Optimization model for Integrated Municipal Solid Waste Management in Gurugram

A DISSERTATION

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Submitted by

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Above all, I owe it all to my Almighty God for granting me the wisdom, health and strength to undertake this research task and enabling me to its completion.

AAKASH PATEL

ABSTRACT

Gurugram, amongst the largest metropolitan city in India, generates 500-600 tons of waste per day. It is the responsibility of the Municipal Corporation of Gurugram and private players to provide Municipal Solid Waste (MSW) management services; however, increase in waste is becoming beyond their ability. As a result of which waste litters all over the places giving rise to health and environmental problems. Hence, there is an urgent need to involve larger contribution from private sector and community participation in waste management. In this project, a linear programming model is developed to integrate different options and stakeholders involved in MSW management in Gurugram.

Solid Waste Management (SWM) is a set of consistent and systematic regulations related to control generation, storage, collection, processing and land filling of wastes according to the best public health principles, economy, preservation of resources, aesthetics, other environmental requirements and what the public attends to. Many countries are continuously facing problems in managing solid waste and need comprehensive and practical solutions. Therefore, the optimization conditions for sustainable approach to SWM are a key factor for managers and planners. Currently, the planners and decision-makers in the area of integrated solid waste management are confronting increased complexity uncertainty and multi-objectivity of this issue. At the beginning, the process of decision-making on SWM was simple. It is because of the decisions were made only through simple comparison of some options out of the available options.

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CHAPTER 1

INTRODUCTION

1.1 Background

New consumption patterns and social linkages are emerging. India, will have more than 40 per cent, i.e. over 450 million people clustered in cities over the next thirty years. Modern living brings on the problem of waste management, which increases in quantity, and changes in composition with each passing day. Urban labour groups, planners, environmental regulators, municipal agencies and NGO need to develop a variety of responses which are rooted in local dynamics, rather than borrow non-contextual solutions from elsewhere.

Solid waste disposal and waste management is both rural as well as urban problem. Every individual is a generator of waste and thus a contributor to this problem. Waste generation and type of waste generation both are different things and the way the generated waste is managed and disposed of is quite a different issue. Currently waste generated is more than the capability to handle. Waste is generated from different sectors such as domestic, commercial, industry and others and in many instances. There is growing issue of waste management and immediate need of stakeholders in the issue of solid waste in this case the residents need to join hands with the authorities in dealing with this problem before far-reaching environmental and human health effects.

India is one of the countries in the world that rank high in urbanization and still the urban population is growing. The implication of this growth is that pollution issues such as solid waste management and the provision of adequate safe water alongside acceptable levels of sanitation coverage will need closer attention. As India's urban areas increase in number and expand in geographical as well as population size solid waste is quickly emerging as a significant issue in environmental management. There are well defined guidelines for solid waste management, but problem lies in practicing those guidelines.

Particularly waste quantity has increased in urban areas due to the growing urban population and concentration of industries and consumption of residents and inadequate finance and facilities to manage waste. This state of affairs has led to the volume of solid waste generated to go beyond what the available facilities can accommodate.

One of the major factors that have contributed to poor waste collection and management in India is very limited public participation. The limited participation has budded from co-ordination and collaboration problems that exist among the three stakeholders in solid waste management- the communities, the public (government) and the private sectors. This study seeks to optimize the solid waste collection system and explore public participation in solid waste management in Gurugram city in Haryana in India.

1.2 Area of Study

Low lying area near the iconic DLF City (costliest residential colony in Gurugram as well as in India) is being used for dumping. Close proximity of Aravali range an ecological fragile area is another favourable place for illegal disposal site. The solid waste management is a low priority. The existing solid waste management is constrained by institutional weakness, lack of proper funding, management and operational systems, public apathy, lack of municipal will. Day by day increasing trend practice of dump to dump yard won't sustain the function. Still in stage of development, such as India, are undergoing a massive migration of their population from rural to urban centres.

Sample area taken for study is residential area with a large proportion of people residing, but they commute to nearby places for work. For my study developed are taken which include South City-1, Green Wood City, and Nirvana Country. Indeed, Gurugram has seen a number of businesses spring up in response to the demand. Hotels, guest houses and restaurants have sprung up to meet the occasional demand for their services The permanent resident population which is on the increase due to the expansion of the city attracted the establishment of such businesses as supermarkets, retail shops, food markets and recreational centres.

The irony in this development is that the volume of solid waste generated from the several development projects and occupational activities is increasing enormously. It has consequently become one of the issues of concern to the authority as well as the public who reside. According to the local authorities poor waste management and waste disposal is identified as one of the environmental threats. This is attributed to the increased urbanisation without proper planning, use of polythene bags, which are non-bio-degradable and inadequate garbage collection points.

Been a resident of South City-1 for the past five years and over this time observed numerous developments taking place and also particularly been concerned about the way people dispose waste and how it's further being carried. As a student of Environmental Engineering, motivated to make my contribution, by studying the solid waste management issue with particular reference to public participation. With hope that the findings of this study will give insight to the concerned parties to work more effective on the management of solid waste in conformity to sustainable development practices.

Figure 1.1 Municipal plan of South City 1

South City 1 is a 300-acre residential township of apartments, private villas located close to Huda City Centre. Important landmarks are Signature Tower, The World Spa, Uniworld City and The Palms are all part of this township.

The integrated township of South City 1 has easy access to very good road network and has abundance of city amenities such as hospital, school and shopping arcade and making it a great place to live and raise a family. The close proximity to various temples, restaurants and shopping malls is an indication of the religious and life of South City 1.

