives of the study include:

- To set up a bin plan within Mohali as per Swatch Bharat Mission (2014) using GIS and remote sensing technique.
- To do route optimization for waste disposal in Mohali using GIS and concept of linear programming technique.
- To evaluate the potential methane generation from landfill in Mohali.

2.5 Scope of Study:

- Generation of MSW is expanded in a split second and the absence of appropriate waste management framework has driven urban areas to turn into a no man's land.Therefore, deficiencies associated with existing MSW management system should be root out and need to embrace the effective solid waste management system to improve the effectiveness of overall system.

- Cost benefit analysis can be figured out for further comparison purposes.

- The landfill or solid wastes are the major anthropogenic source of methane generation which is having high potential of causing global warming.

CHAPTER 3

METHODOLOGY

3.1 General:

This chapter comprises of the objectives being taken up which include the “Bin Plan and Vehicle Routing” and “Assessment for Potential Methane Generation from the Landfill Site of Municipal Solid Waste”. The study of both the objectives was conducted for Mohali city, Punjab. Increased in MSW production has become a threat to the human life, natural environment and also one of the major source of greenhouse emission and the main anthropogenic source of methane emission which has caused global warming **[14]**. Therefore, investigation based on these two objectives was carried out by following the strategic work plans to analysis the situations and the results. The effective work plans of the two objectives are as design in **Fig. 3.1**

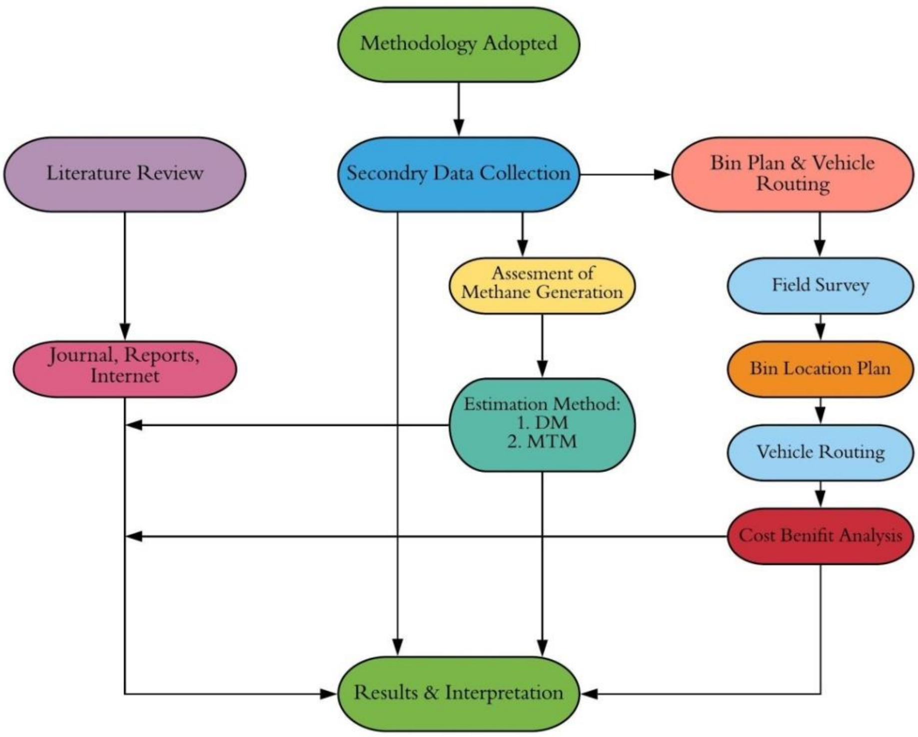


Fig. 3.1 Flow-chart showing methodology adopted for study.

3.2 Bin plan and vehicle routing:

3.2 .1 General:

MSW management plan in Mohali city includes the study of sources of solid waste, allocation of bins, and collection of solid wastes, vehicle routing and cost-benefit analysis. In this a whole setup is made in which the allocation of bins is done as per their categories, collection points are allotted according to the waste production and optimized routes are figured out which is summing up to a cost-benefit analysis.

3.2.2 Introduction:

With an increasing population in urban India, MSW management has become an obstacle to collection efficiency, sustainable development and journey towards the cleaner city because of the huge amount of MSW generated every day **[41]**. According to Central Pollution Control Board (CPBC), 143,449 tonnes per day of MSW was generated in India during 2014-2015, with an average waste of 0.11kg/capita/day**[49]** and approximately 148,694.7 tonnes per day in 2019. Increasing in solid waste generation in India has led to increase in solid waste management problems and the disposal of wastes strikes environment and has negative impact on human health. Therefore, the constructive MSW management system is critically needed **[43]**. The concept of an Integrated Solid Waste Management (ISWM) as a holistic approach is included in Swachh Bharat Mission 2016 and it is a mandatory service in any society to create sustainable and environmental friendly growth to make a city cleaner and aesthetic one. The urban local body (ULB) such as municipality is responsible for better solid waste management system including equipments required, financial aids, vehicles, collection of MSW and the disposal of waste to the safe landfill area **[43]**. Existing MSW management practices will be replaced by an integrated solid waste management (ISWM) plan in order to fulfill the vision of Swachh Bharat Mission 2016.

In Mohali, due to developmental activities such as housing scheme and other construction activities in IT city which was introduced by GMADA (Greater Mohali Area Development Authority) has led to increase in waste generation. It is difficult for the current waste management system in Mohali to handle the large amount of waste and it has become an issue. The major aim of the study is to assess the inefficient waste management practices existing in Mohali and to introduce an integrated solid waste management strategy using a techniques like geographic information system (GIS), remote sensing (RS) and linear programming.

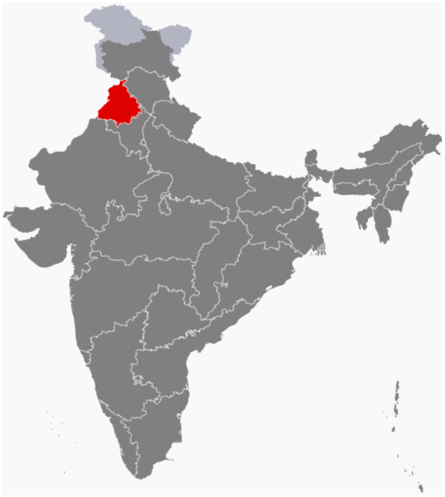
Superiority of using RS and GIS is that they can provide accurate data, inexpensive, easy and simple to use, can explore the world and study the features of places using these techniques without personally visits to the particular places [**1, 6, 43, 49].**

3.2.3 Materials and method

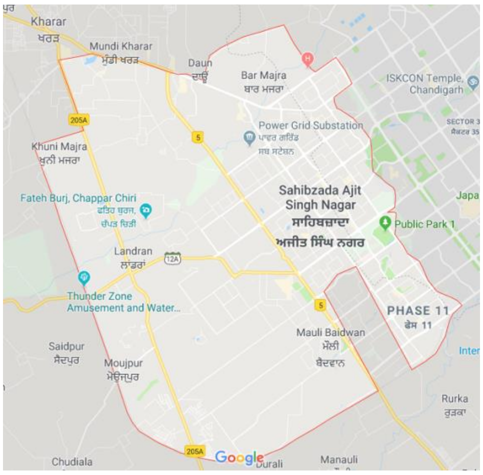
a) Description of study area- Mohali:

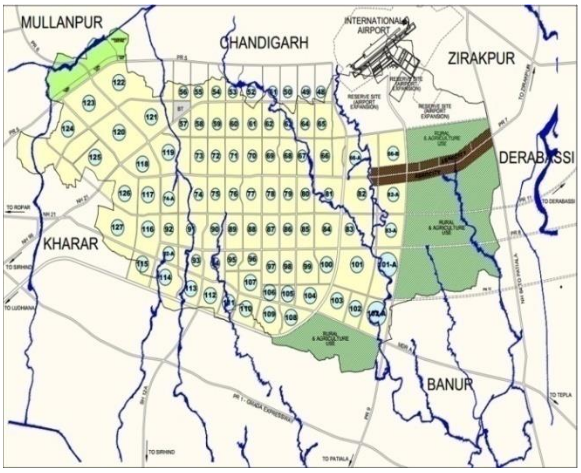
Mohali, formally known as Sahibzada Ajit Singh Nagar is a city in Mohali region in Punjab, India, which is an IT center of the state lying south-west of the capital city of Chandigarh. It was established in 1^{st} November 1996 and prior a piece of the Rupnagar District and was cut out as a different Mohali locale in April 2006. Mohali is located at coordinates: 30.78°N 76.69°E and has an elevation of 313m(1037ft) above mean sea level covering a total area of 1098km^2 having total population of 176,170 (as per population census 2011) and has estimated population of 334,206 in 2019.

Mohali city comprises of eleven phases, fourteen sectors and four villages where each phases and sectors consist of residential buildings, institutional buildings, commercial buildings, and parks and are connected by the roads. There is also a railway station in phase 9 and one municipal corporation in sector 68 of Mohali. The brief location of Mohali city is given below in the **Fig. 3.2.1.**



(a) (b)





(c) (d)

Figure 3.2.1(a) Location of Punjab in India (b) Location of Mohali city (c) Mohali city

(d) Sector-wise map of Mohali

b) Generation and characterization of waste:

In Mohali, MSW is generated from various areas such as residential area including parks, commercial/markets area, institutional area and street sweeping. From the recent studies**,** the total municipal waste generated in Mohali is 150 tonnes per day (0.267 Kg/capita/day) and the amount of waste generated from different sources is given in **Table 3.2.1 [3]**.The residential area contributed the maximum amount of solid waste to the total MSW generation and there is also a considerable amount of inert waste.

