CHAPTER 3

COMPOSITION AND QUANTITY OF SOLID WASTE

3.1 INTRODUCTION

The information on the nature of wastes, its composition, physical and chemical characteristics – and the quantities generated are basic needs for the planning of a Solid Waste Management system.

3.1.1 Terminology and Classification

In the literature, it is observed that various authors have used different terminology to describe the nature of wastes. In this text, 'composition' refers to the limited list of components or constituents, such as paper, glass, metal, plastic and garbage, into which an aggregate of municipal waste may conveniently be separated. 'Characteristics' on the other hand, refers to those physical and chemical properties, which are relevant to the storage, collection, treatment and disposal of waste such as density, moisture content, calorific value and chemical composition. In addition to these general terms, there are a number of more specific terms which, for greater clarity, must also be defined. A comprehensive list of definitions is therefore presented later in this chapter. Some terms, like 'domestic waste' and municipal waste refer to the sources of the wastes, while others, such as 'garbage', 'street waste' and 'hazardous waste', indicate the types of wastes.

3.1.2 Variations in Composition and Characteristics

An examination of the composition and characteristics of wastes in different parts of the country underscores the profound influences of national income, socio-economic conditions, social developments and cultural practices, and thereby focuses attention on the importance of obtaining the data locally.

Since different kinds of solid waste management system are designed for the future as well as the present, careful consideration should be given to changes that may occur during the design life of a system. Changes are inevitable, occur at an increasingly rapid rate in response to the increasing pace of social and technological development and the nature and extent of such changes can not be predicted with accuracy. A built-in flexibility in the waste management system hence becomes essential. Nevertheless, it is possible to identify some of the factors that are likely to cause changes in waste composition and characteristics, which will enable planners to make reasonable judgements about the future.

3.2 DEFINITIONS AND CLASSIFICATION OF SOLID WASTES

In order to plan, design and operate a solid waste management system, a thorough knowledge of the quantities generated, the composition of wastes and its characteristics are essential. As a first step, a proper definition of the terms is necessary to avoid the general confusion that is common in the usage of these terms.

3.2.1 Definitions

There are many terms, which relate to the types and sources of wastes and these too must be defined. Based on the source, origin and type of waste a comprehensive classification is described below:

(i) Domestic/Residential Waste:

This category of waste comprises the solid wastes that originate from single and multi-family household units. These wastes are generated as a consequence of household activities such as cooking, cleaning, repairs, hobbies, redecoration, empty containers, packaging, clothing, old books, writing/new paper, and old furnishings. Households also discard bulky wastes such as furniture and large appliances which cannot be repaired and used.

(ii) Municipal Waste:

Municipal waste include wastes resulting from municipal activities and services such as street waste, dead animals, market waste and abandoned vehicles. However, the term is commonly applied in a wider sense to incorporate domestic wastes, institutional wastes and commercial wastes.

(iii) Commercial Waste:

Included in this category are solid wastes that originate in offices, wholesale and retail stores, restaurants, hotels, markets, warehouses and other commercial establishments. Some of these wastes are further classified as garbage and others as rubbish.

(iv) Institutional Waste:

Institutional wastes are those arising from institutions such as schools, universities, hospitals and research institutes. It includes wastes which are classified as garbage and rubbish as well as wastes which are considered to be hazardous to public health and to the environment.

(v) Garbage:

Garbage is the term applied to animal and vegetable wastes resulting from the handling, storage, sale, preparation, cooking and serving of food. Such wastes contain putrescible organic matter, which produces strong odours and therefore attracts rats, flies and other vermin. It requires immediate attention in its storage, handling and disposal.

(vi) Rubbish:

Rubbish is a general term applied to solid wastes originating in households, commercial establishments and institutions, excluding garbage and ashes.

(vii) Ashes:

Ashes are the residues from the burning of wood, coal, charcoal, coke and other combustible materials, for cooking and heating in houses, institutions and small industrial establishments. When produced in large quantities at power generating plants and factories these wastes are classified as industrial wastes. Ashes consist of a fine powdery residue, cinders and clinker often mixed with small pieces of metal and glass.

(viii) Bulky Wastes:

In this category are bulky household wastes which cannot be accommodated in the normal storage containers of households. For this reason they require special collection. In developed countries bulky wastes are large household appliances such as cookers, refrigerators and washing machines as well as furniture, crates, vehicle parts, tyres, wood, trees and branches. Metallic bulky wastes are sold as scrap metal but some portion is disposed of at sanitary landfills.

(ix) Street Sweeping:

This term applies to wastes that are collected from streets, walkways, alleys, parks and vacant lots. In the more affluent countries manual street sweeping has virtually disappeared but it still commonly takes place in developing countries, where littering of public places is a far more widespread and acute problem. Mechanised street sweeping is the dominant practice in the developed countries. Street wastes include paper, cardboard, plastic, dirt, dust, leaves and other vegetable matter.