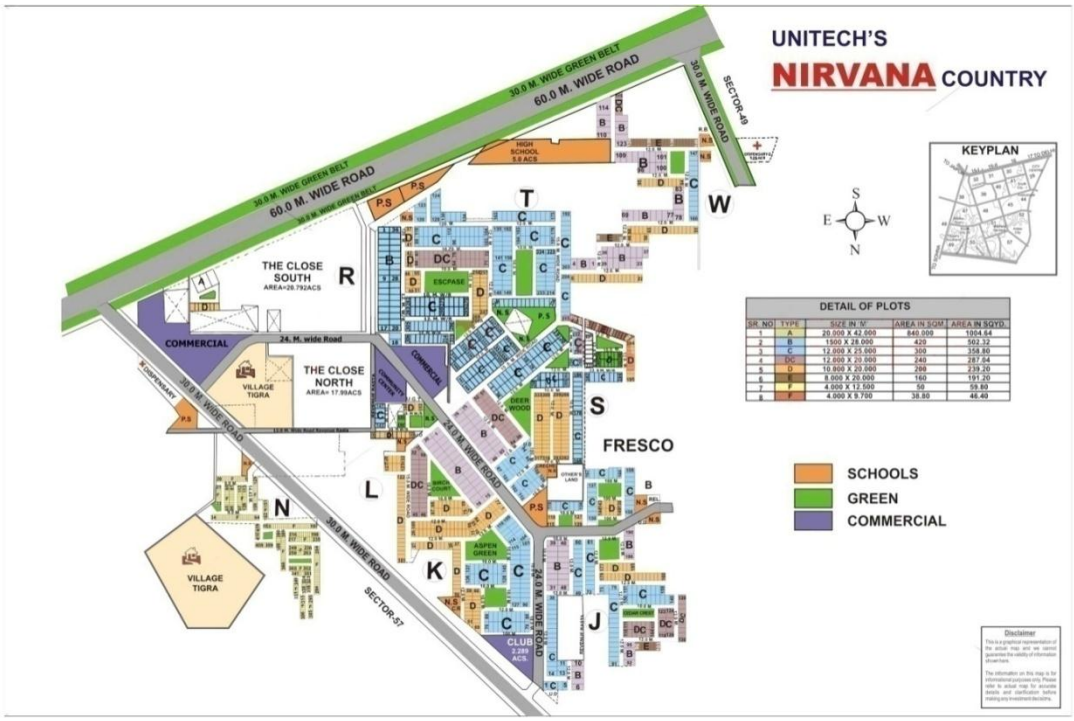

Figure 1.2 Municipal Plan of Nirvana Country

Nirvana Country among Gurugram most well versed and known Township, which comes with villa, apartment, office, retail space, school and club and many more facilities. Landscaped parks with has exclusive play areas and Nirvana Patio- a world-class clubhouse provide ideal living conditions for an upscale neighbourhood.

A good selection of options has been laid before you. Nirvana County is a good place to find a apartment, in it has a very part because of the incredibly very close proximity of the Golf Course Extension Road, the Sohna-Gurugram Highway, which allows quick and easy access to transportation routes from where you live.

Besides the luxury apartments and villas and floors like Fresco, Gurugram, Harmony, Gurugram& Escape, Gurugram, Nirvana Country has easy

Figure 1.3 Municipal Plan OF Green Wood City

Consists of landmark luxury villas project – Vista Villas. Residency Greens -independent floors & plotted developments are among the part of this township.

World class schools Amity International School, Shikshantar & Pathways, the HUDA city metro station, hotels like Taj Vivanta & Ramada Hotel markets like Green Woods Plaza & Huda Market, and also includes commercial destinations like Unitech Cyber Park and world class hospitals like Paras Hospital & Artemis Health Institute are all within easy reach and can easily access them. It is also an easy ride away from both MG Road & Sohna Road – which are amongst the most developed locations in Gurugram.

1.3 Objectives

The main objective of this study is to optimize the solid waste management model and gather information about the level of public participation in solid waste management, in light of the challenges and prospects for future management and determine the current level of public participation what more the public can contribute in solid waste management.

• To determine the locations of waste containers for the area under study.

• To determine the approximate waste generated from each container.

• To determine the distance and route map from waste containers to transfer stations.

• To understand the general awareness about waste management from respondents.

• To formulate mathematical model to optimize the collection system.

Chapter 2

Literature review

2.1 Introduction

The main objective of literature review is to perform literature survey of previous literatures published. This chapter is going to summarize the opinions of various authors related to waste management and it has also draw light on how statistical tools can be used to optimize the waste management.

Sanhita Bandyopadhyay (2013) It is attributed to a number of factors which includes food habits, standard of living and degree of commercial and industrial activities in the area. Currently, about 400 MT of municipal waste is collected per day within the controlled area as per Govt record, of which about 75-80 MT is generated within MCG area and balance is contributed by HUDA sectors, private developers' area, and urban villages. Municipal solid waste in Gurugram, as per Indian scenario, is expected comprises of 50-52 % biodegradable, 12-15 % dry recycles and 30-35 % inert component. But actually the total quantum is 600 Metric tons.

1000 TPD Combined solid waste management facility plant set up at Bhandwari (Faridabad-Gurugram toll road) for processing the MSW for Faridabad (another town) and Gurugram Municipal corporation in PPP model under JNNURM (Jawaharlal Nehru Urban Renewal Mission) scheme for a project cost of euro. 5.3 million where 50 % fund has been funded by Govt: of India, 30 % by Municipal council of Faridabad (town of Haryana) , 20 % by Govt:

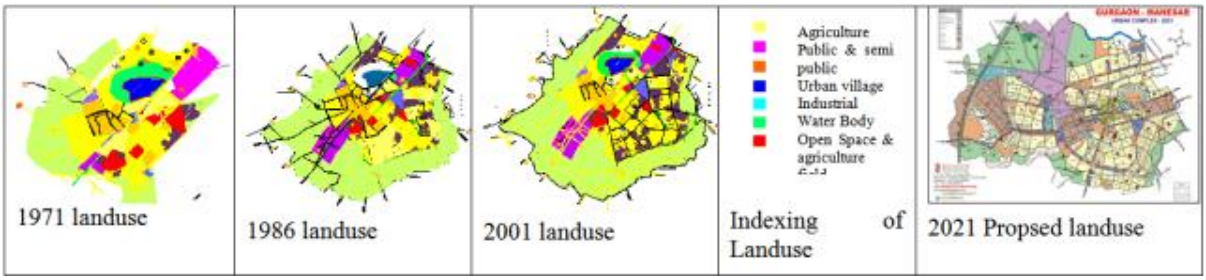

Figure 2.1 Land use Pattern of Gurugram

of Haryana and the Land is provided by MCG at free of cost with an agreement between MCF & MCG. This plant is RDF (Refuse Derived Fuel) plant which is taken 600 tons Waste dumping is the only favourable method to urban local body without any further action. Day

by day increasing trend practice of dump to dump yard won't sustain the function. Developing countries, such as India, are undergoing a massive migration of their population from rural to urban centres.

Table 2.1 Municipal Solid Waste Generation (in MT) of Gurugram

S. No.	Locality	Total MSW Generation (INMT) per day
1.	Old Gurugram	110
2.	DLF	45
3.	Ansal	17
4.	HSSIDC(Industrial area of HUDA)	80
5.	HUDA area	130
6.	Other Private developers	68
	Total	450

Rapid urbanization along with increases in population has led to the deterioration of physical environment in Gurugram. Effective Solid Waste Management is one of the major challenges faced by the local authorities. High volumes of waste generation, inefficient collection and transportation system and limited disposal options are continuously impacting the health, environment and quality of life in the area. Field study indicates that availability of land for disposal is major area of concern in Gurgaon. Real estate boom coupled with NIMBY (Not in My Back Yard) issues have left very less land available for disposal of waste in the urbanized area.

Dawa Zam, Sangay Jamtsh O, Tshering Dema and Jhulen Chettr Ms Chimi (2007) Located at geographical coordinates of 26 51'N 89 23' E, Phuentsholing city is a major gateway into Bhutan and apart from being the most important commercial hub, it operates as the nerve center for economic and commercial activities. The present system of waste collection in Phuentsholing city follows an uncoordinated routine and schedule, and this has given rise to an unhygienic living environment, discomfort to the residents and an uneconomic collection system in the city. Due to the lack of segregation practices, all types of waste produced are mixed and disposed in single bins leading to the filling up of provided bins within a short period of time. Collection vehicles are sent to collect wastes from different areas in a random manner making it ineffective. A questionnaire survey was carried out at 100 houseolds at different areas of te city to understand te present collection system to get

public input on te kind of collection they desired. The current system also presents potential health hazard to the waste collectors as all type of wastes including hospital and residential wastes are disposed to a common storage bin. The onsite survey carried out helped to understand some of the problems with the current system.