Table 3.2.1 Sources of municipal solid waste in Mohali **[35]**

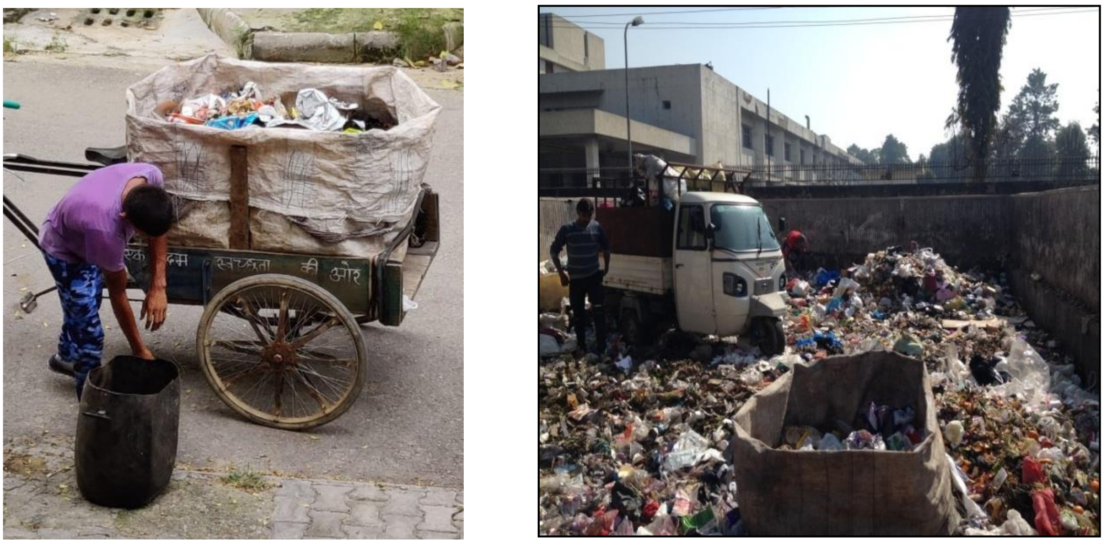
Sources of waste	**Mohali (%)**
Household waste	35.6
Street sweeping	22.0
Institutional waste	15.0
Market and commercial waste	27.4

The factors contributing towards the municipal solid wastes generations are the rapid increase in population, industrialization, civilization, continuous developmental activities, and westernization of people's lifestyles. Many cities in India have got an issue of solid waste management practices (Ministry of environment, Forests and climate change, Government of India, 2016).

Since there is no recent data on composition of MSW in Mohali city documented by CPCB, the value from the 2013 is used in this study. The MSW generated from Mohali included organic matter (55%), plastics and polythene (8.6%), papers (7.1%), clothes (4.6%), glass (1.22%), leather waste (.99%) and inert waste (22.49%) and waste has got high moisture content (50%)[**3].**The density of waste for Mohali is estimated to be 330 kg/m^3 from the literature (Personal communication with employee of Mohali Municipal Corporation, 2015, **[35].**

c) Collection and storage of MSW:

Management of MSW including collection, storage, segregation, transportation and disposal is the responsibility of Municipal Corporation of Mohali. At present the waste is being collected in the residential area by the door to door collection system from household to the collection points nearby, where as in some areas people dispose the waste themselves in nearby community bins. The existing bins are of stationary type and the municipal corporation vehicle collects the waste from the bins on daily basis. There are a total of 17 vehicles in the region comprising of trucks (10 nos.), mini pickups (4 nos.) and tractor-trolleys (3 nos.). For collection of waste a workforce of 2-3 men are diploid per municipal corporation vehicle. The waste collected from the collection points and the stationary bins is taken to the dumping site which is an open dumping point situated in Industrial area Phase-8B. The collection of waste from the source and the point where the waste is collected is shown in **Fig. 3.2.2**.



(a) (b)

Figure 3.2.2 (a) Collection of waste from bin location (b) Stationary waste collection point **[36]**

d) Treatment and Disposal of MSW:

There is only one existing dumping site in Mohali. The municipal waste is dumped on the open land in Industrial area Phase-8B on regular basis by the Municipal Corporation of Mohali. There is lack of waste treatment system or secured landfill for disposal.

The existing dumping site is within the radius of 20 km from the nearest airport that is Chandigarh International Airport and as per Indian regulations, the location of and dumping site should be at least 20 km away from the runway **[49]**.

3.2.4 Problems with existing MSWM practices in Mohali:

a) Source segregation and treatment:

Generally waste should be segregated into two fractions as per Solid Waste Management Rule, 2016**:**

- Wet waste like food, fruits, vegetables and yard waste, and
- Dry waste like papers, glass, wood, metals, cans, clothes and plastics.

In Mohali city, deficiency of present MSWM practices is that, the door to door waste collectors are yet to adopt segregated garbage collection process and some residents did give it a try in segregating of waste but the purpose was defeated when collectors mixed them again while dumping it. There is no separate compartment provided for segregated waste neither in the waste collecting vehicles nor in the collection point. The waste collected by municipality is unsegregated and is carelessly dumped on open landfill area without any treatment. The treatment of waste became very difficult and expensive due to absence of proper waste segregation practices. The careless dumping of waste on open ground has causes negative impact to environment and neighboring residents.

b) Collection:

The overall waste collection efficiency of existing MSW management in Mohali is approximately 70% **[35]** and the main reason is due to lack of proper trained manpower, inadequate number of bins, insufficient bin capacity which leads to overflow of waste, absence of segregation practices, and number of vehicles are not enough to collect the waste in the city. Some bins are located far from houses and shops, and the people are not willing to take those wastes to bins located at a long distance. Most of the secondary collection points where sector and phase level waste is collected are nothing but the open field with no proper boundary or other facilities. Due to all these reasons, illegal dumping of waste is common in some areas. The open field covered with waste is the main source of food for the stray cattle, dogs and other animals causing threat to the safety of residents and dirtied the environment.

c) Lack of financial and human resources:

The budget stated for the financial year 2013-2014 in Mohali Municipal Corporation was INR.6.5 crore (US$ 1 million) and it was not enough to introduced the proper waste collection system in the city**[35]**. Due to insufficient budget allocation, number and capacity of vehicles and bins, and the trained sanitation workers are inadequate to collect the waste generated in the city. Overall efficiency of current MSWM system is very low due to poor working conditions without proper safety measures for sanitation workers, Failed to maintained and replaced the damage or worn-out parts of vehicles increasing maintenance cost and reduced working efficiency, and collection and transfer efficiency is also low due to lack of organized system. All the disorganized practice, insufficient gadgets and poor working conditions in Mohali municipality are due to lack financial sources **[35].**

d) Dumping sites:

The MSW generated every day is unloaded in our surrounding and piled up on our mother earth is a byproduct of human development or advancement in the lifestyles and increased in waste generation every day is an indication of ineffective resources uses and making the products or materials less valuable or worthless**[6].**

At present, the waste generated in Mohali is dumped at the 8 acres open dumping land in the industrial area, Phase 8B as shown in **Fig. 3.2.3**. This dumping site lacks sanitations and is responsible for causing safety related issues and foul smell-related problems in the nearby cities.

This dumping site is located at a distance of 16km away from the Chandigarh Airport along the NH5 (National Highway) route. However, as per the Indian regulation, dumping site should be at least 20 km away from the runway to avoid any problems associated with the waste.

Figure 3.2.3 Dumping site at Phase 8B, Mohali **[36]**

3.2.5 Design and Planning of SWM system for Mohali:

With the help of Remote Sensing, Geographical Information System (GIS) and Linear Programming an integrated MSWM plan is being developed for Mohali shown in **Fig. 3.2.4**.

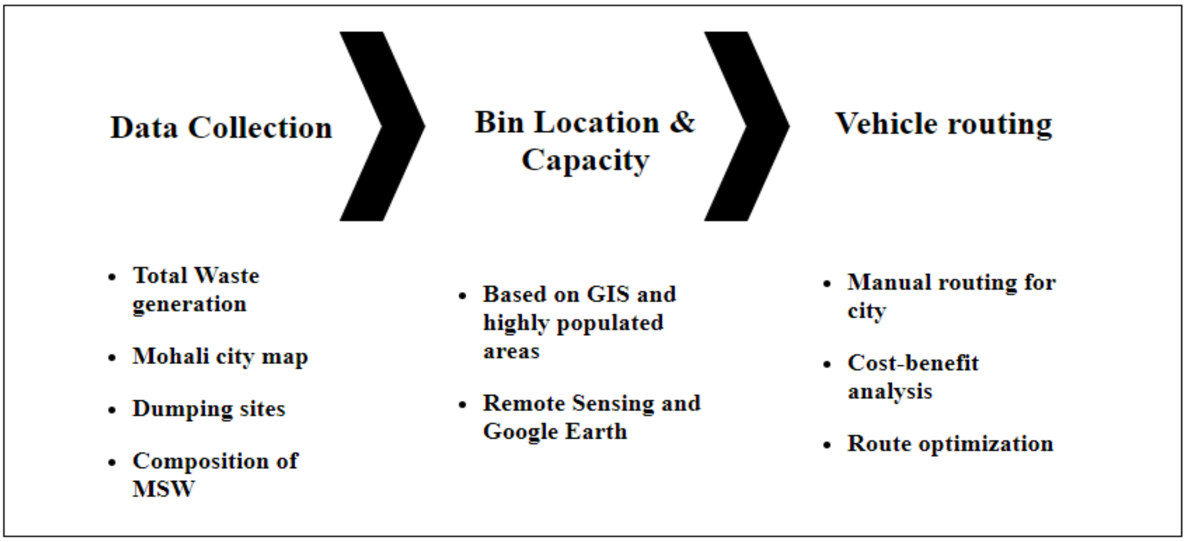


Figure 3.2.4 Step –wise flowchart for developing an ISWM plan for Mohali.

- In the first step we collected all the relevant data in terms of daily waste production, population density, existing system of waste collection etc., to prepare an ISWM. In this we included a prepared digitized map of the city with all the phases, sectors and villages properly distinguished from each other. We have obtained data regarding to the Mohali by doing surveys and some data is being taken from the literature. The location of the dumping site is plotted in the satellite map and verified in the survey.

The data was taken regarding number of vehicles; waste production and collection efficiency were obtained from Municipal Corporation Mohali which is situated in sector 62.

- In the second step we categorized the waste into two components; dry and wet. Bin size was assumed as per daily waste generation then number of bins that have to be plotted is calculated. Collection points were provided as it would be tough to collect waste from every single bin.
- In third step we selected optimized routes which are generally the shortest routes for the transportation of waste from collection point to the dumping site, and further we calculated the number of vehicles that are required to make this system works efficiently. In the last a cost-benefit analysis is also done for further comparison purposes.

For developing the integrated solid waste management plan in Mohali, Google Earth Pro software is used. The Google Earth Pro is software that can be used in planning, mapping and analysis. It can be accessed freely through internet and it is simple and easy to use. It gives an information and data with high resolution image, and we can study the particular area without going there in person. It helps in time management.

a) Bin location plan and bin size:

A proper bin location plan is required to overcome problems like illegal dumping along roadside and near houses, overflowing bins and to improve efficiency of the collection system, adequate number of bins of proper size that is 240L is taken and plotted across the city. As the bin size and number of bins are inversely proportional to each other so to obtain an adequate number of bins we have to consider a bin size which can be easily available in the market hence this 240L bin size is taken.

b) Methodology used for planning bin locations:

Bin locations were determined using data from the literature and the assumptions which are taken are noted here:

- For segregation of waste in the source itself, two bins of equal size are provided at each bin location. Both bins are placed together and count as a single bin. One is “Dry

Waste” for the storage of dry waste like plastic, paper, glass and clothes, etc, and the second is “Wet Waste” for the storage of wet waste like kitchen waste, etc.