(x) Dead Animals:

This is a term applied to dead animals that die naturally or accidentally killed. This category does not include carcass and animal parts from slaughterhouses which are regarded as industrial wastes. Dead animals are divided into two groups, large and small. Among the large animals are horses, cows, goats, sheep, hogs and the like. Small animals include dogs, cats, rabbits and rats. The reason for this differentiation is that large animals require special equipment for lifting and handling during their removal. If not collected promptly, dead animals are a threat to public health because they attract flies and other vermin as they putrefy. Their presence in public places is particularly offensive and emits foul smell from the aesthetic point of view.

(xi) Construction and Demolition Wastes:

Construction and demolition wastes are the waste materials generated by the construction, refurbishment, repair and demolition of houses, commercial buildings and other structures. It mainly consists of earth, stones, concrete, bricks, lumber, roofing materials, plumbing materials, heating systems and electrical wires and parts of the general municipal waste stream, but when generated in large amounts at building and demolition sites, it is generally removed by contractors for filling low lying areas and by urban local bodies for disposal at landfills.

(xii) Industrial Wastes:

In the category are the discarded solid material of manufacturing processes and industrial operations. They cover a vast range of substances which are unique to each industry. For this reason they are considered separately from municipal wastes. It should be noted, however, that solid wastes from small industrial plants and ash from power plants are frequently disposed of at municipal landfills. For details please refer to **Chapter 6** on **“Industrial Wastes”**.

(xiii) Hazardous Wastes:

Hazardous wastes may be defined as wastes of industrial, institutional or consumer origin which, because of their physical, chemical or biological characteristics are potentially dangerous to human and the environment. In some cases although the active agents may be liquid or gaseous, they are classified as solid wastes because they are confined in solid containers. Typical examples are: solvents, paints and pesticides whose spent containers are frequently mixed with municipal wastes and become part of the urban waste stream. Certain hazardous wastes cause explosions in incinerators and fires at landfill sites. Others, such as pathological wastes from hospitals and radioactive wastes, require special handling at all time. Good management practice should ensure that hazardous wastes are stored, collected, transported and disposed off separately, preferably after suitable treatment to render them innocuous. For details please refer to **Chapter 7** on **"Bio-Medical Wastes"**.

(xiv) Sewage Wastes:

The solid by-products of sewage treatment are classified as sewage wastes. They are mostly organic and derive from the treatment of organic sludge from both the raw and treated sewage. The inorganic fraction of raw sewage such as grit is separated at the preliminary stage of treatment, but because it entrains putrescible organic matter which may contain pathogens, must be buried/disposed off without delay. The bulk of treated, dewatered sludge is useful as a soil conditioner but invariably its use for this purpose is uneconomical. The solid sludge therefore enters the stream of municipal wastes unless special arrangements are made for its disposal.

3.2.2 Classification

Because of the heterogeneous nature of solid wastes, no single method of classification is entirely satisfactory. In some cases it is more important for the solid waste specialist to know the source of waste, so that classifying wastes as domestic, institutional or commercial, for example, is particularly useful. For other situations, the types of waste, garbage, rubbish, ashes, street waste is of greater significance because it gives a better indication of the physical and chemical characteristics of the waste. The principal classification is given in **Table 3.1.** The first three types, garbage, rubbish and ashes are those which make up the bulk of municipal wastes, derived principally from households, institutions and commercial areas. These wastes pose the most alarming/serious problems in urban areas.

Table 3.1 : Classification of Solid Wastes

TYPES OF SOLID WASTE	DESCRIPTION	SOURCES
Food waste (garbage)	Wastes from the preparation, cooking, and serving of food. Market refuse, waste from the handling, storage, and sale of produce and meats and vegetable	
Rubbish	**Combustible** (primary organic) paper, cardboard, cartons wood, boxes, plastics, rags, cloth, bedding, leather, rubber, grass, leaves, yard trimmings **Noncombustible** (primary inorganic) metals, tin cans, metal foils dirt, stones, bricks, ceramics, crockery, glass bottles, other mineral refuse	Households, institutions and commercial such as hotels, stores, restaurants, markets, etc.
Ashes and Residues	Residue from fires used for cooking and for heating buildings, cinders, clinkers, thermal power plants.	
Bulky waste	Large auto parts, tyres, stoves refrigerators, others large appliances, furniture, large crates, trees, branches, palm fronts, stumps, flotage	
Street waste	Street sweepings, Dirt, leaves, catch basin dirt, animal droppings, contents of litter receptacles dead animals	Streets, sidewalks, alleys, vacant lots, etc.
Dead animals	Small animals: cats, dogs, poultry etc. Large animals: horses, cows etc.	
Construction & demolition waste	Lumber, roofing, and sheathing scraps, crop residues, rubble, broken concrete, plaster, conduit pipe, wire, insulation etc.	Construction and demolition sites, remodeling, repairing sites
Industrial waste & sludges	Solid wastes resulting from industry processes and manufacturing operations, such as food processing wastes, boiler house cinders, wood, plastic and metal scraps and shaving, etc. Effluent treatment plant sludge of industries and sewage treatment plant sludges, coarse screening, grit & septic tank	Factories, power plants, treatment plants, etc.
Hazardous wastes	Hazardous wastes: pathological waste, explosives, radioactive material, toxic waste etc.	Households, hospitals, institution, stores, industry, etc.
Horticulture Wastes	Tree-trimmings, leaves, waste from parks and gardens, etc.	Parks, gardens, roadside trees, etc.

