Source Specific Quantification and Characterization of Municipal Solid Waste — a Review

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Municipal agencies manage municipal solid wastes from urban areas with the objectives of providing good sanitation facilities as also protecting public health. Estimation of resource requirement for collection, transportation, processing and disposal requires correct assessment of quantity of waste generated per day from different sources and their characteristics. However, it is done arbitrarily merely on number of trips of vehicles basis and without knowing characteristics. As a result, the solid waste management system is not operated satisfactorily. In view of this, source specific quantification and characterization of municipal solid waste assumes great significance which will enable accurate assessment of waste load and it would be easier for proper planning of solid waste management system. This would help in achieving the objectives of proper utilization of available resources and protection of environment and public health. The present paper highlights the importance of source specific quantification and characterization of municipal solid waste. A critical review of earlier work done at various places has been made and salient features of the same have been presented in this paper.

Keywords **:** Municipal solid waste; Segregation of waste; Waste categories; Source specific quantification and characterization; Appropriate methodology

INTRODUCTION

In every urban centre, huge quantity of solid waste is generated during various activities. These wastes are to be stored, collected, transported, processed and disposed of in an environment friendly manner, so as to keep the city neat and clean. In spite of incurring huge expenditure, the services that are provided to the solid waste management are not fulfilling the requirement, causing public health hazards and nuisance. Hence, there is a strong need to develop appropriate technology for the proper management of urban solid wastes.

Solid waste management is a large, ongoing, vital public system spread over the entire city area and the system is responsible for maintaining the public surroundings. Hence, the system has to be planned rationally for a long and short term. Moreover, as the system handles huge quantities of solid waste, it is necessary to have detailed information on quantification and characterization of solid waste for proper handling of solid waste at different stages of the system. Presently, majority of Municipal Corporations/ Councils do not weigh their waste but the quantities are estimated on the basis of number of trips of trucks which carry the waste to disposal site. Moreover, the solid waste management system is not planned or executed rationally due to non-availability of authentic or relevant information on waste generation. As the solid waste quantities are increasing in all cities and towns due to urbanization and industrialization, these have raised concerns about the economic viability and environmental compatibility of the current waste management methodologies.

SOURCE SPECIFIC QUANTIFICATION AND CHARACTERIZATION

In absence of weighbridge facility at disposal sites in number of cities the records are not maintained for quantity of waste per day. All types of wastes are collected and mixed together at community bin. This method does not give correct picture of a waste generation areas. It is very difficult to keep a record of quantity of waste generation from each source. Hence, there should be reliable information on solid waste quantification and characterization, which is the prime requirement of the system. Because of the non-availability of daily records of quantification, one can not assess the total expenditure involved for disposal of the solid waste. It has been observed that 60% - 75% of the generated waste is disposed of at landfill site. Remaining part of the waste is either thrown into the drain or along the roadside, for which data can not be correctly assessed for the design of the system. The municipal solid waste contains vegetable market waste, glass, paper, plastic, and other organic fractions and inert matter from different sources, such as, residential, commercial and institutional areas. Ragpickers are also collecting the recyclable waste from the community bins. The overall effect is non-availability of adequate information on quantification of solid waste.

Source specific solid waste quantification and characterization is very much required to assess the quality and quantity of solid waste generated. Now-a-days, the waste is quantified on the basis of total waste generation in the city. It has not been categorized so far in different categories to know quantity of every component of the waste[1].

In the present paper, an attempt has been made to review the available literature on source specific quantification and characterization of municipal solid waste.

SOLID WASTE QUANTIFICATION

The most important aspect of solid waste management is the quantity of waste to be managed. The quantity determines the size and number of functional units and equipments required for managing the waste. The quantities are measured in terms of weight and volume. The weight is fairly constant for a given set of discarded objects whereas volume is highly variable.

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Waste quantities are usually estimated on the basis of past records of waste generation. The methods commonly used to assess the quantities are (i) load count analysis; (ii) weight volume analysis; and (iii) material balance analysis[2].

SOLID WASTE CHARACTERIZATION

Collection of Sample

There are number of procedures to obtain samples from the municipal solid waste. Some of the methods are mentioned below[3] :

1. Assembling a composite sample from material taken from predetermined points in the load (such as, each corner and middle of each side);

2. Cornering and quartering;

3. Collecting a grab sample from randomly selected point using front-end loader;

4. Manually collecting a column of waste from a randomly selected location.

Size of Sample

Refuse characteristics depend on the number of factors, such as, food habits, cultural traditions, socio-economic and climatic conditions. It varies not only from city to city but even within the same city itself.