Tashmeer Khan, Rishabh Gupta, Deeksha Dhomne (2016) The paper presentation states the proper management and treatment of MSW of Indore .The determination and the type of MSW and treating with respective method is the best way to manage MSW, so that it does not create pollution and harm our society. Indore Municipal Corporation (IMC) generally use Landfill and Composting methods for the treatment of MSW.IMC can also use different treatments like Gasification technology for the treatment of MSW, as it is a source of renewable energy for the production of electricity. As the population is increasing at a rapid speed with the urbanization, the generation of MSW also increases, this paper will help the authorities responsible for the MSWM towards the improvement of the city**.** The present population is 24,73027lakhs. A part from infrastructural development going on for sustainable development MSW management should also be taken care off. However the manual analysis of urban solid waste management is very tedious as it involves a huge data and statists. Hence it demands computerization of system. Geographical Information System is a tool introduced to overcome this limitation and make waste management planning easy efficient and can be implement quickly also.

It will reduce the waste management work load to great extent. This literature analyses the aims at existing status of generation, collection, storage, transportation, treatment and disposal activities of MSW of Indore city. To review in detail the present scenario of SWM in Indore city with reference to the MSW Rules, 2000. To implement the developed model to study area to solve some of the present situation problems like proper allocation of waste bins, optimizing waste transportation routes and planning location of waste disposal facility. This model will help to get rid of solid waste as per the study area.

Tilaye M van Dijk Mp (2013) Privatization of urban services focuses often on the involvement of foreign enterprises. This contribution deals with micro-privatization, the partial transfer of government responsibility for solid waste collection to micro-enterprises. It tries to shed light on whether the current private sector participation (PSP) of micro-enterprises in solid waste collection service is the best way to capture the expected advantages of private sector involvement. This literature examines the relations of the micro-

enterprises with the beneficiaries and the public sector by focusing on the contract procedure, the cost recovery mechanism and institutionalizing of market principles for micro-enterprises. This research was carried out using secondary and primary data sources. Primary data were collected through the interviewing of public sector officials at different levels, focus group discussions with community groups and micro-enterprises, and observation. A survey was conducted among 160 micro-enterprises in the city of Addis Ababa, Ethiopia, using a standard questionnaire. New opportunities were created by formalization and taken up by communities and micro-enterprises. Coverage and waste collected both increased. The initiation and institutionalization of the formalization process was not without problems.

The public sector overstressed the autonomy of micro-enterprises. The fate of the micro-enterprises is largely determined by the reforms undertaken at local government level. The rapid changes in policies at the local level made waste-collecting micro-enterprises lose confidence and more dependent on the public sector. The study shows the continued power of the state and its agents in shaping developments in this domain.

Mohsen Akbarpour Shirazi1, Reza Samieifard, Mohammad Ali Abduliand Babak Omidvar (2016) Solid Waste Management (SWM) in metropolises with systematic methods and following environmental issues is one of the most important subjects in the area of urban management. In this regard, it is regarded as a legal entity so that its activities are not overshadowed by other urban activities. In this paper, a linear mathematical programming model has been designed for integrated SWM. Using Lingo software and required data from Tehran, the proposed model has been applied for Tehran SWM system as a case study. To determine the optimal status of the available system for Tehran's Solid Waste Management System (SWMS), a novel linear programming model is applied. Tehran has 22 municipal regions with 11 transfer stations and 10 processing units. By running of the model, the transfer stations and processing units are decreased to 10 and 6 units, respectively.

Nikoloas V. Karadimas Alessendra Orsoni Vassili Loumos (2006) The model retrieves the required information from a spatial Geodatabase, integrated in a GIS environment. The model takes into consideration several parameters of waste production, such as population density, maximum building density, commercial traffic, area and type of shops, road network and its relative information linked with the allocation of waste bins. Additionally, ground-based analysis has been applied for the estimation of the interrelations between the aforementioned factors and the variations in waste production between residential and commercial areas.

Therefore, the proposed model follows a unified and correlated categorization approach for all commercial and industrial activities in the area of study using a weighting system for all of the considered factors.

Mr. Ankit Verma and Prof. B.K Bhonde (2014) The paper presentation states an efficient designing and developing of a proper storage, collection and disposal system plan for Indore municipal corporation (Madhya Pradesh) India. A GIS optimal routing model has been developed by considering the parameter like population density, waste generation capacity, road network and transporting waste from transfer station to devaguradia disposal site. The proposed transfer stations are not located on the basis of waste generation and transportation distance as seen from city map. This model helps to find minimum cost/distance efficient collection pattern for transportation of solid waste to landfill. Indore Municipal Corporation can use this model as decision support tool for efficient management of moving the solid waste, fuel consumption.

Rajkumar Joshi1 and Sirajuddin Ahmed (2016) India is rapidly shifting from agricultural-based nation to industrial and services-oriented country. About 31.2% population is now living in urban areas. Over 377 million urban people are living in 7,935 towns/cities. India is a vast country divided into 29 States and 7 Union Territories (UTs). There are three mega cities—Greater Mumbai, Delhi, and Kolkata—having population of more than 10 million, 53 cities have more than 1 million population, and 415 cities having population 100,000 or more (Census, 2011a). The cities having population more than 10 million are basically State capitals, Union Territories, and other business/industrial-oriented centres.The abysmal state of and challenges in municipal solid waste management (MSWM) in urban India is the motivation of the present study. Urbanization contributes enhanced municipal solid waste (MSW) generation The current status of MSWM in Indian states and important cities of India is also reported. The essential conditions for harnessing optimal benefits from the possibilities for public private partnership and challenges thereof and unnoticeable role of rag-pickers are also discussed. The study concludes that installation of decentralized solid waste processing units in metropolitan cities/towns and development of formal recycling industry sector is the need of the hour in developing countries like India.

Muztoba Ahmad Khan (2014) Optimization means using resources and existing technology at the best possible way. Better planning and its execution results in optimization of many problems. Quantitative models and mathematical tools such as linear programming allows for

better result. We can use modern computing equipment for this purpose. Nowadays various problems of operational planning for transportation problems are solved by mathematical methods. Linear programming method is used to model most of these transportation problems. Excel Solver has been used to model and solve this problem. Among many possible activities, cost reduction in logistics is regarded as one of the core areas presenting enormous opportunities. Linear programming can be applied to various fields of study. It is used in business and economics, but can also be utilized for some engineering problems. Industries that use linear programming models include transportation, energy, telecommunications, and manufacturing.

Sarika Rathi (2007) Mumbai, the largest metropolitan city in India, generated 6,256 tons of waste per day in 2001. It is the responsibility of the Municipal Corporation of Greater Mumbai (MCGM) to provide Municipal Solid Waste (MSW) management services; however, the MCG to handle the increasing quantity of waste. As a result, waste litters all over the place giving rise to health and environmental problems. Hence, there is need to involve private sector and community participation in waste management. In this paper, a linear programming model is developed to integrate different options and stakeholders involved in MSW management in Mumbai. Various economic and environmental costs associated with MSW management are taken into consideration while developing the model. The optimal solution of the model indicates community compost plants are the best option whereas sanitary landfills are indispensable for waste management in Mumbai. Further, three scenarios are constructed to test the optimal solution under various situations. The optimal solution is based on the assumptions of no cost of segregation of waste at the household level, revenue recovery from compost and considerations of environmental costs.