- The bin size is taken same throughout the city, providing different numbers of bins for the residential areas consisting the societies, residential buildings, etc, the commercial areas which consists the market places, vegetable mandis, meat markets and slaughter houses, hotels and restaurants, marriage halls and crowded bus stops, the institutional areas like schools, colleges and workplaces, etc.
- According to Indian government guidelines, a bin should be provided every (100 - 125) m along roadside (Swachh Bharat Mission 2016).
- The per capita waste generation rate is taken as 267 g/capita-day. **[35]**
- The number of people per household is 5, based on Census of India, 2011.

Daily collection of solid waste from the bins to the nearby collection points is provided due to high moisture content of solid waste since the majority waste is organic in nature and extremely hot climate of Mohali.

c) Bin location plan:

Bin location plans for Mohali city are shown in **Fig. 3.2.5**. Each pin/node represents a bin location and consists of two bins: ‘Dry waste’ and ‘Wet waste’. Green color pin/node represents the bins for residential areas. Yellow nodes represent for the bins in commercial areas and the blue nodes are for the institutional areas. Bin size is taken same for the entire city since the selected bin size would be easily available and cost effective. The ‘wet waste’ bin will be green in color whereas the ‘dry waste’ will be blue following the guidelines of Swachh Bharat Mission 2016.

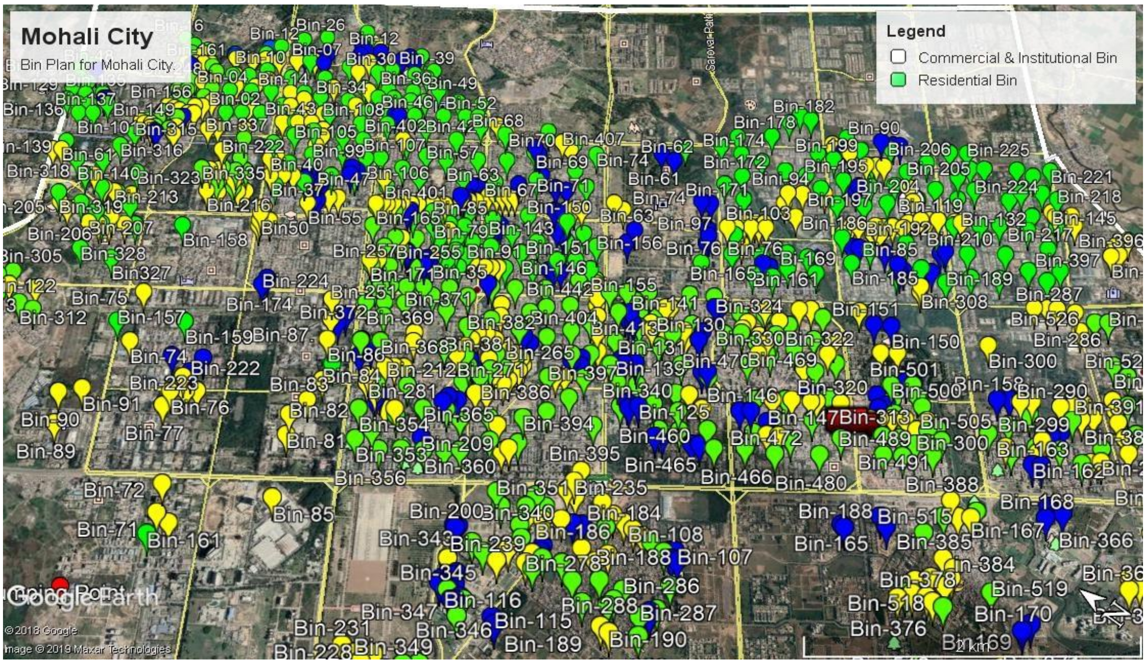


Figure 3.2.5 Bin Plan for Mohali city.

d) Calculation of number of bins:

The amount of waste generated in Mohali is 150 tons per day from the study **[35]** and for the design purpose, generated waste of 117.1296 tons per day is considered by ignoring the waste from street sweeping (inert waste).

Using generalized bin size of 240L=0.24m^3.

To covert m^3 to ton, the factor of 0.21 is considered for the mixed waste as per Environmental Agency Standard.

Each bin will have a capacity to store a mixed waste of .21*.24=.0504 tons

Total number of bin required =117.1296/.0505

=2324 bins.

The total number of bins is then calculated according to the waste production sectors which are shown in the **Table 3.2.2**.

Table 3.2.2 Number of bins required in specific area

Area	Waste generated per day (tons)	Number of bins required
For Residential area	54.4	54.4/0.0504=1060
For Institutional area	22.5	22.5/0.0504=447
For Market and Commercial area	41.1	41.1/0.0504=816

Number of bin for residential area, market/commercial area, and institutional area is calculated by considering the amount of waste generated from the sources. And for the different phases, sectors and villages; the number of bin is given as per the population density. Densely populated area, highly commercial area, and covered by more institutional area is fixed with more number of bins and slightly less for others.

3.2.6 Vehicle Routing:

Approximately 80-90% of the total budget of MSW management in India is absorbed in waste collection and transportation while the collection efficiencies were remaining low. But in some high income countries, collection efficiency is more than 90% by keeping the collection budget less than 10% of the total SWM budget **[43]**. Where as in Mohali, nearly 80% of total SWM budget is kept for the salary of sweepers and rag pickers and only about 7-8% is allocated for the collection purposes and the collection efficiency is about 60-70% **[35]**.Therefore, an integrated solid waste management plan including route optimization and bin location plan is necessary in cities and the developing countries like India.

a) Assumptions and basic requirements for vehicle routing:

- Assumed number of crew: a driver and three collectors.
- Collection route starts from garage (at municipality office, phase 9) to secondary collection point and after collection goes to dumping site. All the following routes on the same day begin from collection point to dumping site and back to collection point. After the collection works is done, the collection vehicles return to the garage from the dumping site.
- Average velocity of truck on road is assumed as 25km/h**.**

- Sizes of trucks provided are assumed to be 19m^3.
- Two compartments are provided in the truck with the proportion of 70:30 for residential area assuming 70% of wet waste and 30% of dry waste.
- Truck used for commercial and institutional waste collection is assumed to have two compartments, one for wet waste (50%) and other for dry waste (50%).
- Density of compacted truck is assumed to be 500kg/m^3.
- Collection time at the secondary collection point is 20 minutes and at the bin location is 5 minutes.
- Maximum time for unloading at the collection point and dumping site is 10 minutes.
- The surplus time of 25% is provided for off-route time to compensate for the traffic problems, vehicle problems, and bad weather conditions and for the personal requirements.

b) Calculation of location served per trip to the collection point:

Waste collected in bins or at location is emptied once a day to the secondary collection point. The number of locations/bins served per trip to the collection point is calculated below for residential area, market/commercial area, and institutional area.

Truck size-19m^3 and bin size-0.24m^3

Locations/bins served per trip for residential area:

Volume available for wet waste = 70% of total=.70*19=**13.3m^3**=13.3*500=**6650kg**

Volume available for dry waste=30% of total =.30*19=**5.7m^3**=5.7*500=**2850kg**

Wet waste=.24*330=**79.2kg** (weight) =dry waste

Locations/bins served per trip=maximum weight of waste/weight of bin=6650/79.2=**84** locations (wet waste)

Location served per trip=maximum weight of waste/weight of bin=2850/79.2=**36** locations

Locations/bins served per trip for commercial and institutional area:

Volume available for wet waste and dry waste =50% of total=0.50*19=**9.5m^3**=9.5*500=**4750kg**

Wet and dry waste=.24*330=79.2kg (weight)

Location served per trip=maximum weight of waste/weight of bin=4750/79.2=**60** locations.

A truck will carry 19m^3 of waste per trip and everyday there is waste generation of 557.76m^3.Therefore, a single truck will take 30 rounds to collect all the waste from the collection point to the dumping site.

c) MSW collection from secondary collection point to dumping site:

Secondary collection points are provided in every phases, sectors and villages according to the amount of waste generated and number of bins allocated in different areas. Collection points are provided to improve the efficiency of daily waste collection from the bin location. Size of collection point at every phases, sectors and villages will be different depending upon the amount of waste coming into it in order to avoid the overflow of waste and to make relatively a cost effective one.

Waste disposed at the collection point will be collected by the dumper truck once after three days or once a week. The total of about 1673.28m^3 of waste is needed to be collected every time after three days. Collection round or trip from each collection point will depends on the amount of waste disposed in it.

d) Routes for collection of waste from collecting points to dumping site:

With the help of Google Earth Pro software, routes were developed and time was calculated from route length and average speed of truck (25 km/hr). Routes are drawn to collect waste from secondary collection points to dumping site. The route will start from the garage which is located in the municipal corporation sector 68, Mohali then it will first cover the nearest secondary collection point and goes to dumping site afterwards it will keep on covering the other secondary collection points and it will end in the garage itself.

The total numbers of secondary collection points are 26, in which a huge amount of waste has to be collected in every third day and optimized routes are planned by using a single vehicle. The time which is required to complete this work can be reduced by providing more number of vehicles, as the working capability of one vehicle is (6-8) hours.

A total of 24 routes are provided to cover a total distance of 382.2 km and time required is

37.6 hours. It would be quite challenging for a single vehicle to perform this task hence sub-dividing the task. The working capacity of one vehicle is taken as 6 hours hence after every third day:

Total distance to be covered: 1146.6 km

Total time required: 112.8 hours

Number of vehicles required: 19 vehicles.

The route plan for route R1 is given below, which is the made with the help of linear programming using the same concept as the "*travelling salesman problem*". This problem considers the shortest of all the routes to minimize the time and maximize cost efficiency. With the help of using the above concept we have calculated the distance of route one which starts from the truck garage then it will go to the nearest collection point which is approximately 1.1 km away from the garage then it will collect the waste and dump it into the disposal site and then visit the nearest collection point via the shortest route and keep on repeating the same procedure until all the waste gets collected and dumped.

Route 1:R1

Garage to collection point: 2.64min [1.1km (with 25km/h velocity)]

Picking up time =80min [4 trips *20]

Travelling time=89.04min [Route length: 5.3km* 4trips (25km/h velocity)]

Routing time=169.04min+42.26min (25% extra time) = 211.3min

Distance covered=38.2km (R1 shown in **Fig 3.2.6**)

Similarly Route R2 is shown in **Fig. 3.2.7**.