Source: Solid Waste Management in Developing Countries by Bhide & Sunderasan, INSDOC April, 1983

3.3 COMPOSITION, CHARACTERISTICS AND QUANTITIES

3.3.1 Need for Analysis

An analysis of the composition, characteristics and quantities of solid wastes is essential for the following reasons:

- It provides the basic data on which the management system is planned, designed and operated
- The changes/trend in composition and quantity of waste over a period of time are known which help in future planning
- It provides the information for the selection of equipment and appropriate technology
- It indicates the amount and type of material suitable for processing, recovery and recycling
- The forecast trends assist designers and manufacturers in the production of vehicles and equipment suitable for future needs.

For such information to be of the widest possible benefit it must be collected by a responsible national, regional or local authority and made available to all who require it.

3.3.2 Field Investigations

Field investigations are necessary for providing the basic data on solid wastes and are carried out in three ways:

- Weighing of vehicles at disposal sites
- Sorting of wastes into predetermined components for weighing and sampling in order to determine the percentage of each component and the physical and chemical characteristics of the wastes.
- Visiting institutional and industrial sites to identify wastes being generated and disposal methods being used.

The weighing of loaded and unloaded vehicles is accomplished with a weighing scale or weighbridge with a capacity of 20,000 kg. The loaded vehicles are weighed when they enter the disposal site and empty vehicles are weighed when they leave the site after unloading. Weighing is carried out each day of weighing period in order to determine the average weight. Ideally the weighing scale should be operated during the entire daily period of operation of the landfill site, round the clock, if necessary. A shift system should be employed, the weighing team comprising four workers for each scale – a supervisor, an assistant and two helpers moving the scale platform to the desired spacing for each vehicle.

The quantities of waste measured at disposal sites more correctly reflect the quantities being disposed rather than those generated since the measurements do not include:

- Waste salvaged at the site of generation
- Waste disposed of in unauthorised places-empty lots, alleys, ditches etc.
- Waste salvaged by collectors
- Waste salvaged at the disposal site

Differences between the two are insignificant with well-managed collection systems, enlightened public attitude and strict enforcement of legislation. This is frequently not the case, particularly in some cities and it is then necessary to measure waste quantities at source. Flintoff (1984) describes a method for collecting samples with the active cooperation of householders wherein containers or plastic bags are filled by a representative number of householders and labeled before being taken to the depot where the contents are weighed and the volume measured.

Sorting is carried out manually, each sample size being about 100-150 kg for desired accuracy of analysis. This process separates the waste into pre-determined components, each component being separately weighed. Equipment used for this purpose includes:

- A sorting table, 3m long x 1.5m wide
- A measuring box, 1m long x 0.5m wide x 1m high
- Bins or boxes for storage of about 60 litre i.e. 0.06 m^3 capacity sorted material
- A platform weighing machine – 500 Kg

This procedure may not be feasible in developing countries where time for study and resources are limited. For such situations a suitable procedure of sample collection is described.

3.3.3 Number of Samples to be Collected

Solid waste is very heterogeneous in nature and its composition varies with place and time. Even samples obtained from the same place (sampling point) on the same day, but at different time may show totally different characteristics. Due to this reason the method by which the sample is collected and the number of samples collected is critical.

In the planning of sample survey, a stage is always reached at which some decision must be made about the size of the sample. This decision is extremely important as unduly large number of samples result in waste of resources, while less number of samples diminish the accuracy and utility of the results.

A method of determining the number of samples by statistical technique has been suggested by Dennis E. Carruth and Albert J. Klee*.

The data on physical analysis of solid waste is presented in percentage. Since the percentage of one constituent differs greatly from the other, the data follows a multinomial distribution. So the data is subjected to a normalising transformation by using arcsin function.

$$Y = 2 \arcsin \sqrt{X}$$

Where X is the original percentage value of a component expressed as a decimal; and

Y is transformed value of X.

To determine the number of samples required for composition analysis following formula is used.

$$n = (ZS/\delta)^2$$

Where,

n	=	number of samples
Z	=	the standard normal deviate for confidence level desired
S	=	estimated standard deviation (transformed basis)

* Analysis of Solid Waste Composition, Statistical Technique to Determine Sample Size, SW-19ts, US Department of Health, Education and Welfare, Bureau of Solid Waste Management, 1969

δ = sensitivity (transformed basis)

$$= \left| 2 \arcsin \sqrt{X} - 2 \arcsin \sqrt{X \pm \Delta} \right|$$

The value for Δ is set according to the desired level of precision. In this case the values for acceptable precision are obtained from the range e.g. paper content in Indian Cities ranges between 2.91 – 6.43%. The average percentage of paper content is 4.036. Therefore X = p.04036. (Y = 0.4045). There will be two values i.e. 0.02126 and 0.02394. The choice of sign for $X\pm\Delta$ is positive if X is less than 0.5. Therefore, corresponding values for $X\pm\Delta$ are 0.0516 & 0.0643 and transformed values Y -> 0.4582 & 0.5126.