Studies were carried in USA with 100 kg to 1000 kg samples and it was found that a 100 kg sample gave as much accuracy as compared to 1000 kg sample. When the collection at a point is small, 100 kg sample can not be obtained. In such a case, smaller sample could be collected for analysis. Repetitive sampling and analysis would provide a more representative data.

The sample so collected should be sorted physically into various ingredients, such as, paper, glass, plastics, etc on a sorting platform. The individual components are separated and weighed. The weights are then expressed as a per cent of original sample[4].

Segregation of Collected Samples

Characterization methods had been detailed out by David, *et al* [3] which showed that sorting area should be accessible to vehicles and protected from winds and precipitation. Basic sorting sequences can be initiated when collection of sample is complete as given hereunder:

- A copy of data form;
- Sample is unloaded onto a surface of sorting area;
- Large items and bags containing single waste category (most of the yard waste) are removed from the sample and set aside for weighing, bypassing the sorting box;
- The waste is segregated into different components in the container; and
- The containers are brought to scale, checked for accuracy of sorting and weighed.

LITERATURE REVIEW

Quantification of MSW

Even, *et al*[5] in their study reported that 20 collection routes serving the nine road lanes were chosen which covered 88% of the city's population. Data records were made available by department of public works. Daily collection records gave the mass of material collected on each route. Selected 20 collection routes were comprised eight Monday-Thursday routes, eight Tuesday-Friday routes and four Wednesday-Saturday routes. The original data was from weight-scale readings at the landfill site in operation.

The Waste Wise Resource Centre[6] carried out a study on quantification, the details of which are as given below :

Random Sampling

Since, the number of establishments to be sampled were known they were divided by a week. Randomly, number of routes were selected in the establishment. Weighing scale of 2-kg capacity was used and it was ensured that establishments are intimated about the waste sampling process. At each establishment, collection and segregation of the waste was done.

Methodology

- The waste was grouped according to various components present and classified; and
- The waste source was identified according to the allotted number, street name and number of occupants.

Study carried out in Hong Kong during the year 2000[7] resulted in solid waste data which was collected by two approaches, namely, weighing exercise at all waste facilities throughout the year. All the solid waste facilities were managed by the different departments. The data was collected throughout the year as under :

- Waste intake records from landfill weighbridge and refuse transfer stations;
- Results of quarterly exercise; and
- Quantities of special waste and other solid waste from relevant specialist groups.

Characterization of MSW

EPA had formulated methodology for households and commercial waste for Ireland[8] as per following approach:

Household Waste Characteristics

Material required for characterization: The requirement of the items were a cover shed, a truck, weighbridge, mechanical shovel, JCB, hand shovel, 60 kg precision scale, one box, sieve with 20 mm round mesh, tray for fine recovery, container for storing separated fractions, brooms, gloves, masks, first aid kit, oven, plastic graduated container (200 l - 300 l) for bulk density analysis.

Timing of Waste Analysis

Waste analysis was carried out with three months interval. Sampling

was avoided on Bank holidays, Christmas, Easter and Public holidays. To facilitate the sampling selection, it was suggested that social class be combined into three categories. For larger area, it was recommended to split the area into several small areas. Public was made aware about the time and day of sample collection from their area. Sample size collected was a minimum of 100 kg and it was thoroughly mixed on the floor and placed in a uniform pile of 0.8 m high. By coning and quartering, 100 kg - 200 kg of sample was obtained. The large items, such as, glass, paper and plastic were segregated from the reduced sample. Any remaining material was passed through 20 mm mesh sieve. Any unclassified material was categorised as combustible and incombustible.

Commercial Waste Characterization

The commercial sector was divided into four broad categories, namely,

- Retail trade, *eg*, super market;
- Wholesale trade, *eg*, sale of goods to retailer;
- Non-distribution, *eg*, hotels, catering, office premises etc; and
- Education, *eg*, school and college.

The waste was collected directly from each outlet. After this, the waste generated/employee for each outlet surveyed was calculated. Alternatively, when contractor vehicles were used for transportation of waste, the waste was brought to central location prior to collection.

Total number of employees from the selected commercial areas or outlets were recorded so that the average weight of waste/ employee could be determined for each activity. In this case also, coning and quartering technique was adopted to reduce sample weight to 100 kg - 200 kg. After weighing and sorting the sample, picking out the large items, such as, glass, paper and plastic was done. The remaining material was passed through 20 mm mesh sieve and unclassified material was categorised as combustible and incombustible.