Following the same methodology, total taken to cover the optimized route was calculated for the remaining 24 routes and the results are summarized in **Table 3.2.3.**

Table 3.2.3 Time & distance of routes in Mohali city

Routes	Loading Time (min)	Routing Time (25% extra time) (min)	Unloading Time(min)	Total Time (min)	Distance (km)
R1	80	211.3	40	251.3	38.2
R2	20	70.6	10	80.6	15.2
R3	20	76	10	86	17
R4	40	148.4	20	168.4	32.8
R5	20	59.2	10	69.2	11.4
R6	20	59.8	10	69.10	11.6
R7	20	56.8	10	66.8	10.6
R8	20	47.8	10	57.8	7.6
R9	20	51.4	10	61.4	8.8
R10	20	52	10	62	9
R11	20	56.2	10	66.2	10.4
R12	20	56.2	10	66.2	10.4
R13	20	59.2	10	69.2	11.4
R14	20	61	10	71	12
R15	20	52	10	62	9
R16	20	35.8	10	45.8	3.6
R17	20	22.8	10	32.8	7.6
R18	40	87.6	20	107.6	29.2
R19	60	148.8	30	178.8	24.6
R20	20	46	10	56	7
R21	40	117.2	20	137.2	22.4
R22	40	140	20	160	30
R23	20	50.2	10	60.2	8.4
R24	40	152	20	172	34
Total				**2257.6**	**382.2**

From the above table we observe that a set of total 24 optimized routes are prepared which is covering almost a total distance of 382.2 km and the total time duration for completing this total distance is 37.6 hours. The above table is prepared for daily routing but to keep it more economical we have calculated the total time and distance as per every third day that is the total distance would be 1146.6 km and time required to cover it is 112.8 hours. The whole collection process will be carried by the 19 vehicles of Municipal Corporation Mohali, which are having a capacity of 19 cubic meters.

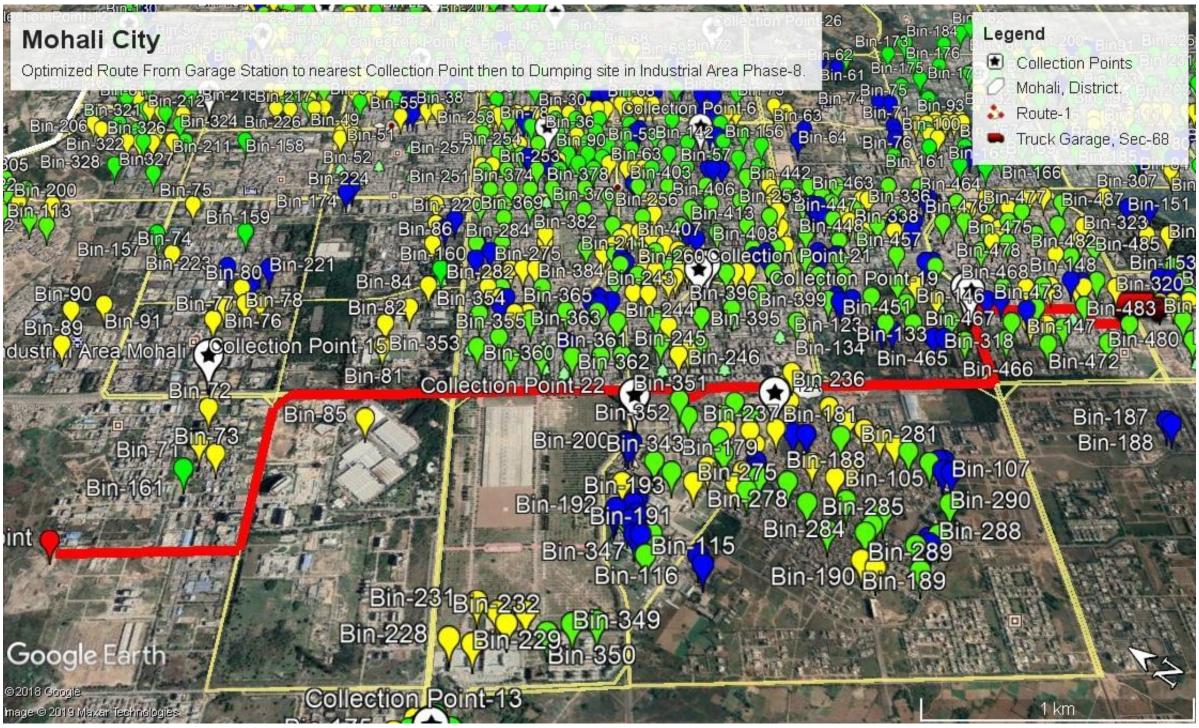


Figure 3.2.6 Route (R1), one time collection in every third day.

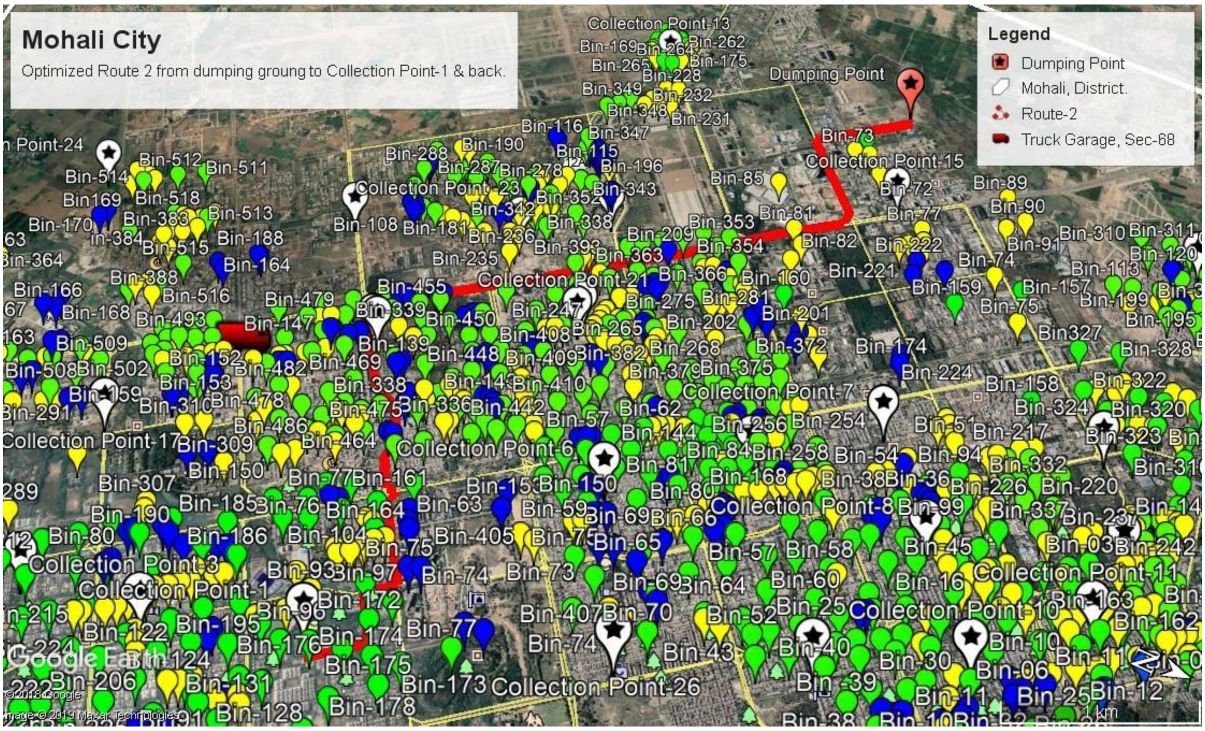


Figure 3.2.7 Route (R2)

e) Cost analysis:

The basic tool applied to reduce the cost is to purpose the collection of waste after every third day since it will be so tough to manage it on daily basis because of the lack of proper human resources. After every third day the collection will do only in one shift, this will reduce the fuel and labor cost. Therefore, collection on third day with single shift is more cost-effective and will provide better collection efficiency. The cost analysis is given below in the **Table 3.2.4**.

Table 3.2.4 Cost analysis of collection of waste once in every third day.

Factors	Cost in Rs.
Bin Price	Rs. 2600
Price of all bins (2324 nos.)	Rs. 6042400
Fuel required (diesel) (Average of vehicle- 5 km/L)	27977.04 L
Fuel Price	Rs. 63 per L
Cost due to fuel in a year	Rs. 1762553.52
Cost for 5 years	148.5 lakhs

The above table refers to the total costs that have to be paid for 5 years which includes the cost of total bins plotted within the city and the fuel cost for the operations of vehicles. The total cost comes out to be one crore forty-eight lakhs and fifty thousand only, in which the cost of total bins is sixty lakhs forty-two thousand and four hundred only. This table can be use for comparing purposes.

3.2.7 Manual Routing Area wise:

In this routing we have taken the major segments which are residential, commercial and institutional area under that the areas have been chosen by doing surveys and using the remote sensing like goggle maps, places etc., where the majority of each segment is found. The residential areas includes the areas where housing predominates these can be societies and multi-stories apartments whereas the commercial area comprises of markets and food joints and institutional consists of government offices , schools and bus stops etc. Now the manual routing is been done where in one place only a major segment is considered and the other minor segments are ignored. Hence three different places are selected and the results are made-

Residential Area- Sector (3B-1 & 3B-2)

Commercial Area- Phase 10

Institutional Area- Sector 62

These areas are selected on the basis of the survey that has been done using remote sensing technique. The total bin plotted across the Mohali city are as per the population density and waste collected in each bin is also known to be .1 tons hence the total waste generation in each sector or phase can be easily determined.

Phase 3B-1 &3B-2 (Collection point- 4)

Total bins plotted- 54 nos.

Total waste production - 5.5 tons/day

Total bins plotted in residential sector- 26 nos.

Waste produced in residential sector - 2.8 tons/day

The area layout of Phase (3B-1 & 3B-2) is given in the **Fig. 3.2.8**.