Therefore
$$\delta_1 = \left| 2 \arcsin \sqrt{0.04036} - 2 \arcsin \sqrt{0.0516} \right| = \left| 0.4045 - 0.4582 \right| = 0.0537$$

and
$$\delta_2 = \left| 2 \arcsin \sqrt{0.04036} - 2 \arcsin \sqrt{0.0643} \right| = \left| 0.4045 - 0.5126 \right| = 0.1081$$

Substituting the values of δ_1 in equation $n = (ZS/\delta_1)^2$

We get n = 6

Z = 1.96, Z+0.684

Similarly substituting value of δ_2 in equation $n = (ZS/\delta_2)^2$

We get n = 2

Therefore samples required for paper is in the range of 2-6.

Similarly number of samples required for other constituents were calculated and results are given in **Table 3.2.**

An advantage of this method is that number of samples can also be determined for any important chemical parameter. For example, carbon to nitrogen (C/N) ratio is important for determining the suitability of the solid waste for composting. The number of samples required can be calculated from values of C/N ratio. Normally the range of C/N ratio in Indian Municipal Solid Waste is 21.13-30.94 and the typical average value of C/N ratio is 25.66. The desired precision can be obtained from upper and lower values of the range and the average.

Table 3.2 : Critical Statistics Obtained from Typical Indian Data

	X	**Y**	**V**	**Range (no. of samples)**
Paper	0.04036	0.4045	0.0742	2 – 6
Rubber, Leather & Synthetics	0.00596	0.1545	0.0298	13 – 35
Glass	0.00558	0.1495	0.0285	9 – 10
Metals	0.00506	0.1424	0.0277	13 – 20
Total Compostable Matter	0.4221	1.4144	0.1766	1 – 36
Inert	0.4793	1.4979	0.0731	2 – 3

X -> **mean of n observations expressed as decimals**
Y -> **transformed value of X**
V -> **standard deviation**

Data for C/N ratio is transformed as follows:

C/N ratio Average value	X	Y	δ	no. of samples
25.66	0.2566	1.0570	0.1137 0.0980	1

Number of samples can be calculated separately for nitrogen and carbon. The number of samples required in case of nitrogen is about 380 and that for carbon is one. Similarly number of samples can be calculated for Phosphorus, Potassium and other chemical parameters.

It is evident from the statistical results obtained from the method mentioned above that the number of samples to be taken does not exceed thirty-five in any case. Though larger number of samples will increase precision, the required number of samples for increased precision increase at a very large disproportionate rate making it very uneconomic and analysis a hard task. The basic aim should be to obtain a sample size which is a compromise between economy and precision.

3.3.4 Collection of Samples of Solid Waste

When collecting samples of municipal solid waste major collection sites are identified which are covering a larger size of population. Based on the type of area such as residential, commercial, industrial, market, slum etc. sampling points are distributed uniformly all over the study area. The sampling points are further classified based on economic status of population such as high, middle and low-income group.

About 10 kg of Municipal Solid Waste (MSW) is collected from ten points from outside and inside of the solid waste heap. The total quantity of waste so collected is thoroughly mixed and then reduced by method of quartering till a samples of such a size is obtained which can be handled in the laboratory. The sample so obtained is subjected to physical analysis, determination of moisture and then the sample is processed for further chemical analysis.

Samples collected for physical and chemical analysis are double bagged in plastic bags, sealed and sent to the laboratory for analysis, each sample being in the range 10 to 12 kg. Wastes from industries and institutions are usually investigated by visiting the facility, viewing the waste handling system and completing a questionnaire with the assistance of the plant manager or senior technical personnel.

3.3.5 Composition and Characteristics

The composition and characteristics of municipal solid wastes vary throughout the world. Even in the same country it changes from place to place as it depends on number of factors such as social customs, standard of living, geographical location, climate etc. MSW is heterogeneous in nature and consists of a number of different materials derived from various types of activities. Even then it is worthwhile to make some general observation to obtain some useful conclusions.

- The major constituents are paper and putrescible organic matter;
- Metal, glass, ceramics, plastics, textiles, dirt and wood are generally present although not always so, the relative proportions depending on local factors;
- The average proportion of constituents reaching a disposal site(s) for a particular urban area changes in long term although there may be significant seasonal variations within a year.

For these reasons an analysis of the composition of solid waste, for rich and poor countries alike, is expressed in terms of a limited number of constituents. It is useful in illustrating the variations from one urban center to another and from country to country. Data for different degrees of national wealth (annual per-capita income) are presented in **Table 3.3.** Waste composition also varies with socio-economic status within a particular community, since income determines life-style – consumption patterns and cultural behaviour.