Jim Kundell[9] observed waste composition of MSW as: paper and paperboard 37.6%, yard waste 15.9%, plastic 9.3%, metals 8.3%, wood 6.6%, glass 6.6%, food waste 6.7% and miscellaneous inorganics (including textile, rubber, leather and other) 9.1%.

Undergraduate students from the university of North America[10] carried out the study for determining waste quantities from commercial and residential sources. In their study, the waste generating categories considered were residential, office, restaurant, industrial, grocery and apartments and complexes using commercial containers but garbage cans from single-family dwellings were not covered. Forty-two locations were sampled which included residential :13 numbers, office : 11 numbers, industrial : 3 numbers, retail : 7 numbers, restaurant : 5 numbers, and three grocery shops.

Commercial waste was delivered in 2, 3, 4, 6 and 8 cubic yards capacity containers. The waste was dumped into piles on a large platform. 14 groups with 20 environmental science students each sorted out the waste into 18 gallon capacity bins. Each of the 20 bins contained different categories of waste. The bins were weighed when full and empty and weights were recorded. The waste categories identified were, paper which included newspaper, high-grade paper, corrugated and other paper. Plastics included, plastic bottle (PET and HDPE), films and bags, other plastic. Other waste included food, textile/rubber/leather, wood, yard, glass, other glass, ferrous or non-ferrous metal, other organics and miscellaneous. The students went through weighment exercise for 42 samples and it was found to be 9981 lb. The paper, plastic, food, glass and metals categories contributed very similar percentage to the total waste stream in each study. Large difference was observed between yard and other categories. The EPA study considered all MSW whereas present study considered only commercial waste, paper accounted for the highest percentage (37.9%). Food, plastic and others contributed to 10% of the total. Grocery shop contributed 75.8% paper, including large amount of cardboard. Office and restaurants waste also contained large paper fraction.

Metro and Department of Environmental Quality in Oregon[11](DEQ) conducted study wherein samples were drawn from garbage trucks which could not be accurately sorted in the field because wastes were mixed and compressed together in the truck. Wet wastes like soft drinks and food waste got absorbed into paper, plastic film which in turn got absorbed. For this purpose, further sorting, drying and re-weighing was suggested.

Disposal sites were selected for sampling (15-samples/day approximately) so as to include different demographic conditions and geographic conditions. Half of the samples were taken from garbage trucks and others from the vehicle.

Seven to eight trucks were randomly selected on the basis of garbage hauler along garbage routes:

- Residential route garbage trucks — route with = > 90% of waste from residential customers;
- Commercial route garbage trucks — routes with > 90% of waste from commercial customers;
- Mixed route garbage trucks — routes with mixture of residential and commercial customers; and
- Drop boxes, both loose filled and compacted.

The minimum weight of samples was taken as 175 pounds for garbage trucks and 150 pounds for self haul vehicles. For most of the loads, a sample weighing about 200 pounds was extracted from a randomly selected position in the load. Self-haul samples were taken from the first large truckload (waste weighing 1 t or more) coming to site and from the first three loads weighing 600 pounds to 1 t in total estimated weight. More than 600 loads were selected for sorting. Each sample was sorted in 76 categories and weight of each category was recorded.

During 1992-1993, study on waste composition was carried out and the quantity of waste was estimated by DEQ. It was observed that about 27% of the MSW disposed in Oregon, was self hauled to disposal site by the household or business generating the waste and 73% of the waste was being transported by commercial garbage hauling companies. For the four-garbage haulers waste sub-stream, the weighting factor used was based on same garbage route/ tonnage. Percentage composition for each waste sub-stream and

weighted factor were calculated for all sub-streams.

Metro staff used hazardous material as one of the category while DEQ studies classified oil filter as mixed metal/material category. Significant amount of recovery of material, such as, cardboard, wood and scrap metal could be achieved before any post-collection recovery of recyclable material had occurred.

Waste sub-streams were different from each other. Paper was about twice as high in commercially hauled loads as in self-haul loads and wood was also much higher. Residential hauler routes had significantly higher percentage of magazines, rigid plastic container yard debris, diapers containers, glass and aluminium foil. On the other hand, commercial hauler routes had significantly higher percentage of corrugated board, high grade paper, film plastic, food waste, wood lumber, and pellets.

During characterization of New York's solid waste stream[12], segregation of solid waste into different components and quantification was carried out. The methodology adopted was based on national disposal figures, recycling rate and purchasing of the items. The components analyzed were as follows:

Furniture and furnishing, major and small appliances, carpet and rags, clothing and footwear, towel sheets and pillow cases, vehicle associated products, motor oil, disposable razors, shaving cream cans, toothbrushes, disposable diapers, non-deposit beverages containers, clear HDPE jugs, mill cartons, aerosol cans, folding cartons, office papers etc.