2.2 Conclusion

From the above literature review, it helped to draw an outline of the project. Different papers on solid waste management are studied in depth to get an idea about sort of waste generated, and their management. As the study requires use of mathematical model formulation, different papers related to linear programming were also studied. To carry out the interview, it was necessary to understand the type of questions that needs to be asked from respondent in order to get the required data.

Chapter 3

Methodology

3.1 Overview

The problem is to determine the optimal waste to be transferred from collection stations to transfer station in order to obtain the minimum transportation cost. The transfer station which receive waste from different waste container locations, so if linear programming is applied to determine the optimal quantity of waste transferred from different locations to transfer stations it will be able to minimize the transportation cost significantly, which will result in increased profitability. For my scope of study taken 4 transfer stations, and located the collection bin stations contributing to transfer stations. It is also necessary to determine the approximate waste collected, for this interview was carried to calculate approx weight generated at each location. Three different localities are taken to gather the data required for conducting the study by preparing a set of questioners. From this data an estimate of per capita waste generation is made and further calculation regarding estimated waste received at each collection location is carried out. Three waste collection containers of 1.1 $m^3$are placed at various locations, from this location they are being taken to transfer stations. Hence after gathering the required data distance from each container location to transfer station is calculated and using solver tool in excel, optimization is carried out.

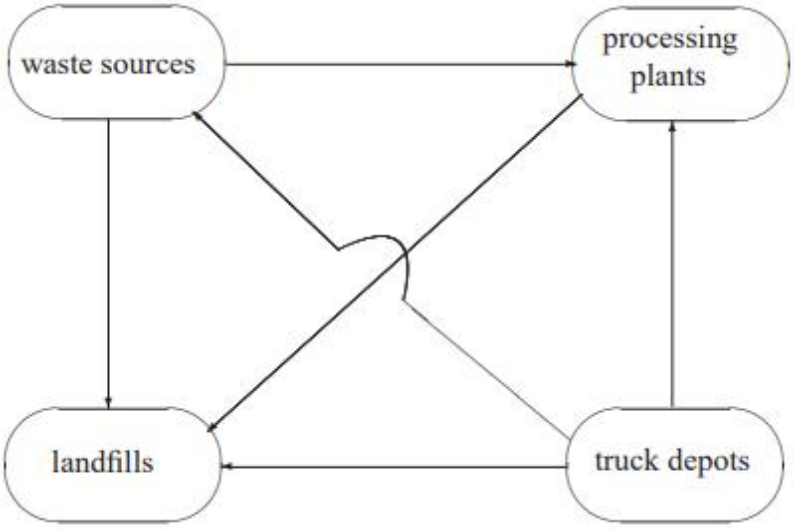

Figure 3.1: A compact representation of key components in a decision support mathematical model.

3.2 Data

Data on MSW management in India are not readily available and Gurugram is no exception to this. Hence, questionnaires were prepared and personal interviews were carried out. During survey carried out in morning, it was easy to calculate the waste disposed from household using automatic hand weighing balance. Hence it becomes easier further to calculate the total waste generated from locality which is contributing to particular waste container placed in their respective localities

3.3 A combination of both Quantitative and Qualitative approaches for data collection

For required data gathering adopted a combination of both quantitative and qualitative approaches. The objectives for the study clearly show that there are needs of preparation of questioner to conduct interview to gather the required data sets.

Quantitative:-

Quantitative research is applauded for the fact that "the findings are general sable and the data are objective". It was believed that the findings from this study would help in reflecting what is happening in the whole area under study. Quantitative data and statistical analysis would also help in testing some hypotheses and increases the validity of the findings from this study.

Qualitative:-

In this study, there was need for me to "dig deep" in order to get a complete understanding of the situation from the perspective of the stake holders in the solid waste management sector. The perspective of the people could only be appreciated with the collection and analysis of qualitative data also. To understand whether there was any kind of collaborative relationship between the public and the local administration in solid waste management. Special focus was put on the hurdles involved in the public in solid waste management and was further interested in exploring whether there is any mechanism in place by authority to enhance collaboration in SWM with the public.

3.4 Mathematical Model Formulation

3.4.1 Linear Programming

Linear programming or linear optimization is a mathematical method for determining a way to achieve the best outcome in a given mathematical model for some list of requirements represented as linear relationships.

$$Minimize\ c^T x$$

$$subject\ to\ Ax \leq b$$

$$and\ x \geq 0$$

Where x represents the vector of variables (to be determined), c and b are vectors of (known) coefficients, A is a (known) matrix of coefficients, and $(.\ )^T$ is the matrix transpose. The expression to be minimized is called the objective function ($c^T x$ in this case). The inequalities $Ax \leq b$ are the constraints which specify a convex polytope over which the objective function is to be optimized. In this context, two vectors are comparable when they have the same dimensions. If every entry in the first is less-than or equal-to the corresponding entry in the second then we can say the first vector is less-than or equal-to the second vector.

The objective function contains costs associated with each of the variables. It is minimization problem.

3.4.2 Linear Programming Model

Waste goes from container location i to transfer station j. For any i and any j, the cost parameter is c_{ij} ; and the size of the shipment is x_{ij} . Since we assume that the cost function is linear, the total cost in terms of distance is given by $c_{ij}x_{ij}$. Summing over all i and all j now

$$Minimize \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}x_{ij}$$

Formulate a mathematical description called a mathematical model to represent the situation. This model consists of following components:

Decision variables: These variables represent unknown quantities

Objective function: The objective of the problem is expressed as a mathematical expression in decision variables. The objective is minimizing cost.

Constraints: The limitations or requirements of the problem are expressed as inequalities or equations in decision variables.

3.4.3 Constraints

Consider waste container location as i. The total outgoing waste from waste container is the sum $x_{i1} + x_{i2} + \cdots + x_{in}$. In summation notation, this is written as

$$\sum_{j=1}^{n} x_{ij}$$

Since the total supply from container location i is a_i , the total outgoing waste cannot exceed a_i . That is, we must require

$$\sum_{j=1}^{n} x_{ij} \leq a_i \text{ for } i = 1,2,3\ldots,n$$

Consider transfer station as j. The total incoming waste at this outlet is the sum $x_{1j}+x_{2j}+\cdots+x_{mj}$ In summation notation, this is written as $\sum_{i=1}^{m} c_{ij}$. Since the demand at outlet j is b_j , the total incoming waste should not be less than b_j . That is, we must require

$$\sum_{j=1}^{n} c_{ij} \leq b_j \text{ for } j = 1,2,3\ldots,m$$

This results in a set of m + n functional constraints. Of course, as physical shipments, the x_{ij} ’s should be nonnegative.

3.4.4 Linear Programming Formulation

In summary, we have arrived at the following formulation:

$$Minimize \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}x_{ij}$$

Subject to

$$\sum_{j=1}^{n} x_{ij} \leq a_i \text{ for } i = 1,2,3\ldots,n$$

$$\sum_{j=1}^{n} c_{ij} \leq b_j \text{ for } j = 1,2,3\ldots,m$$

$x_{ij \geq 0}$for i=1,2,3….,m and j=1,2,3…..n.