Table 3.3 : Patterns of Composition, Characteristics and Quantities

	Low Income Countries (1)	**Middle Income Countries (2)**	**High Income Countries (3)**
Composition : (% by weight)			
Metal	0.2 – 2.5	1 – 5	3 – 13
Glass, Ceramics	0.5 – 3.5	1 – 10	4 – 10
Food and Garden waste	40 – 65	20 – 60	20 – 50
Paper	1 – 10	15 – 40	15 – 40
Textiles	1 – 5	2 – 10	2 – 10
Plastics/Rubber	1 – 5	2 – 6	2 – 10
Misc. Combustible	1 – 8	–	–
Misc. Incombustible	–	–	–
Inert	20 – 50	1 – 30	1 – 20
Density (kg/m^3)	250 – 500	170 – 330	100 – 170
Moisture Content (% by wt)	40 – 80	40 – 60	20 – 30
Waste Generation (kg/cap/day)	0.4 – 0.6	0.5 – 0.9	0.7 – 1.8

(1) Countries having a per capita income less than US$360 (1978 prices)
(2) Countries having a per capita income US$360-3500 (1978 prices)
(3) Countries having a per capita income greater than US$3500 (1978 prices)

Source : Holmes, J : Managing Solid Waste in Developing Countries.

Several conclusions may be drawn from this comparative data:

- The proportion of paper waste increases with increasing national income;
- The proportion of putrescible organic matter (food waste) is greater in countries of low income than those of high income;

- Variation in waste composition is more dependent on national income than geographical location, although the latter is also significant;
- Waste density is a function of national income, being two to three times higher in the low-income countries than in countries of high income;
- Moisture content is also higher in low-income countries; and
- The composition of waste in a given urban center varies significantly with socio-economic status (household income).

3.3.5.1 Characteristics of Municipal Solid Waste in Indian Urban Centres

National Environmental Engineering Research Institute (NEERI) has carried out extensive studieson characterisation of solid waste from 43 cities during 1970-1994. The average characteristics have been presented in **Tables 3.4 and 3.5.** The paper content generally varies between 2.9 to 6.5% and increases with the increase in population. The plastics, rubber and leather contents are lower than the paper content, and do not exceed 1% except in metropolitan cities. The metal content is also low, viz. less than 1%. The low values are essentially due to the large scale recycling of these constituents. During a study in Bombay (1993-94), samples were collected both at the source as well as disposal sites to ascertain the extent of recycling. The paper is recycled on a priority basis while the plastics and glass are recycled to a lesser extent. The biodegradable fraction is quite high, essentially due to the habit of using fresh vegetables in India. The high biodegradable fraction also warrants frequent collection and removal of solid waste from the collection points. The ash and fine earth content of Indian municipal solid waste is high due to the practice of inclusion of the street sweepings, drain silt, and construction and demolition debris in municipal solid waste. The proportion of ash and fine earth reduces with increase in population due to improvements in the road surfaces. Percentage of inert material increases with the increase in population may be due to fast than construction and demolition waste find its way into the municipal solid waste disposal stream. High ash and earth content increases the densities of municipal solid waste which are between 350 and 550 kg/m^3 in Indian cities.

The chemical characteristics indicate that the organic content of the samples on a dry weight basis ranges between 20 to 40%. The nitrogen, phosphorus and potassium content of the municipal solid waste ranges between 0.5 to 0.7%, 0.5 to 0.8% and 0.5 to 0.8% respectively. The calorific value ranges between 800-1000 kcal/kg. Knowledge of the chemical characteristics is essential in selecting and designing the waste processing and disposal facilities.

Ragpickers are observed to be more active in bigger cities. They prefer to remove paper, plastics, rags and packaging and such other material, which is light and also have a high calorific value. The remaining waste hence tends to have a higher inert content and a lower calorific value.

The demolition activity is observed to increase with population leading to increased inert content and reduced organic content in MSW.

Table 3.4 : Physical Characteristics of Municipal Solid Wastes in Indian Cities

Population Range (in million)	Number Of Cities Surveyed	Paper	Rubber, Leather And Synthetics	Glass	Metals	Total compostable matter	Inert
0.1 to 0.5	12	2.91	0.78	0.56	0.33	44.57	43.59
0.5 to 1.0	15	2.95	0.73	0.35	0.32	40.04	48.38
1.0 to 2.0	9	4.71	0.71	0.46	0.49	38.95	44.73
2.0 to 5.0	3	3.18	0.48	0.48	0.59	56.67	49.07
> 5	4	6.43	0.28	0.94	0.80	30.84	53.90

All values in table 3.4 are in percent, and are calculated on net weight basis

Source : Background material for Manual on SWM, NEERI, 1996

Table 3.5 : Chemical Characteristics of Municipal Solid Wastes in Indian Cities

Population range (in million)	No. of Cities surveyed	Moisture %	Organic matter %	Nitrogen as Total Nitrogen %	Phosphorous as P_2O_5 %	Potassium as K_2O %	C/N Ratio	Calorific value* in kcal/kg
0.1-0.5	12	25.81	37.09	0.71	0.63	0.83	30.94	1009.89
0.5-1.0	15	19.52	25.14	0.66	0.56	0.69	21.13	900.61
1.0-2.0	9	26.98	26.89	0.64	0.82	0.72	23.68	980.05
2.0-5.0	3	21.03	25.60	0.56	0.69	0.78	22.45	907.18
> 5.0	4	38.72	39.07	0.56	0.52	0.52	30.11	800.70

All values, except moisture, are on dry weight basis.
*Calorific value on dry weight basis

Source : Background material for Manual on SWM, NEERI, 1996.