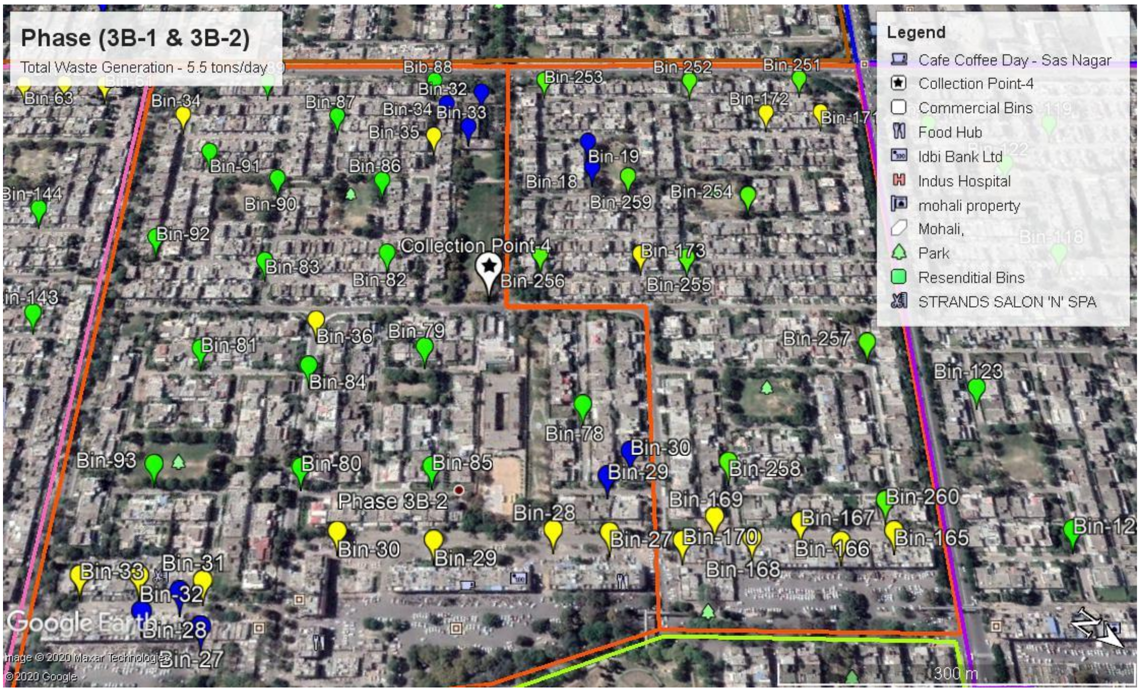


Figure 3.2.8 Area layout of Phase (3B-1 & 3B-2)

Phase 10 (Collection point- 3)

Total bins plotted- 62 nos.

Total waste production – 6.3 tons/day

Total bins plotted in commercial sector- 23 nos.

Waste produced in commercial sector – 2.5 tons/day

The area layout of Phase 10 is given in the **Fig. 3.2.9**.

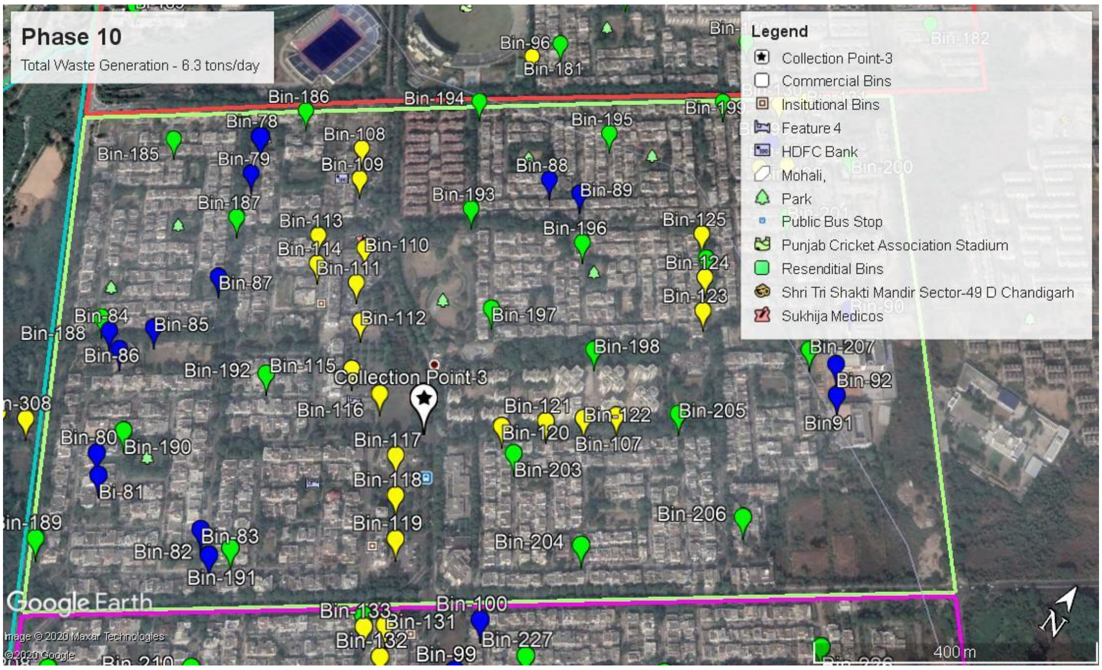


Figure 3.2.9 Area layout for Phase 10.

Sector 62 (Collection point- 23)

Total bins plotted- 17 nos.

Total waste production – 4.5 tons/day

Total bins plotted in institutional sector- 26 nos.

Waste produced in institutional sector – 1.9 tons/day

The area layout of Sector 62 is given in the **Fig. 3.2.10**.

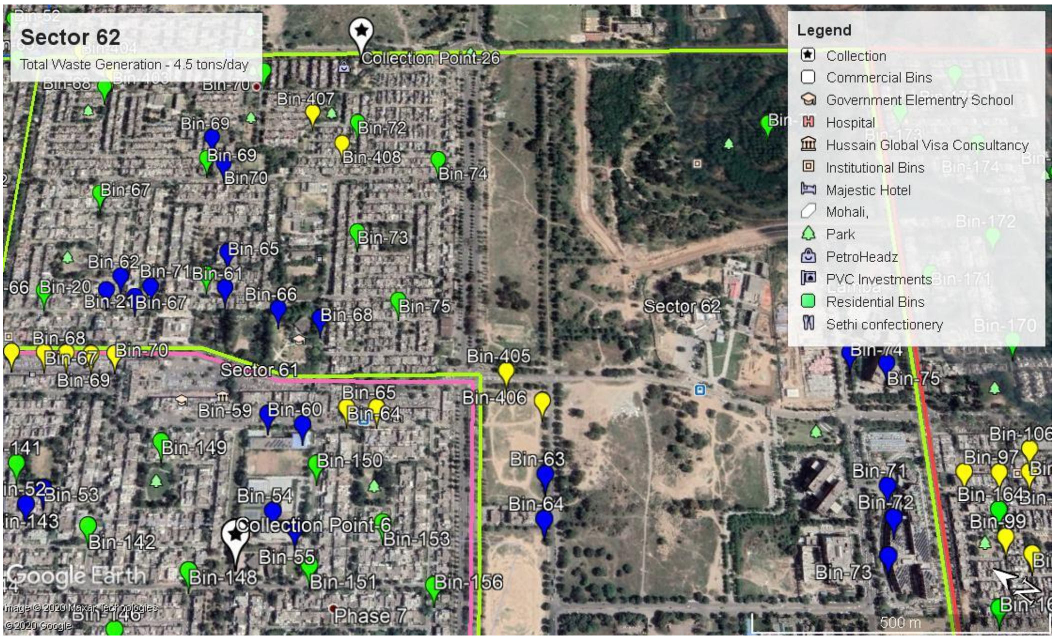


Figure 3.2.10 Area layout for Sector 62.

a) Assumptions and basic requirements for hand-cart routing:

As the Mohali city is already sub divided into a total of 26 collection points where all the nearby waste generated is collected on a daily basis and after minor segregation then the collected waste carried by a municipal vehicle to the place where it has to be dump. The routing of waste generated from homes, markets, workplace to the nearby collection points is carried with the help of hand carts. The benefits of using handcarts over the small pickups are because of its economical as well as eco-friendly nature. These carts can be easily moved though some congested places also. A pair of person is provided on a cart whose duty is to collect the waste from the bins and drop it to the allotted collection point. Now here are the assumptions and basic requirements which are required-

1. The capacity of the handcart is .25 tons

2. Two persons are allotted on a single cart.

3. Assuming loading and unloading time to be 10 minutes each.

4. The government had provide the rate of Rs. 80/hr for a waste worker working on daily wages.

b) Calculation of time and distance for the selected areas:

A basic route is formed in which one trip of hand cart will have to collect waste from the two consecutive bins and return back to the collection point and again went back to the next ones. As per the assumptions considered the loading and unloading of the waste from bins to be 10 minutes. An extra routing time of 25% is also considered for any hurdles throughout the way.

Routing for residential area -

For the routing purpose in the residential area which is the Phase 3B-1 & 3B-2 is done by assuming a single cart will collect waste from the whole area. In this routing two bin locations can be covered in one route as looking out the capacity of the cart and avoid overloading. The first route R1 is shown in the **Fig. 3.2.11** in which the green color signifies the step to step collection and red shows the route back to the collection point. Simultaneously the other routes will be calculated by performing the same principle and they are mentioned in the **Table 3.2.5**.

Table 3.2.5 Time and distance of routes for residential area

Route	Loading Time (min)	Unloading Tim(min)	Distance (meters)	Routing Time (25% extra time)(min)	Total Time (hr)
R1	10	10	880	33.0	0.88
R2	10	10	1000	37.5	0.96
R3	10	10	1300	48.8	1.15
R4	10	10	950	35.6	0.93
R5	10	10	1190	44.6	1.08
R6	10	10	680	25.5	0.76
R7	10	10	710	26.6	0.78
R8	10	10	1020	38.3	0.97
R9	10	10	800	30.0	0.83
R10	10	10	720	27.0	0.78
R11	10	10	950	35.6	0.93
R12	10	10	1270	47.6	1.13
R13	10	10	910	34.1	0.90
Total			**12380**	**464.3**	**12.07**

In the above table a total of 13 optimized routes have been selected for transportation of waste from source to the nearby collection points by using hand-carts. For the residential dominant area a total of 12.38 km is to be covered with time consumption of 12.07 hours

Figure 3.2.11 Route R1 for residential area (Phase 3B-1 & 3B-2

Routing for commercial area -

For the routing purpose in the commercial area which is the Phase 10 is done by assuming a single cart will collect waste from the whole area. In this routing two bin locations can be covered in one route as looking out the capacity of the cart and avoid overloading. The first route R1 is shown in the **Fig. 3.2.12** in which the green colour signifies the step to step collection and red shows the route back to the collection point. Simultaneously the other routes will be calculated by performing the same principle and they are mentioned in the **Table 3.2.6**.

Table 3.2.6 Time and distance of routes for commercial area-

Route	**Loading Time (min)**	**Unloading Time (min)**	**Distance (meters)**	**Routing Time (25% extra time) (min)**	**Total Time (hr)**
R1	10	10	446	16.7	0.61
R2	10	10	281	10.5	0.51
R3	10	10	600	22.5	0.71
R4	10	10	690	25.9	0.76
R5	10	10	950	35.6	0.93
R6	10	10	1105	41.4	1.02
R7	10	10	366	13.7	0.56
R8	10	10	575	21.6	0.69
R9	10	10	1304	48.9	1.15
R10	10	10	1860	69.8	1.50
R11	10	10	2210	82.9	1.71
Total			**10387**	**389.5**	**10.16**

In the above table a total of 11 optimized routes have been selected for transportation of waste from source to the nearby collection points by using hand-carts. For the commercial dominant area a total of 10.38 km is to be covered with time consumption of 10.16 hours.