This is a linear program with m × n decision variables, m + n functional constraints, and m × n nonnegative constraints

Table 3.1 Transfer stations (Decision Variables)

Transfer Station	Code
Sheetla Mata Road	A1
Kadipur Chowk	A2
Saraswati Kunj	A3
Atul Kataria Chowk	A4

Objective function: The objective function contains costs associated with each of the variables. It is a minimization problem.

Waste container locations BX(X=1,….33)

3.4.5 Modelling the problem using excel solver

The first step is to organize the spreadsheet to represent the model. Once the model is implemented in a spreadsheet, next step is to use the Solver to find the solution. In the Solver, we need to identify the locations (cells) of objective function, decision variables, nature of the objective function (minimize) and constraints.

Step by step solution of the problem using Excel Solver is given below:

Step 1: At first we will construct a table in excel that will contain cost parameter (distance) between each constraint.

Here in this excel sheet, container at different locations are given name B1 to B33 indicating 33 waste container locations, and there distance (in Kilo metre) to transfer stations is calculated using Google map.

This table corresponds to input data which represents distance between container locations and 4 transfer stations.

L	M	N	O	P	Q
	TO				
CONTAINER LOCATIONS	Sheetla Mata Road (A1)	Kadipur Chowk(A2)	Saraswati Kunj(A3)	Atul Kataria chowk (A4)	
B1	0.5	0	4	5.2	
B2	1.1	0.9	4.2	5.5	
B3	1.3	1.7	4.7	5.7	
B4	1.4	1.2	5	6	
B5	1.9	2.4	6.2	6.5	
B6	1.7	3.2	7	7.5	
B7	2	3.5	7.6	8.2	
B8	2.2	3.8	8	8.5	
B9	1.5	0.5	0.3	4.2	
B10	2	0.9	1.3	4.5	
B11	1.5	1.3	1.2	4.4	
B12	2.4	1.7	2.5	5	
B13	3.1	2	3	5.5	
B14	2.9	1.8	3.2	6	
B15	3.4	3.4	4.1	4.4	
B16	3	1.9	4	4	
B17	4	3.2	0.3	0.4	
B18	3.9	3.4	0.5	0.6	
B19	4.5	3.7	0.9	1.2	
B20	5.5	3.5	1	1.4	
B21	5.3	4	1.3	1.1	
B22	5.7	4.4	1.6	1.2	
B23	6	4.2	1.7	2.3	
B24	5.9	3.9	2	1.9	
B25	5.7	4.2	1.8	1.5	
B26	6.1	3.9	1.2	1.5	
B27	5.2	0.7	0.7	1	
B28	6.3	4.6	1.5	1.5	
B29	6.9	4.5	3	1	
B30	7.5	5	3.1	1.3	
B31	8	5.5	3.3	1.4	
B32	7.2	5.4	3.6	1.7	
B33	9.2	5.9	2	2	

Figure 3.2 Input Table Representing distance in kilometre of container location from 4 transfer stations

Step 2: Creating output table with constraints in it. It gives solid waste in metric tons that goes from source to destination.

On I column in figure 3.2 extreme right, it indicates the waste received daily at that particular BX(X varies from 1 to 33) container location, hence there is a limit that waste transfers form BX (X varies from 1 to 33) will be equal to the waste produced at that particular location.

In row 38 in figure 3.2, shows the capacity of particular transfer station in metric ton. Hence there is a limit that waste received at particular transfer station will not exceed its capacity.

This output table which is to be determined shows that given waste container BX(X=1 TO 33) it has 4 different options where it can be transferred.

	A	B	C	D	E	F	G	H	I
1		TO				Objective value		0	
2	CONTAINER LOCATIONS	Sheetla Mata Road (A1)	Kadipur Chowk(A2)	Saraswati Kunj(A3	Atul Kataria chowk (A4)				Waste Generated(in MT)
3	B1					0			1.5
4	B2					0			1.3
5	B3					0			1.4
6	B4					0			1.5
7	B5					0			1.3
8	B6					0			1.2
9	B7					0			1.1
10	B8					0			2
11	B9					0			2.2
12	B10					0			1.3
13	B11					0			1.3
14	B12					0			1.6
15	B13					0			1.2
16	B14					0			2
17	B15					0			1.5
18	B16					0			1.3
19	B17					0			1.7
20	B18					0			1.4
21	B19					0			1.5
22	B20					0			1.3
23	B21					0			1.3
24	B22					0			1.2
25	B23					0			1.3
26	B24					0			1.4
27	B25					0			1.9
28	B26					0			1.7
29	B27					0			2.2
30	B28					0			2
31	B29					0			1.7
32	B30					0			1.4
33	B31					0			1.3
34	B32					0			1.3
35	B33					0			1.2
36		0	0	0	0				
37		<=	<=	<=	<=				
38	Capacity of trasfer station (in MT)	20	20	25	25				

Figure 3.3 Output Table to be determined

Step 3: Now we will create a cell that will automatically calculate objective value.

F	G	H
Objective value		0

Figure 3.4 Objective Value

To calculate total cost we need the function SUMPRODUCT. This will automatically sum all the product of unit and cost per unit.

i.e. Total Cost =sumproduct(B3:E35,M3:P35)

Step 4: In this step we will setup Excel Solver according to this problem. First we will open Solver from Data tab and locate the Total Minimum Cost cell in to 'Set Objective' in solver (i.e. H1). As we want to minimize the function we will choose 'Min'.

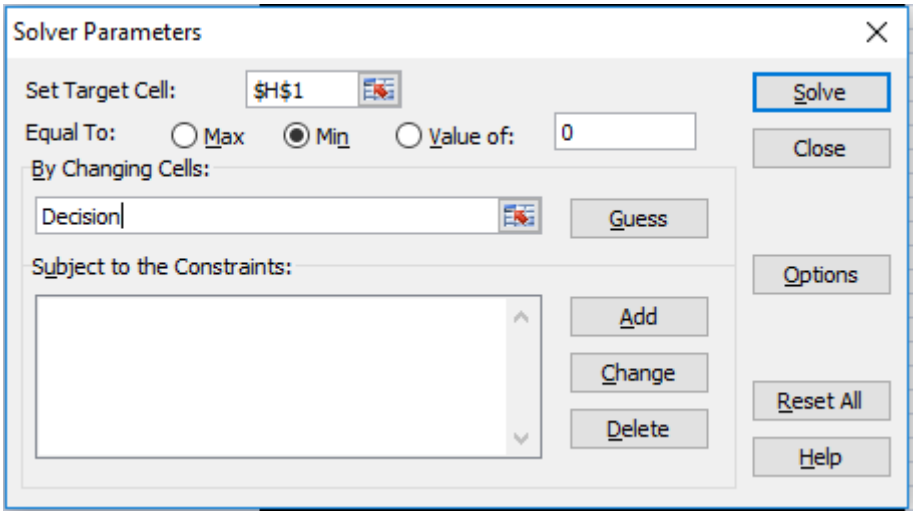

Figure 3.5 Solver Parameters

Step 5: Now we will add constrains of this problem in Solver. As previously discussed, there are two constrains in this problem.