3.3.6 Quantities

The information regarding waste quantity and density coupled with waste generation rate (by weight), is important while assessing the payload capacity of the collection equipment. It is possible to estimate the number of vehicles required for the collection and transportation of waste each day.

While per capita waste generation is a statistic, which is necessary for indicating trends in consumption and production, the total weight and volume of wastes generated by the community served by the management system are of greater importance in planning and design. As in all other aspects of data collection for the planning and design phases, data on waste generation, weight and volume should be collected by each authority for application in its own area of operation.

3.3.6.1 Per Capita Quantity of Municipal Solid Waste in Indian Urban Centres

The quantity of waste from various cities was accurately measured by NEERI. On the basis of quantity transported per trip and the number of trips made per day the daily quantity was determined. The quantity of waste produced is lesser than that in developed countries and is normally observed to vary between 0.2-0.6 kg/capita/day. Value upto 0.6 kg/capita/day are observed in metropolitan cities **(Table 3.6).** The total waste generation in urban areas in the country is estimated to be around 38 million tonnes per annum.

Forecasting waste quantities in the future is as difficult as it is in predicting changes of waste composition. The factors promoting change in waste composition are equally relevant to changes in waste generation. An additional point, worthy of note, is the change of density of the waste as the waste moves through the management system, from the source of generation to the point of ultimate disposal. Storage methods, salvaging activities, exposure to the weather, handling methods and decomposition, all have their effects on changes in waste density. As a general rule, the lower the level of economic development, the greater the change between generation and disposal. Increases in density of 100% are common in developing countries, which mean that the volume of wastes decreases by half.

Table 3.6 : Quantity of Municipal Solid Waste in Indian Urban Centres

Population Range (in million)	Number of Urban Centres (sampled)	Total population (in million)	Average per capita value (kg/capita/day)	Quantity (tonnes/day)
< 0.1	328	68.300	0.21	14343.00
0.1 – 0.5	255	56.914	0.21	11952.00
0.5 – 1.0	31	21.729	0.25	5432.00
1.0 – 2.0	14	17.184	0.27	4640.00
2.0 – 5.0	6	20.597	0.35	7209.00
> 5.0	3	26.306	0.50*	13153.00

* 0.6 kg/capita/day generation of MSW observed in metro cities

Source : Background material for Manual on SWM, NEERI, 1996

3.3.6.2 Estimation of Future Per Capita Waste Quantity

For purposes of project identification, where an indication of service level must be estimated and data from the project preparation stage have not yet been developed, the following municipal refuse generation rates are suggested:

Residential refuse	:	0.3 to 0.6 kg/cap/day
Commercial refuse	:	0.1 to 0.2 kg/cap/day
Street sweepings	:	0.05 to 0.2 kg/cap/day
Institutional refuse	:	0.05 to 0.2 kg/cap/day

If industrial solid waste is included in municipal refuse for collection and/or disposal purposes, from 0.1 to 1.0 kg/cap/day may be added at the appropriate step where the municipality must estimate service delivery requirements. These generation rates are subject to considerable site-specific factors and are required to be supported by field data.

3.3.6.3 Relation between Gross National Product (GNP) and Municipal Solid Waste Generation

The consumption of raw materials and finished product by the community is directly proportional to the Gross National Product (GNP) of the country. Since the solid waste quantities are directly proportional to the quantity of material consumed the increase in per capita solid waste quantities would be directly proportional to the per capita increase in GNP. **Table 3.7** shows the relation between GNP and expected generation of municipal solid waste, based on the study conducted by the United Nations in 1995.

Table 3.7 : Relation between GNP and Expected Generation of Municipal Solid Waste

Sl. No.	Country	During the year 1995			During the year 2025		
		GNP Per Capita (US$)	Urban Population (% of Total)	Urban MSW Generation (kg/capita/day)	GNP Per Capita (US$)	Urban Population (% of Total)	Urban MSW Generation (kg/capita/day)
Low Income		**490**	**27.8**	**0.64**	**1,050**	**48.8**	**0.6-1.0**
1.	Nepal	200	13.7	0.50	360	34.3	0.6
2.	Bangladesh	240	18.3	0.49	440	40.0	0.6
3.	Myanmar	240	26.2	0.45	580	47.3	0.6
4.	Vietnam	240	20.8	0.55	580	39.0	0.7
5.	Mangolia	310	60.9	0.60	560	76.5	0.9
6.	India	340	26.8	0.46	620	45.2	0.7
7.	Lao PDR	350	21.7	0.69	850	44.5	0.8
8.	China	620	30.3	0.79	1,500	54.5	0.9
9.	Sri Lanka	700	22.4	0.89	1,300	42.6	1.0
Middle Income		**1,410**	**37.6**	**0.73**	**3,390**	**61.1**	**0.8-1.5**
10.	Indonesia	980	35.4	0.76	2,400	60.7	1.0
11.	Philippines	1.050	54.2	0.52	2,500	74.3	0.8
12.	Thailand	2,740	20.0	1.10	6,650	39.1	1.5
13.	Malaysia	3,890	53.7	0.81	9,400	72.7	1.4
High Income		**30,990**	**79.5**	**1.64**	**41,140**	**88.2**	**1.1-4.5**
14.	Korea, Republic of	9,700	81.3	1.59	17,600	93.7	1.4
15.	Hong Kong	22,990	95.0	5.07	31,000	97.3	4.5
16.	Singapore	26,730	100	1.10	36,000	100	1.1
17.	Japan	39,640	77.6	1.47	53,500	84.9	1.3