Newspapers, magazines, books, telephone directories, third class mails, paper towels, paper plates and cups, polybags from dry cleaners, hangers from dry cleaners, household batteries, thermostats, latex paints, fluorescent tubes and ballast, incandescent bulbs, pallets and wood packaging, food wastes, plastic wraps, paper and plastic grocery bags, plastic plates and cups, used cameras, writing instruments and trash bags were analyzed for characterization in the study.

In the vicinity of Hyderabad, there are four landfill sites used by the Municipal Corporation. For the study by Jeevanrao and Shantaram [13] three landfill sites selected were Amberpet, Golkonda, Autonagar.

Samples of fresh urban solid waste weighing approximately 10 kg were collected from 10 different locations of Autonagar and Golkonda landfill sites. Similarly, stabilized solid waste samples were also collected from Amberpet and Golkonda sites to cover the entire area of waste dumps. 100 kg of collected sample was thoroughly mixed and by quartering technique the sample was reduced to 12.5 kg. Similarly, stabilized solid waste samples at different depths ranging from 0-30 cm, 30-60 cm, 60-90 cm were collected to obtain 12.5 kg sample.

Fresh solid waste represented the material disposed of at the landfill sites within eight days of the date of collection whereas stabilized solid waste represented the material, which was disposed of at least 180 days before the date of collection. The samples were sorted out into separate components. Non-compostable matter was more in Autonagar and Amberpet than Golkonda. Major portion of waste generated was from market yard and public eating places like hotels, tea shops and residential area. This metro city is rapidly growing and there is lot of infrastructure activity resulting into higher quantity of soil and ash in the solid waste where street sweeping is mixed with the refuse. Weight-volume relationship of the wastes for Hyderabad city varied from 410 kg/m^3 for Autonagar fresh solid waste, 365 kg/m^3 for Golkonda fresh solid waste and 480 kg/m^3 for stabilized Amberpet waste and 265 kg/ m^3 for stabilized Golkonda waste.

Initially, all the 11 wards/circles were surveyed to get basic information regarding refuse generation. Samples were collected once in 10 days for four times from each sampling station of each ward and samples were collected in the morning, keeping in view the activities of ragpickers for removing paper, plastic, metals etc. Sampling was not done on odd days like days of heavy rains, which could affect the density and moisture of the solid waste. The density was measured using box of size $0.5 \times 0.5 \times 0.5$ m^3. Ten points were chosen in the dust bin where from sample was grabbed at different depths and also from the area of the bin.

In national waste database for commonwealth[14], the waste composition system was divided into material type, material detail, material details sub-category 1 and sub-category 2.

Material details meant more detailed description of broad material type and the categories were selected on the basis of recycling potential of the waste components.

With regard to material details sub-category 1, the category for glass and plastic was considered under material details whereas it provided more descriptive information relevant to recyclability of the material. Here, ferrous and non-ferrous metal was further divided into beverage cans and other cans material.

In material details sub-category 2, the category was further sub-divided into components, such as, coloured glass and different types of paper.

Chang Ching, *et al*[15] compared two waste streams quantification and characterization methodologies which contained direct waste analysis for determining the waste quantity and waste composition using a social science approach (questionnaire survey) for dealing with the same problem. The advantages and disadvantages of the method were as given here.

Direct Waste Analysis (DWA) involved the direct examination of waste set out for collection at point-of-generation or waste delivered to a waste processing facility or to a waste disposal site.

In contrast to DWA and the questionnaire survey, methodology was normally restricted to collection of data at the point-of-generation, rather than at waste processing or waste disposal facilities. The methodology involved questionnaire survey for waste generators by means of personal interview, correspondence or telephone survey. Respondent were asked to inform based on the waste stream records and visual inspection of the waste containers about the quantity of waste sent for the disposal, composition of that waste and seasonal variations of waste generation.

In Washington, questionnaire survey was carried out; the survey was based on telephone interviews to collect data from 259 firms

which achieved 61% response rate. After interviews, 159 firms were contacted and approximately. 30% of the firms were found to have difference between their survey rates. In order to achieve satisfactory confidence levels for estimation of different materials in the waste stream, samples were sorted out and weighed 90 kg - 180 kg approximately.

The density for mechanically compacted cardboard was about 13 times of its uncompacted density. This problem could be minimized by collecting information in the questionnaire survey about whether or not a company had compactor on site and, it was using density figure for a compacted waste stream or for an uncompacted waste stream. The estimates from DWA studies differed from those produced from questionnaire survey.