Constraint 1st:- Sum total solid waste received at each transfer station should be less than or equal to its capacity.

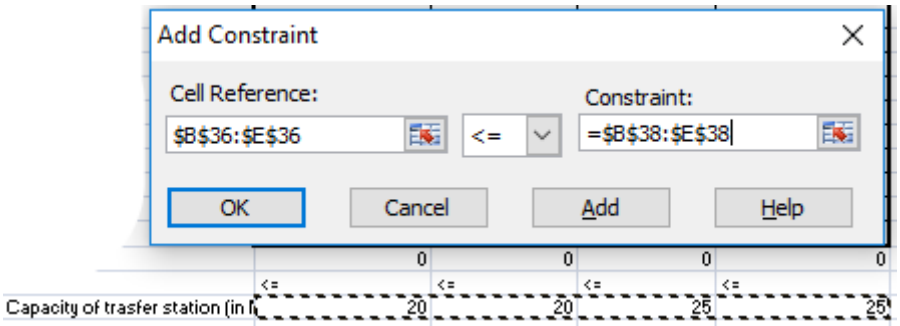

Figure 3.6 Constraint 1

Constraint 2nd:- Sum of the solid waste transported from each waste container would be equal to waste generated at that location.

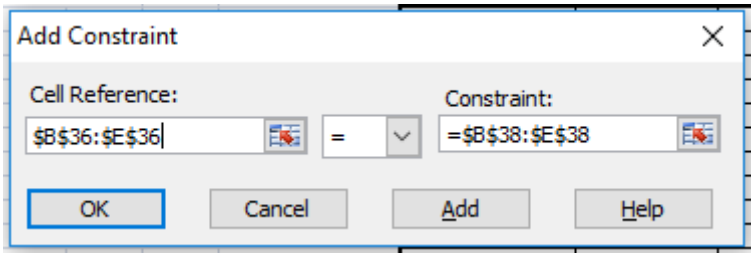

Figure 3.7 Constraint 2nd

Step 6:-Constraints are added in solver, now we are done with the setup, all that is left is to click on ‘Solve’ button. This way we will find the following solution from Solver.

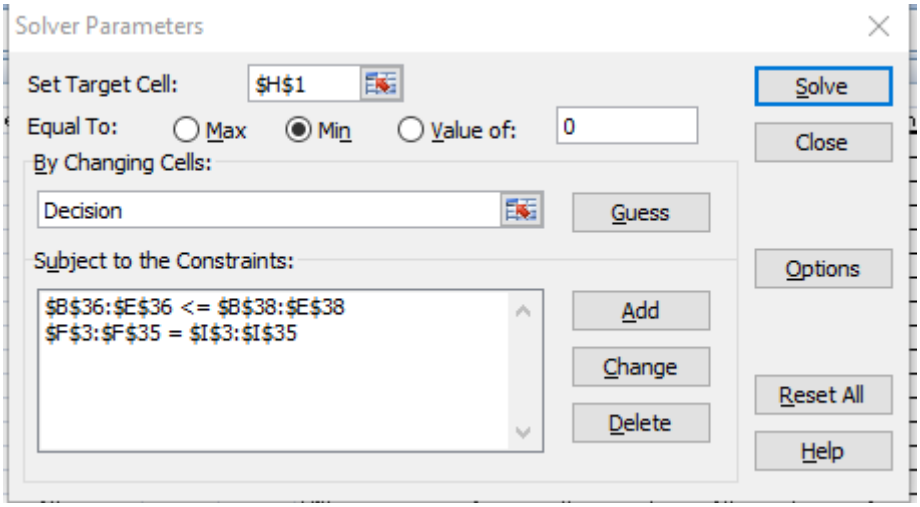

Figure 3.8 Solver

Chapter 4

Results and Discussions

4.1 Results from Excel Solver

	A	B	C	D	E	F	G	H	I
1		TO				Objective value		67	
2	CONTAINER LOCATIONS	Sheetla Mata Road (	Kadipur Chowk(A2)	Saraswati Kunj(A3)	Atul Kataria chowk (A4)				Waste Generated(In MT)
3	B1	1.5	0	0	0	1.5		1.5	1.5
4	B2	0	1.3	0	0	1.3		1.3	1.3
5	B3	1.4	0	0	0	1.4		1.4	1.4
6	B4	0	1.5	0	0	1.5		1.5	1.5
7	B5	1.3	0	0	0	1.3		1.3	1.3
8	B6	1.2	0	0	0	1.2		1.2	1.2
9	B7	1.1	0	0	0	1.1		1.1	1.1
10	B8	2	0	0	0	2		2	2
11	B9	0	0	2.2	0	2.2		2.2	2.2
12	B10	0	1.3	0	0	1.3		1.3	1.3
13	B11	0	0	1.3	0	1.3		1.3	1.3
14	B12	0	1.6	0	0	1.6		1.6	1.6
15	B13	0	1.2	0	0	1.2		1.2	1.2
16	B14	0	2	0	0	2		2	2
17	B15	0.75	0.75	0	0	1.5		1.5	1.5
18	B16	0	1.3	0	0	1.3		1.3	1.3
19	B17	0	0	1.7	0	1.7		1.7	1.7
20	B18	0	0	1.4	0	1.4		1.4	1.4
21	B19	0	0	1.5	0	1.5		1.5	1.5
22	B20	0	0	1.3	0	1.3		1.3	1.3
23	B21	0	0	0	1.3	1.3		1.3	1.3
24	B22	0	0	0	1.2	1.2		1.2	1.2
25	B23	0	0	1.3	0	1.3		1.3	1.3
26	B24	0	0	0	1.4	1.4		1.4	1.4
27	B25	0	0	0	1.9	1.9		1.9	1.9
28	B26	0	0	1.7	0	1.7		1.7	1.7
29	B27	0	1.1	1.1	0	2.2		2.2	2.2
30	B28	0	0	1	1	2		2	2
31	B29	0	0	0	1.7	1.7		1.7	1.7
32	B30	0	0	0	1.4	1.4		1.4	1.4
33	B31	0	0	0	1.3	1.3		1.3	1.3
34	B32	0	0	0	1.3	1.3		1.3	1.3
35	B33	0	0	0.6	0.6	1.2		1.2	1.2
36		9.25	12.05	15.1	13.1				
37		<=	<=	<=	<=				
38	Capacity of trasfer station (in MT)	20	20	25	25				
39									

Figure 4.1 Optimized Results (in Metric Tons)

This is the result from excel solver, which indicates which transfer station should receive solid waste (in metric tons) from which container location in order to minimize the cost. Here cost parameter is distance. Hence it shows that an optimal network of waste collection system can be built using this optimization. The waste received at each transfer station is less than its capacity means it is built with keeping future requirements also. But there is a need of optimization at container locations because waste generated is not uniform, as there are certain locations where waste collected is more and at some location less waste is being received.

The capacity of transfer station A1 and A2 is 20 metric tons and tat of A3 and A4 is 25 metric tonnes and waste received at these locations after optimizing is 9.25, 12.05, 15.1 and 13.1 metric tonnes from different locations.