(1 US$ = 40 INR)

Source: "What a Waste", Solid Waste Management in Asia, Urban Development Sector Unit, East Asia and Pacific Region, October, 1998

3.3.6.4 Rate of Increase Based on Experience in Other Cities

If data from other cities having registered similar pattern of development in the past is available, it can be used. However, data from other similar cities on rate of increase in per capita per day of solid waste may not be readily available. Due to difference in socio-economic factor, migration of population, industrialisation and waste quantities, a comparison of increase in per capita waste of one Indian city with that of comparable cities in other developing countries will also not be applicable.

3.3.6.5 Seasonal Variations

Seasonal variations in waste quantities must be accommodated by the management system. They arise from seasonal factors with respect to both climate, cultural and religious events. During monsoon, the waste becomes wet and heavy and total tonnage increases. Quantities of solid waste may also increase during cultural and religious festivals. Climate affects the generation of vegetative waste (yard and garden) or plant growth responds to favorable temperatures and soil to autumn while in tropical areas, where temperatures are always favorable, maximum growth is in the season of rainfall. At the end of the growth season (autumn dry season) leaves may comprise a significant proportion of the solid wastes.

3.3.7 Physical Characteristics

3.3.7.1 Density

A knowledge of the density of a waste i.e. its mass per unit volume (kg/m^3) is essential for the design of all elements of the solid waste management system viz. Community storage, transportation and disposal. For example, in high-income countries, considerable benefit is derived through the use of compaction vehicles on collection routes, because the waste is typically of low density. A reduction of volume of 75% is frequently achieved with normal compaction equipment, so that an initial density of 100 kg/m^3 will readily be increased to 400 kg/m^3. In other words, the vehicle would haul four times the weight of waste in the compacted state than when the waste is uncompacted. The situation in low-income countries is quite different: a high initial density of waste precludes the achievement of high compaction ratio. Consequently, compaction vehicles offer little or no advantage and are not cost-effective.

Significant changes in density occur spontaneously as the waste moves from source to disposal, as a result of scavenging, handling, wetting and drying by the weather, vibration in the collection vehicles. The values shown in **Table 3.8** reflect densities at the pick-up point.

Table 3.8 : Density of Municipal Solid Wastes in Some Cities

Sl.No.	City	Density (Kg/m^3)
1.	Bangalore	390
2.	Baroda	457
3.	Delhi	422
4.	Hyderabad	369
5.	Jaipur	537
6.	Jabalpur	395
7.	Raipur	405

Source : Solid Waste Management in Developing Countries INSIDOC, 1983

N.B.: The above figures may be taken as indicative and actual field measurements must be made while designing solid waste management schemes for towns and cities.

Density is as critical in the design of a sanitary landfill as it is for the storage, collection and transportation of waste. Efficient operation of a landfill requires compaction of the waste to optimum density after it is placed.

Bulk Density Measurement

Materials and apparatus:

- Wooden box of l m^3 capacity
- Wooden box of 0.028 m^3 capacity
- Spring balance weighing upto 50 kg.

Procedure: The solid waste should be taken in the smaller 0.028 m^3 box to give a composite sample, from different parts of the heap of waste, then weighed with the help of a spring balance. After weighing, this smaller box (0.028 m^3) is emptied in bigger l m^3 box and the weight of the waste poured into the bigger box is noted. This is repeated till the larger box is filled to the top. The waste should not be compacted by pressure.

Fill the 1 m^3 box three times and take the average. Thus the weight per cubic meter is obtained.

3.3.7.2 Moisture Content

Moisture content of solid wastes is usually expressed as the weight of moisture per unit weight of wet material.

$$\text{Moisture Content (\%)} = \frac{\text{Wet weight} - \text{dry weight}}{\text{Wet weight}} \times 100$$

A typical range of moisture contents is 20 – 45% representing the extremes of wastes in an arid climate and in the wet season of a region having large precipitation. Values greater than 45% are however not uncommon. Moisture increases the weight of solid waste and therefore the cost of collection and transport. Consequently, waste should be insulated from rainfall or other extraneous water.

Moisture content is a critical determinant in the economic feasibility of waste treatment and processing methods by incineration since energy (e.g. heat) must be supplied for evaporation of water and in raising the temperature of the water vapour.

Climatic conditions apart, moisture content is generally higher in low-income countries because of the higher proportion of food and yard waste.

3.3.7.3 Size of Waste Constituents

The size distribution of waste constituents in the waste stream is important because of its significance in the design of mechanical separators and shredder and waste treatment process. This varies widely and while designing a system, proper analysis of the waste characteristics should be carried out.