Figure 3.2.12 Route for commercial area (Phase-10)

Routing for institutional area -

For the routing purpose in the institutional area which is the Sector 62 is done by assuming a single cart will collect waste from the whole area. In this routing two bin locations can be covered in one route as looking out the capacity of the cart and avoid overloading. The first route R1 is shown in the **Fig. 3.2.13** in which the green color signifies the step to step collection and red shows the route back to the collection point. Simultaneously the other routes will be calculated by performing the same principle and they are mentioned in the **Table 3.2.7**.

Table 3.2.7 Time and distance of routes for institutional area-

Route	Loading Time (min)	Unloading Time (min)	Distance (meters)	Routing Time (25% extra time) (min)	Total Time (hr)
R1	10	10	1131	42.4	1.04
R2	10	10	2008	75.3	1.59
R3	10	10	1978	74.2	1.57
R4	10	10	1930	72.4	1.54
R5	10	10	2390	89.6	1.83
R6	10	10	2678	100.4	2.01
R7	10	10	4270	160.1	3.00
R8	10	10	4340	162.8	3.05
R9	10	10	4200	157.5	2.96
Total			**24925**	**934.7**	**18.58**

In the above table a total of 10 optimized routes have been selected for transportation of waste from source to the nearby collection points by using hand-carts. For the institutional dominant area a total of 24.92 km is to be covered with time consumption of 18.58 hours.

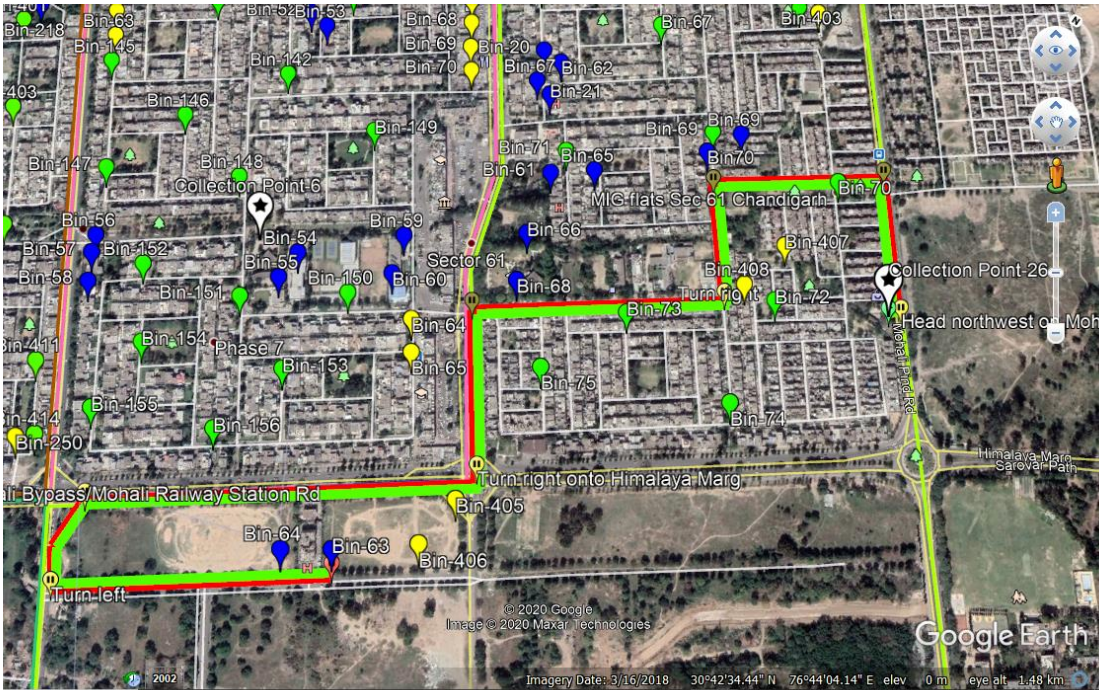


Figure 3.2.13 Route for institutional area (Sector-62)

c) Cost Analysis for manual routing within different areas:

The total cost for all the three different sectors are calculated on the basis of how much would be the expense when only major segments are considered. This cost is not added in the overall cost analysis because generally the manual routing is done by the third party contractors, who takes fixed money from the people living in that particular area on monthly basis. The cost analysis is given below in the **Table 3.2.8**.

Table 3.2.8 Cost analysis for manual routing:

Category	Factors	Cost in Rs.
Residential Area (Phase 3B-1& 3B-2)	1. Hand Carts Required – 4 nos. (Cost per cart is Rs. 14,500/-)	Rs. 58,000/-
	2. Waste worker required – 8 persons (Daily wage rate – Rs 80/hour)	Rs. 1,920/-
	3. **Total cost per year**	**Rs. 7,58,800/-**
Commercial Area (Phase-10)	1. Hand Carts Required – 3 nos.	Rs. 43,500/-
	2.Waste worker required – 6 persons	Rs. 1,440/-
	3. **Total cost per year**	**Rs. 5,69,100/-**
Institutional Area (Sector-62)	1. Hand Carts Required – 6 nos.	Rs. 87,000/-
	2.Waste worker required – 12 persons	Rs. 2,880/-
	3. **Total cost per year**	**Rs. 11,38,200/-**

The above table gives the overall cost of manual collection of the waste from the sources to the collection point, for this hand-cart has been used as they are economical and easily accessible in congested places. The cost of number of hand-cart used in different areas are calculated which is highest for the institutional area and lowest for the commercial area. As mentioned in the assumptions that there will be two waste workers associated with one hand-cart and their daily wage cost is Rs 80/hour hence the total cost per day is also calculated. Finally the total cost is calculated on annual basis which is highest in institutional area at around eleven lakhs thirty-eight thousand and two hundred only, the lowest cost is for commercial area with five lakhs sixty-nine thousand and one hundred only.

3.2.8 Summary and Discussions:

In this study, an integrated MSW management plan for Mohali city has been formulated using Google Earth Pro and Remote Sensing techniques. The MSW generated from different areas such as residential area, market and commercial area, institutional area and waste generated from the parks are considered while designing for the effective waste management plan. The activities of the study included the boundary mapping of Mohali city, different sectors, phases, villages and other important figures. The amount of waste generated in Mohali was taken from the previous study and calculated the total number of bins required to collect the total waste generated in the city. Bin location is planned in view of the amount of waste generated and population density in different areas and it was plotted with the helped of Google Earth Pro. Different color is given to bins in different area like green color bins in residential area, blue color bin in institutional area, and yellow color bin for collecting the waste generated from market and commercial area.

Waste collection frequency is set as every day collection from community bins to the secondary collection points and waste disposed at the collection point should be collected and disposed in the dumping sites every after three days. Assuming six hours working time per day, Mohali municipality is in need of 19 collecting vehicles to collect the waste disposed in the secondary collection point after three days.

The total of 24 optimized routes was determined using the concept of linear programming from the Google Earth Pro by considering the variables like time, distance and cost-benefit analysis. Further the routes were optimized for the manual collection of waste from the source trough handcarts and different area segments were chosen in which the waste generated from the three types that is residential, commercial and institutional is dominant. The manual operating handcart consist two persons who generally work on daily wages so the cost analysis is also drawn for the three segments differently including the cost of the number of handcarts used within that area.

3.3 Assessment for potential methane generation from the landfill site of municipal solid waste:

3.3.1 General:

This topic contains the amount of MSW generation and the projected amount of waste in various years in Mohali city and their corresponding methane emission from the MSW in each year.

3.3.2 Introduction:

The India has been facing major environmental issues over few years because of a significant increase in generation of MSW and it has caused negative impact to the environment and the heaps of MSW in the open area has also causes health hazards, destroyed the beauty of places and has generated some landfill gases from the MSW due to microbial decomposition of the organic waste under aerobic or anaerobic conditions **[3].** The organic composition of MSW has released a major greenhouse gas (GHG) and the significant increase in the emission of GHG has change the global climate pattern and ultimately causes the global warming, a threat to the natural environment **[10, 11, 25, 27, 31, 33]**.

The methane is considered as significant gas among GHGs as its global warming effect has accounted to be more than 20 times serious than that of carbon dioxide (CO_2) and the methane concentration in the atmosphere have been increasing at the rate of 1-2 % per year over the last few decades **[14]**.The MWS landfills are the principal sources of methane which is estimated to consider for 3-19 % of the global anthropogenic emission of methane and of GHGs methane is one of the significant contributor to global warming **[14].**

The methane emission can be calculated and studied using several landfill gas model/methods such as IPCC default method (IPCC DM), modified triangular method (MTM), zero order decay method, first order decay method (FOD, multi order decay method and the software like Land GEM can be also used for the assessment for potential methane generation from the waste landfill **[15, 30].**

In India there is limited number of gas recovery plant and many more number of plants is required in order to reduce the rate of methane emission. The means for the reduction and recovery of methane can be adopt by using the knowledge on quantitative and qualitative of methane emission otherwise their unnoticeable presence will destroy the home of all living beings and therefore, an assessment for potential methane generation is an important task that has to be carry out.

3.3.3 Materials and methods:

a) Waste generation in Mohali city:

Due to increase in population and the developmental activities took place every year; there is significant increase in the total amount of waste generation in the city. The generated waste in the year 2017 is 54.46 Gg **[25]**, projected amount of waste generated based on projected population in the year 2020 is 56.28 Gg and the total amount of waste generation in sixteen years from 2015 to 2030 is 898.77Gg and this huge amount will produce greenhouse gas with most percentage of methane gas. Approximately more than 90 % of the total waste generated in the city is dumped in the open landfill and 10% or less than 10% is used in other purposes like recycling and reuse **[24].**

The per capita waste generation in the city for 16 years (2015-2030) is calculated in **Table 3.3.1** using the projected population and their corresponding per capita MSW generation.