4.2 Results from questioner

These data are conclusion obtained from questioner set of 11 questions**.** A total of 300 respondents were interviewed using a structured interview. Table 4.1 represents the number of respondents from each location**.** A total of 300 respondents were interviewed using a structured interview.

Table 4.1 No. of Respondents

Locality	Number of respondents
South City-1	100
Greenwood City	100
Nirvana Country	100
Total	300

4.2.1 Respondents by category and gender

Table 4.2 Category wise distribution of respondents of South City-1

Respondents	Resident	Unauthorised Vendor	Trader	Total
Sex:- Male	20	3	4	27
Female	53	5	15	73
Total	73	8	19	100

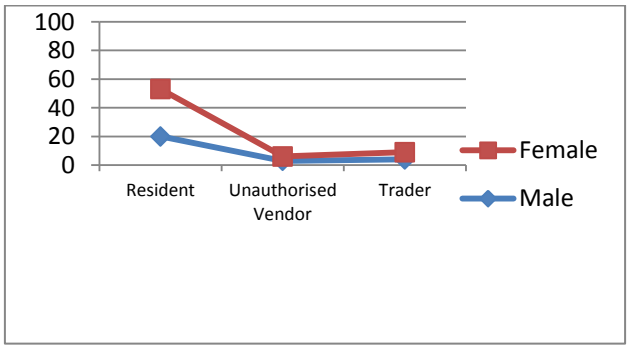

Figure 4.2 Graphical comparison of above data

Table 4.3 Category wise distribution of respondents of Green wood city

Respondents	Resident	Unauthorised Vendor	Trader	Total
Sex:- Male	17	4	15	36
Female	53	3	8	64
Total	70	7	23	100

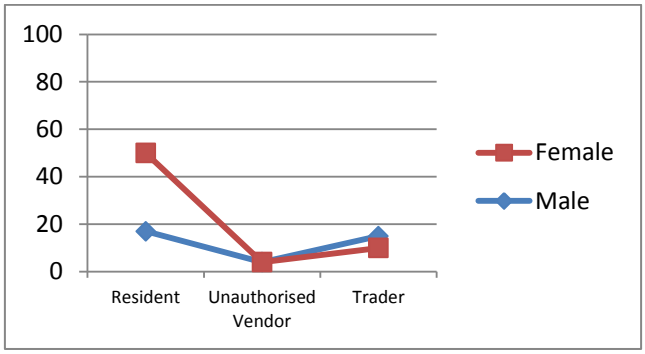

Figure 4.3 Graphical comparison of above data

Table 4.4 Category wise distribution of respondents of Nirwana Country

Respondents	Resident	Unauthorised Vendor	Trader	Total
Sex:- Male	14	6	17	37
Female	51	4	8	63
Total	65	10	25	100

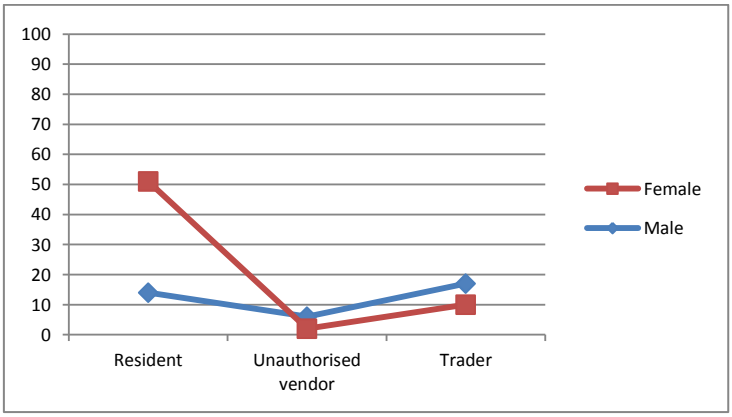

Figure 4.4 Graphical comparison of above data

These table above shows that in the major respondent categories, more female respondents were sampled than their male counterparts. However, this was not purposively done, but was due to the convenience sampling procedure that was adopted in this study.

4.3 Calculation of approximate weight generated from household/commercial places

The biggest challenge is to calculate the amount of waste that is being disposed daily, for this used a digital weighing balance and concluded that waste of nearly 1.3 to 1.7 kg is generated from household of 4-6 persons. It is observed that retailers like restaurants, vegetable vendors, food stalls are major contributors of solid waste from market and waste generated has seen a huge variance depending upon the scale of operation and can contribute to 20-30kg for and on lower side 6-7kg and to come on single data simple average is being taken into account depending upon their operation size and total waste generated from market is simply calculated by counting no. of such contributing sources.

4.4 Role players in solid waste disposal

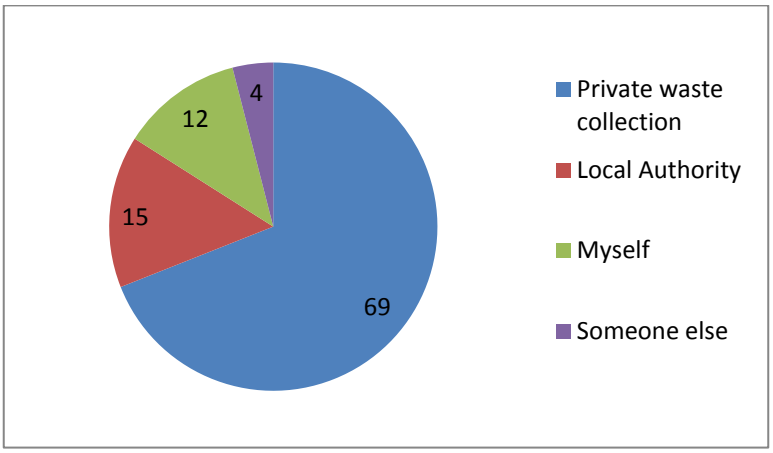

Figure 4.5 Response comparison

The respondents were asked to answer who takes the solid waste from their premises, for disposal. The biggest proportion of the respondents takes the solid waste for disposal by private waste collection. The response "myself" represents that the person who was interviewed is the one who carries the waste away by themselves. The response someone else implies that another person other than the one who was interviewed in the residence, or commercial premises, took the waste away for disposal.

4.5 Public participation in Solid Waste Management

The respondents were asked whether they possessed and used waste containers in their homes (for residents), at their shops (for traders) and, at their stalls (for unauthorised vendors). This was asked to establish, at that level, whether the people bother to have their waste collected in containers.