3.3.7.4 Calorific Value

Calorific value is the amount of heat generated from combustion of a unit weight of a substance, expressed as kcal/kg. The calorific value is determined experimentally using Bomb calorimeter in which the heat generated at a constant temperature of 25^{O}c from the combustion of a dry sample is measured. Since the test temperature is below the boiling point of water, the combustion water remains in the liquid state. However, during combustion the temperature of the combustion gases remains above 100^{O}c so that the water resulting from combustion is in the vapour state. **Table 3.5** shows typical values of the residue and calorific value for the components of municipal solid waste.

While evaluating incineration as a means of disposal or energy recovery, the following points should be kept in view:

- Organic material yields energy only when dry;
- The moisture contained as free water in the waste reduces the dry organic material per kilogram of waste and requires a significant amount of energy for evaporation; and
- The ash content of the waste reduces the proportion of dry organic material per kilogram of waste. It also retains some heat when removed from the furnace.

3.3.8 Chemical Characteristics

A knowledge of chemical characteristics of waste is essential in determining the efficacy of any treatment process. Chemical characteristics include (i) chemical; (ii) bio-chemical; and (iii) toxic.

Chemical: Chemical characteristics include pH, Nitrogen, Phosphorus and Potassium (N-P-K), total Carbon, C/N ratio, calorific value.

Bio-Chemical: Bio-Chemical characteristics include carbohydrates, proteins, natural fibre, and biodegradable factor.

Toxic: Toxicity characteristics include heavy metals, pesticides, insecticides, Toxicity test for Leachates (TCLP), etc.

The waste may include lipids as well.

3.3.8.1 Classification

A knowledge of the classes of chemical compounds and their characteristics is essential in proper understanding of the behaviour of waste as it moves through the waste management system. The products of decomposition and heating values are two examples of the importance of chemical characteristics. Analysis identifies the compounds and the percent dry weights of each class. The rate and products of decomposition are assessed through chemical analysis. Calorific value indicates the heating value of solid waste. Chemical characteristics are very useful in assessment of potential of methane gas generation. The various chemical components normally found out in municipal solid waste are described below. The product of decomposition and heating values are two examples of the importance of chemical characteristics. Analysis identifies the compounds and the per cent dry weight of each class.

(i) Lipids:

Included in this class of compounds are fats, oils and grease. The principal sources of lipids are garbage, cooking oils and fats. Lipids have high calorific values, about 38000 kcal/kg, which makes waste with a high lipid content suitable for energy recovery processes. Since lipids in the solid state become liquid at temperatures slightly above ambient, they add to the liquid content during waste decomposition. They are biodegradable but because they have a low solubility in waste, the rate of biodegradation is relatively slow.

(ii) Carbohydrates:

Carbohydrates are found primarily in food and yard waste. They include sugars and polymers of sugars such as starch and cellulose and have the general formula $(CH_2O)_X$. Carbohydrates are readily biodegraded to products such as carbon dioxide, water and methane. Decomposing carbohydrates are particularly attractive for flies and rats and for this reason should not be left exposed for periods longer than is necessary.

(iii) Proteins:

Proteins are compounds containing carbon, hydrogen, oxygen and nitrogen and consist of an organic acid with a substituted amine group (NH_2). They are found mainly in food and garden wastes and comprise 5-10% of the dry solids in solid waste. Proteins decompose to form amino acids but partial decomposition can result in the production of amines, which have intensely unpleasant odours.

(iv) Natural Fibres:

This class includes the natural compounds, cellulose and lignin, both of which are resistant to biodegradation. They are found in paper and paper products and in food and yard waste. Cellulose is a larger polymer of glucose while lignin is composed of a group of monomers of which benzene is the primary member. Paper, cotton and wood products are 100%, 95% and 40% cellulose respectively. Since they are highly combustible, solid waste having a high proportion of paper and wood products, are suitable for incineration. The calorific values of ovendried paper products are in the range 12000 – 18000 kcal/kg and of wood about 20000 kcal/kg, which compare with 44200 kcal/kg for fuel oil.

(v) Synthetic Organic Materials (Plastic):

In recent years, plastics have become a significant component of solid waste accounting for 5-7%. Plastic being non-bio-degradable, its decomposition does not take place at disposal site. Besides, plastic causes choking of drains and environmental pollution when burnt under uncontrolled condition. Recycling of plastics is receiving more attention, which will reduce the proportion of this waste component at disposal sites.

(vi) Non-combustibles:

Materials in this class are glass, ceramic, metals, dust, dirt, ashes and construction. Non-combustibles account for 30-50% of the dry solids.

3.4 CONCLUSION

No rational decisions on municipal solid wastes system are possible until data of composition and quantity of solid waste are available. The method and capacity of storage, the correct type of collection vehicle, the optimum size of crew and the frequency of collection depend mainly on volume and density of wastes. Climate also has some influence. The disposal method may be dependent on the type of material recycled, organic content of waste, which could be composted, and the combustible material, which could be a source of energy.