Table3.3.1. Calculation of per capita waste generation in Kg per day

Sl. No	Year	Per capita waste(Kg/day)	Remarks
1.	2015	0.46	Based on population
2.	2016	0.46	Based on population
3.	2017	0.51	Calculated from total waste generation and population of Mohali
	Average	**0.48**	

Per capita waste generation for the year 2015 and 2016 is taken as the allotted value for the particular population range and for the year 2017, the per capita waste is calculated based on the total MSW generated in Mohali per day and the projected population as per population census report of 2011**[8, 27].**

The average per capita waste of 0.48Kg/day is used along with the projected population to calculate the total waste generation in various years. The population used in this study is calculated using the geometrical growth method as it gives the most accurate number compared to other methods **[8].**The total waste generation in the city per year and the amount of MSW reached at landfill site per year is calculated in **Table 3.3.2.**

Table 3.3.2 Amount of waste generation per year in Mohali from population and per capita waste generation

Sl. No	Year	Population(estimated as per population census of 2011)	Amount of waste(tonnes per day)	Amount of waste(tonnes per year)	Amount of waste (Gg /year)	Amount of waste reached landfill site
1	2015	246559	113.42	41397.26	41.40	37.26
2	2016	271117	124.71	45520.54	45.52	40.97
3	2017	292587	149.22	54465.07	54.46	49.01
4	2018	315794	151.58	55327.11	55.33	49.80
5	2019	318498	152.88	55800.85	55.80	50.22
6	2020	321225	154.19	56278.62	56.28	50.65
7	2021	323976	155.51	56760.60	56.76	51.08
8	2022	326750	156.84	57246.60	57.25	51.53
9	2023	329547	158.18	57736.63	57.74	52.00
10	2024	332369	159.54	58231.05	58.23	52.41
11	2025	335215	160.90	58729.67	58.73	52.86
12	2026	338085	162.28	59232.49	59.23	53.31
13	2027	340980	163.67	59739.70	59.74	53.77
14	2028	343900	165.07	60251.28	60.25	54.23
15	2029	346844	166.48	60767.07	60.77	54.69
16	2030	349814	167.91	61287.41	61.29	55.16
	Total				**898.77**	**808.95**

The amount of MSW reached landfill site per year is calculated by considering 90% of collected waste reached to landfill site every year **[24].**From the **Table 3.3.2,** we observed that the total MSW generated for the span of 16 years is 898.77Gg/year and the amount of MSW reached landfill site is 808.95Gg/year in span of 16 years.

b) Physical characterization of municipal solid waste in Mohali City.

Physical characterization of MSW plays significant role in management strategy of MSW. Physical characterization of MSW made easy and effective MSW management system. MSW is characterized based on their composition like organic/ vegetables, paper and plastics, wood and leaves, iron and steel, clothing etc. The details on physical characterization is given in **Table 3.3.3**

Table 3.3.3 Physical waste characterization of MSW in Mohali **[40]**

Sl.No	Component	HIG	MIG	LIG	Average
1	Density(kg/m^3)	395±2.9	430±8.7	550±8.8	465
2	Compostable	46±6.1	53.9±2.56	54.9±1.4	46.7
3	Paper/cardboard	7.8±1.8	4.5±2.9	4.6±2.9	5.3
4	Plastic/polythene	8.0±1.44	5.7±1.7	4.7±0.2	6.6
5	Glass	1.9±4.10	1.0±2.0	0.4±3.1	1.4
6	Rubber/leather	1.9±0.03	0.7±0.04	0.5±0.02	1.2
7	Metals	0.1±1.6	o.1±0.03	0.1±1.7	0.6
8	Inert	30.1±9.6	25±1.58	32.2±7	28.6
9	Miscellaneous	4.2±3.89	9.3±5.29	2.6±1.7	9
10	Total	100	100	100	100

From the table we observed that compostable waste is generated more from the low income group whereas non compostable waste like papers and plastics are relatively more in the high income group. And we can also see that average of 46.7 % of total waste generated is compostable waste and the very less of metal composition.

c) Methods for assessment of methane generation:

Amount of methane generation from the landfill is studied and calculated using different methods and software. The method for the assessment of methane generation used in this study is discussed below:

i) IPCC Default Method (DM):

IPCC default method (DM) is one of the widely used empirical methods for the assessment of methane gas emission from the landfill site. This method is most suitable in the situation when there is limited data available on MSW.

The default method is mainly based on the following equation.

Equation 2

$$\boldsymbol{CH_4\left(\frac{Gg}{year}\right) = (MSW_T \times MSW_F \times MCF \times DOC \times DOC_F \times F \times \frac{16}{12} - R) \times (1 - OX)}$$

Where 1 Gg/year=1000tonnes/year

CH_4= amount of methane emission per year

MSW_T=total amount of municipal solid waste generated per year in Giga gram (Gg) which was 54.75Gg/year

MSW_F= the fraction of MSW that reaches the landfill site (in this study considered 90%), which was 49.275Gg/year

MCF=methane correction factor (since depth of landfill site is less than 3 meter, the value 0.4 is used in this study)

DOC=degradable organic carbon, the value is calculated using following formula

DOC=0.4A+0.17B+0.15C+0.3D

Where A= paper/cardboard, B=leaves, straws and other (consist of plastics/polythene, glass, rubbers, metals, inert and miscellaneous wastes), C=fruits and vegetable waste (in this we considered the value of compostable wastes.

The value of DOC is calculated using the average data given in **Table 3.3.3**

Where A=5.3%=.053,

B=6.6+1.4+1.2+0.6+28.6+9=47.4%=0.474,

C=46.7%=0.467,

D =0

DOC=0.4×0.053+0.17×0.474+0.15×0.467

=0.172

DOC_F=0.014T+0.28,

Where T is temperature of a landfill at which under anaerobic condition methane will be generated.

Value of the dissimilated fill gas 0.77 was considered for temperature 35℃ of landfill from which methane is to be generated.

F= fraction of methane gas, which was considered 0.5

R=recovered methane gas (considered 0 in this study as there is no recovery techniques in Mohali till 2019)

OX=oxidation factor, considered 0 (as default value)

Assumptions on Default Method:

- All potential methane is assumed to be emitted in the same year as the waste is disposed of.
- Compositions of waste are assumed to remain constant in every year.
- Fraction of methane gas emission is taking constants (0.5).

The assumptions on Default method are considered mainly because the methane is generated due to decomposition of organic waste and the decomposition of organic composition will complete within the same year as the waste deposited. And there is only little variations in the composition of MSW in year and therefore it assumed to be remain constant in every. The fraction of methane gas emission was assumed as 0.5 in default method because it is already documented by IPCC that 50% of landfill gas emitted from MSW is methane gas.

ii) Modified Triangular method (MTM):

This method is applicable when there is lack of detailed data, the volume of emission of methane gas is assumed to be same as that from DM method and the degradation of MSW are assumed to be taking place in two phases. This method assumed that the methane emission will begin only after one year of waste dumped. First phase assumed that methane gas will released at the start of two years after waste disposal and will linearly increase up to 6th year and after that second phase starts and there is declining of methane emission from 7th year and becoming zero at the 16th year. The Triangular form of gas production is shown in **Fig. 3.3.1**.

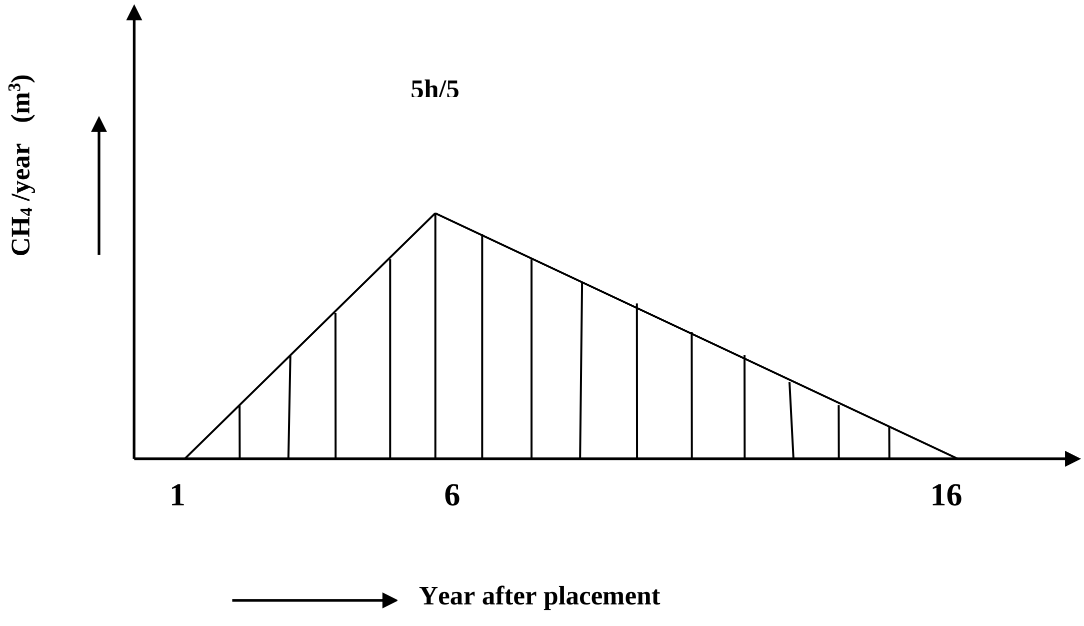


Figure3.3.1 Triangular form of gas production

The volume of methane emission is calculated from the amount of methane from DM method along with density of methane (0.714Kg/m^3).By equating the volume of methane to the area of triangle, the height of triangle (m^3) is obtained. By taking the reference of height of triangle of 6th year, the height of other triangles is calculated. The height of triangle of 6th year is represented as methane emission. The area of each triangle will give the yearly emission profile of methane.

3.3.4 Results and Discussion:

(a) Methane emission by Default Method:

Using the equation 2, amount of methane gas emitted from the MSW disposal site in Mohali city is obtained in **Table 3.3.4**

Table 3.3.4 Methane emission in various years by Default method

Sl.No (*1*)	**Year** (*2*)	**Amount of waste reached landfill site (Gg per year)** (*3*)	**CH_4(Gg/year)** *=(3)×**0.032** (4)*
1	2015	37.26	1.19
2	2016	40.97	1.31
3	2017	49.01	1.57
4	2018	49.80	1.59
5	2019	50.22	1.61
6	2020	50.65	1.62
7	2021	51.08	1.63
8	2022	51.53	1.65
9	2023	52.00	1.66
10	2024	52.41	1.68
11	2025	52.86	1.69
12	2026	53.31	1.71
13	2027	53.77	1.72
14	2028	54.23	1.74
15	2029	54.69	1.75
16	2030	55.16	1.77
	Total	**808.95**	**25.89**

For the year 2020, the amount of MSW reached landfill site is 50.65Gg/year and that of methane emission is 1.62Gg/year and by the year 2030, the amount of waste is estimated to reach 55.16 Gg/year and the methane emission is 1.77Gg/year. The emission coefficient of methane calculated from DM is estimated to 0.032. The total amount of MSW reached to disposal site is estimated as 808.95Gg/year and that of total methane emission is 25.89 Gg/year for the span of 16 years (2015 to 2030). The emission of methane in various years is shown graphically in **Fig 3.3.2**

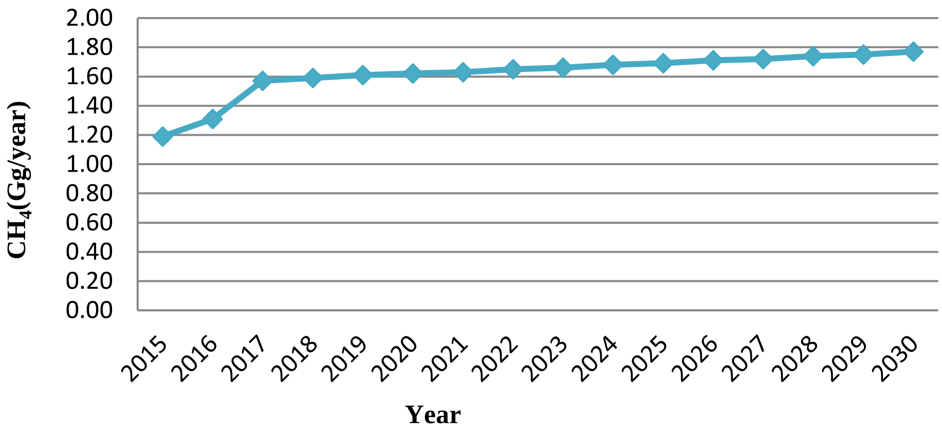


Figure 3.3.2 Methane emission profile.