Table 4.4 Comparative table representing use of waste container by respondents

Locality			Possession of waste container		Total
			Yes	No	
South City 1	Type of respondent	1) Resident 2) Unauthorised Vendor 3) Retail shops	73 2 13	0 6 6	73 8 19
Total					100
Greenwood City	Type of respondent	1) Resident 2) Unauthorised Vendor 3) Retail shops	70 3 18	0 4 5	70 7 23
Total					100
Nirvana Country	Type of respondent	1) Resident 2) Unauthorised Vendor 3) Retail shops	67 4 17	0 4 8	67 8 25
Total					100
Total			267	33	300

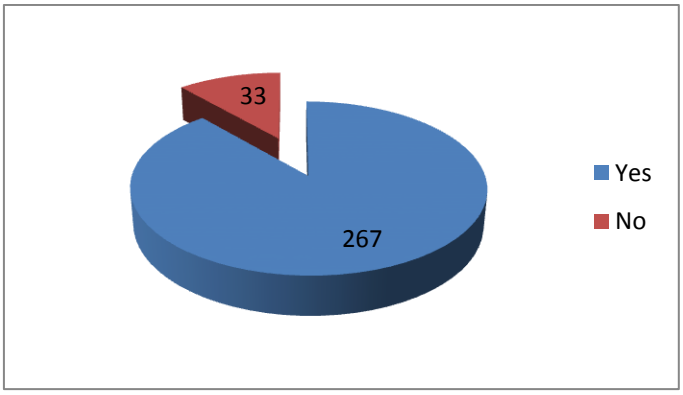

Figure 4.6 Conclusion of the above data

From the above outcome, it can be concluded that residents are aware of to keep bins at their home, from sanitation point of view. This awareness lack in unauthorised vendors, thus on

site disposal of waste is taking place which causes unhygienic conditions, and in case of traders as depending upon their work they have kept bins like food shop will keep a dustbin because there would be huge amount of waste due to use of disposable items and food waste. A trader like property dealer has not kept bins, because of type of work trader is related to. Other than this, it can be concluded that there is lack of awareness in unauthorised vendors and if this is increased than there won't be illegal dumping of waste.

4.6 On site Waste Sorting

Table 4.5 Comparative table representing on site waste sorting

Locality			On site waste sorting Yes	No	Total
South City 1	Type of respondent	1) Resident 2) Unauthorised Vendor 3) Retail shops	49 0 9	24 8 10	73 8 19
Total					100
Greenwood City	Type of respondent	1) Resident 2) Unauthorised Vendor 3) Retail shops	47 0 12	23 7 11	70 7 23
Total					100
Nirvana Country	Type of respondent	1) Resident 2) Unauthorised Vendor 3) Retail shops	44 0 18	23 7 8	67 7 26
Total					100
Total			179	121	300

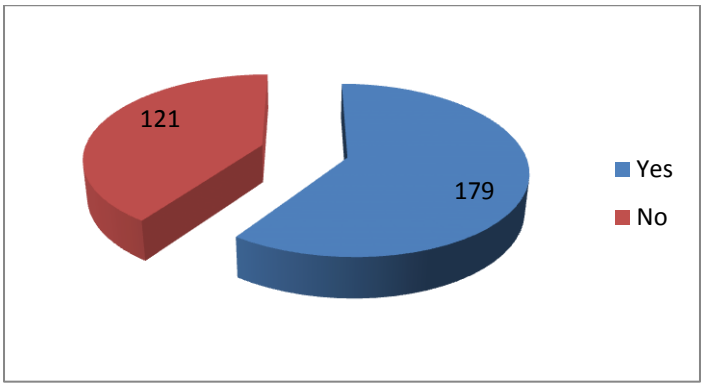

Figure 4.7 Conclusion of above data

In order to establish the level of concern and effort by the public, in solid waste management, respondents were asked questions regarding their waste disposal mannerism and practices.

Those who responded “YES” to this question; were asked to specify the kind of items they reused. During the interviews, requested some of the respondents to say what they reused

- Cardboard boxes which some used as waste containers (especially the traders in shops and merchandise stores)
- Sacks (were mostly specified by traders and market vendors). Sacks usually are used for packing grain and serials but when they are empty, instead of disposing them off, some traders explained that they sold them to customers and used others to separate their cereals and grain for display in their shops. Old clothes were also reused especially for cleaning (mopping the house) for the case of residents. In one of the residences, a respondent said that he used the old clothes for washing the car, while one trader said he used old clothes for making pillows sale.
- Old cans; these were reused as waste containers in some homes as well as by some traders who could dump in the waste which was not needed.
- Polythene bags; some respondents recounted that they used old polythene bags for carrying items from the market (instead of buying new ones each time they do shopping).

Chapter 5

Conclusions

The results from optimization indicated that, there is requirement of analysis of size of bins to be kept at each location as there is variation in waste collected at each location. The capacity at transfer station is appropriate and is more than current requirement, as these are developed areas; increase in solid waste due to future expansion is less. Increase in solid waste would probably because of increase in living standards. There will be some real life constrains, which we won't be able to solve with any model. In those cases, we will have to depend on our intuition and experience. Waste reduction through waste reuse is a primary function of the public at the stage of waste generation. Gurugram Municipal Corporation can use this model as decision support tool for efficient management of moving the solid waste, fuel consumption.

Optimization problems could be solved more easily with linear programming approach if one should be able to formulate the problem using linear equation for both the objective function and the binding constraints or restrictions. The major proportion of the wastes emanates from the residential sectors and recycling is not currently practiced formally in the metropolis. The consequences of the poor waste management are manifested in environmental degradation, road encroachment, air pollution, residential land encroachment and loss of aesthetic view of the metropolis. From face to face interview came to know that there is need of creating awareness amongst people about waste management.

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Appendix

Structured interview instrument for residents/traders and market vendors

STRUCTURED INTERVIEW FOR RESIDENTS/TRADERS AND MARKET VENDORS

Optimization model for Integrated Municipal Solid Waste Management in Gurugram

Dear respondent,

I am a student at the Delhi Technological University pursuing a master's degree in Environmental Engineering. I am in my second year of study and as part of the requirements for the program; I have to conduct a study. I am therefore carrying out a study of Optimization Model for Integrated Municipal Solid Waste Management in Gurugram. I request you to allow me ask you some questions which you can answer as you feel. The information you will give will be treated confidentially and will be anonymously used for purposes of writing the thesis, and will not be used for any other purpose. Thank you very much in advance.

Aakash Patel

IDENTIFICATION DATA

PART 1

1) **Type of respondent**
    a) **Resident**
    b) **Unauthorised Vendor**
    c) **Retail shops**
2) **Sex**
    a) **Male**
    b) **Female**

PART II

ROLE PLAYED BY RESIDENTS IN SOLID WASTE MANAGEMENT

3) **Do you have any waste container in home/shop/stall?**
    a) **Yes**
    b) **No**

4) **Do you sort waste container in your home/shop/stall?**
    a) **Yes**
    b) **No**

5) **Are there any items which you reuse?**
    a) **Yes**
    b) **No**

    If yes please specify

6) **Who takes the waste from your home/shop/stall for disposal?**
    a) **Myself**
    b) **Local Authority**
    c) **Private waste collector**
    d) **Someone else**

PART III

ROLE THE RESIDENTS CAN PLAY IN SOLID WASTE MANAGEMENT

7) **Do you think you can reduce on the amount of waste you generate in your home/shop/stall?**
    a) **Yes**
    b) **No**

8) **Do you think it helps to sort waste before disposing it of?**
    a) **Yes**
    b) **No**

9) **Which waste items do you think should be sorted for recycling?**
    a) **Hard Plastics**
    b) **Polythene**
    c) **Glass**
    d) **Paper**
    e) **Metal**
    f) **If Other, please specify**

10) **Do you think it is necessary for you to work together with other residents/traders/market vendors for better waste management?**
    a) **Yes**
    b) **No**

11) **Approximate waste generated**

Thank you very much for your time.