Daskalopoulos, *et al* [16] predicted the amount and the composition of the Municipal Solid Waste (MSW) to be generated in future in order to devise a most appropriate treatment/disposal strategy in European Union Countries and the United States of America. A typical composition of MSW was expressed in terms of the fraction of the total consumer expenditure on goods and products resulting in the generation of MSW, *ie*, Related Total Consumer Expenditure (RTCE)

The factors affecting annual quantity and composition of the MSW generated and the key parameters considered were population and mean living standard of the people.

The first major parameter for determining the amount of waste generated was based on the fact that with more population, more will be the waste produced. The second major parameter, *ie*, the mean living standard of the population of a country, indicated the ability of population to purchase consumer goods and products.

In this study, only a fraction of the total consumer expenditure was spent on food and drinks, clothing and footwear, furniture and floor coverings, books, paper and magazines.

Analysis of the available data on Gross Domestic Product (GDP) and Total Consumer Expenditure (TCE) for European countries and USA have revealed that there exists a strong correlation between the two economic parameters.

DISCUSSION

The published literature indicates that work has been carried out by several research workers only for the whole residential and commercial and institutional sources and not for source specific waste, in absence of which, it was not possible in respective cases to know the waste generation from the individual category of each source. The quantification was practiced on the basis of number of trips and previous data available with the concerned department and seasonal variations were not considered. The characterization study carried for New York's solid waste indicated segregation of waste into many categories. Some of these categories are not available in India. The literature also indicates that source specific solid waste quantification and characterization study has not been carried in India so far for residential, commercial and institutional source.

Even, *et al* [5] had chosen nine road lanes for the study covering 88% of the city's population. Quantification was carried on the selected route on the selected day.

The Waste Wise Resource Centre[6] carried out the study on quantification by selecting number of routes randomly.

In Hong Kong[7] a study was undertaken involving use of waste intake records, quantities of special wastes and other solid wastes from relevant specialist groups.

EPA[8] formulated a methodology for household and commercial waste for Ireland. Material required for characterization was assembled and timing of waste analysis was decided. To facilitate the sampling selection, social groups were combined into three categories. Some commercial sectors were selected for the study, such as, retail trade, wholesale trade, non-distribution and education. Coning and quartering technique was adopted to reduce and select the representative samples.

Undergraduate students from the university of North America[10] carried out the study for residential, office, restaurant, industrial, grocery and apartments and complexes using commercial containers. Filled bins were weighed for the quantification. The waste material categories, such as, high grade paper, newspaper, corrugated and other paper, plastic bottles (PET and HDPE) were also encountered during characterization of the waste.

Oregon[11] carried out the study on the basis of demographic and geographic conditions. Half of the samples were taken from the garbage trucks and others from the vehicles. Seven to eight trucks were randomly selected on the basis of garbage hauler along garbage routes. Minimum sample weight was 175 pounds for garbage trucks and 150 pounds for self haul vehicles. For most of the loads, 200 pounds of waste was extracted from randomly selected positions in the load.

Jeevanrao, *et al* [13] in their study, selected Amberpet, Golkonda and Antonagar landfill sites. The 100 kg of sample was selected and thoroughly mixed by quartering technique. The results of physical composition were compared and assessment of the sites based on quantities of compostable matter in the waste was carried out.

Direct Waste Analysis and Questionnaire Survey was carried out by Chang Ching, *et al* [15]. The study was carried out and the results were compared to adopt appropriate methodology.

CONCLUSION

The literature cited in the text does not directly address the source specific quantification and characterization. Each study has adopted different methodology without addressing the source specific data collection. The existing system of quantification of solid waste for a city involves use of waste generation rate for mixed waste contributed by the prevailing population and leads to inadequate design of MSW system with the result that the solid waste management system can either get over-designed or under-designed.

From the data on composition of waste from residential areas, it is seen that recovery of recyclables from every household is impossible through source separation of paper, plastic, glass and

metal unless awareness is generated amongst the residents or incentives are offered to the citizens in the form of relief in taxes.

Design and operation of appropriate solid waste management systems are necessary for ensuring good sanitation and clean environment. The source specific solid waste quantification and characterization will be helpful in predicting the waste quantity from various waste generating sources in a city and this can be used as a basis for the planning of the system. This will also enable in saving of time, manpower, and financial inputs required to be spent for estimating the waste quantity for the entire city. Such a developed methodology can be very easily adopted by the municipal agency and would help them in managing the system in a befitting manner.

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