The graph indicated that the methane gas emission from the Landfill site increases linearly as per the calculated data from Default Method. The DM method tends to give overestimated value of methane emission as compared to other method **[15]**.

b) Methane emission by MTM:

The methane emission coefficient from DM is used in MTM to calculate the amount of methane gas emission. Compare to the DM, this method estimated quite reasonable amount of methane gas emission. Calculations of methane emission by MTM method is shown in **Table 3.3.5.**

Table 3.3.5 Methane emissions from MSW using Modified Triangular Method (MTM)

Sl. No (*1*)	**Year** (*2*)	**CH_4(Gg/year)**=*(3)*×***0.032*** *(4)*	**CH_4(m^3)** =*(4)*×***10^6*****/density of CH4(0.714kg/m^3)** *(4)*	**Height of triangle(m^3)** **=2×**(5)/**15** *(5)*	**Height of triangle,CH_4 (m^3) by MTM** *(6)*	**Height of triangle,CH_4(Gg) by MTM** **=0.714×10^{-6}×*(6)*** *(7)*	**CH_4(Gg) by MTM(area of triangle)** *(8)*
1	2015	1.19	1666666.67	222222.22	0	0	
2	2016	1.31	1834733.89	244631.18	60504.20	0.043	0.022
3	2017	1.57	2198879.55	293183.94	121008.40	0.086	0.064
4	2018	1.59	2226890.76	296918.77	181512.61	0.129	0.107
5	2019	1.61	2254901.96	300653.59	242016.81	0.173	0.153
6	2020	1.62	2268907.56	**302521.01**	302521.01	0.216	0.194
7	2021	1.63	2282913.16	304388.42	272268.91	0.194	0.205
8	2022	1.65	2310924.37	308123.25	242016.81	0.173	0.184
9	2023	1.66	2324929.97	309990.66	211764.71	0.151	0.162
10	2024	1.68	2352941.18	313725.49	181512.61	0.129	0.139
11	2025	1.69	2366946.78	315592.90	151260.51	0.108	0.120
12	2026	1.71	2394957.98	319327.73	121008.40	0.086	0.098
13	2027	1.72	2408963.58	321195.14	90756.30	0.065	0.076
14	2028	1.74	2436974.79	324929.97	60504.20	0.043	0.052
15	2029	1.75	2450980.39	326797.38	30252.10	0.022	0.035
16	2030	1.77	2478991.60	330532.21	0	0	0.009
	Total						**1.620**

Using the volume of methane emission calculated from the DM, the height of triangle in the MTM is calculated. The area of each small triangle is obtained and represents the emission profile of methane in each year. The highest amount of methane emission from MTM is 0.205 Gg or 146370 m^3 in the year 2021 and that of minimum amount is 0.009Gg or 6426 m^3 in the year 2030.Ussing MTM, the total amount of methane gas emitted by MSW at landfill site in the span of sixteen years is estimated as 1.62Gg or 1156680m^3. The graphical representation of total methane emission by MTM is as shown in **Fig 3.3.3** and **Fig3.3.4.**

Figure 3.3.3 Triangular form for gas production

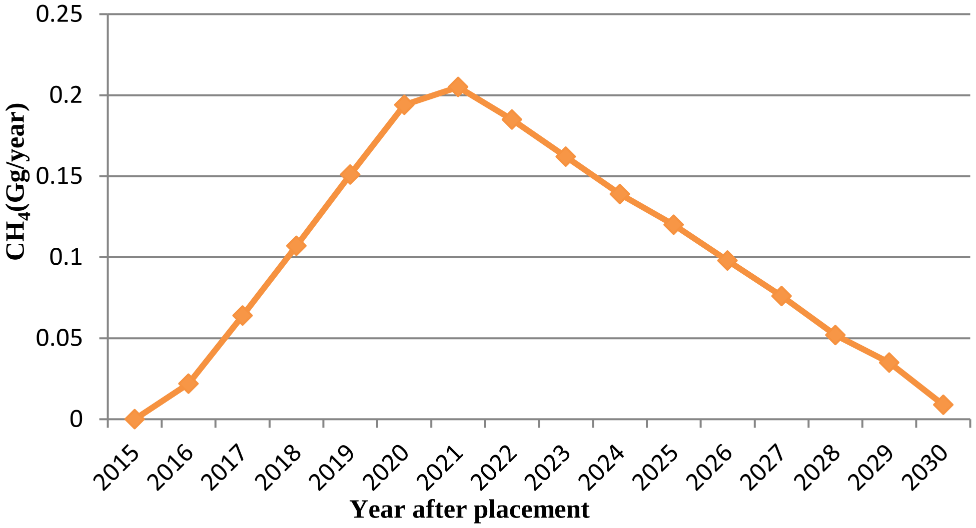


Figure 3.3.4 Emission profile of LFG

The area of each triangle is the emission profile for the yearly deposition of MSW. The emission and emission factor for the year 2021 is .205Gg and 0.004 which is very less as compared to the one calculated from default method.

3.3.5 Uncertainty incorporated in estimation of methane emission:

There is uncertainty in estimation of methane gas emission from different methods and mostly associated with the emission from default method where the composition of waste, fraction of methane gas and other values are as taking constant for different years of waste disposal which is not always possible. The uncertainty of default parameters that is used in the DM has been compiled by IPCC and is given in **Table 3.3.6** and using those values the percentage of uncertainty can be worked out.

Table 3.3.6 The uncertainty of empirical constants as documented by IPCC **[20]**

Sl.No	**Parameters**	**Uncertainty range**	**Value range**
1.	Degradable Organic Carbone(DOC)=0.21(maximum default value)	-50% to 30%	0.105-.252
2.	Fraction of degradable organic carbon dissimilated(DOC_F)=0.77	-30% to 0%	0.539-0.770
3.	Methane correction factor(MCF)=0.4	-30% to 30%	0.280-0.520
4.	Fraction of CH_4 in landfill gas(F)=0.5	0% to 20%	0.500-0.600

The final result of the estimation of total methane emission will depend on what kind of model is used. And the DM also assumed that methane emission coefficient is constant every year which sometimes can lead to miscalculation of methane emission. All those factors will lead to uncertainty and give over estimation of emission of methane gas.

CHAPTER-4

CONCLUSIONS AND RECOMMENDATIONS

4.1 General:

The chapter discusses the summary and conclusions drawn from the study conducted to fulfill the objectives of the study. The study of first objective is done effectively using the information, data and satellite images which is easily and freely accessible with the help of Google Earth Pro from the internet. These techniques are simple, easy to use and cost effective. It can be further used for other purposes like cost estimation, cost-benefit analysis, study of places and for monitoring the projects.

And that of second objective which is on assessment of methane emission from the MSW disposal site in Mohali city is done using the two different methods for estimation of methane emission that Default method and Modified Triangular Method.

4.2 Conclusions drawn from the two objectives:

- Recent year solid waste generation in Mohali city is increasing suddenly mostly due to developmental activities relating to housing scheme and commercial activities in Mohali IT city. Major source of MSW generation from residential area, market and commercial area, institutional area and street sweeping (inert waste) and in this study conducted inert waste is ignored while determining the number of bins.
- Mohali city is adopting an improper MSW management practices which is leading to environmental contaminations and affecting the health of human being as well as other living creatures. SWM has insufficient numbers of vehicles, bins and its capacity, and sanitation workers resulting in low collection efficiency.
- Number of bin was calculated based on the size of bins assumed and the amount of waste generated per day in the city to solve the problems of insufficient number of bins. A bin location plan was developed for the city comprising of residential area, commercial area and institutional area based on waste generation from respective area to avoid the and overflow of wastes and illegal dumping of waste in the city.

- Identified and located the Secondary collection point for every phases, sectors and villages to reduce the daily collection time from the bin location and to ensure that bin is emptied every day.
- Vehicle routing from the secondary collection point to dumping site was done using Google Earth Pro and identified the optimized route that can increase the collection efficiency to account the budget allocated for the collection purposes.
- The bin allocation plan and vehicle routing in some specific phases are done using the Google Earth Pro software and using the concept of linear programming. The cost benefit analysis is also done by considering all possible cost associated with those strategic procedures.
- Based on optimized route generated, effective time and cost-benefit analysis is done and it is in the acceptable range.
- The assessment on methane emission in the Mohali city is done using two methods that is default method (DM) and the modified triangular method (MTM).
- The default method and modified triangular method is more applicable and significantly use when there is absence of detailed data or information related on the particular topic.
- The amount of methane gas emission calculated from two methods is not coming same. The amount of emission using default method is significantly higher than that from the modified triangular method.

4.3 Recommendations:

- Segregation of the waste (wet waste and dry waste) should be done seriously while disposing and collecting the municipal solid waste.
- Waste disposed in the community bins should be collected every day to avoid overflow of the waste and ruin the aesthetic views of the city.
- Waste collected in the secondary collection point should be emptied every intervals of days mentioned.
- Budgets allocation, collecting vehicles, necessary equipments and the sanitation workers should be sufficient enough to complete the works in assigned time in the effective ways.

- As MSW is the major anthropogenic source of methane gas emission, effective MSW management system is highly recommended and the proper study on methane gas is necessary in every part of the city.
- If possible the methane recovery plant is needed to be established in order to reduce the amount of methane in the atmosphere and therefore to reduce their potential effect on climate change and to reduce global warming which is the major threat faced by the world for the last few decades.

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