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Municipal Solid Waste Quantification, Characterization and Management in Rajam

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ABSTRACT
*To plan effectively and successfully manage the solid wastes, proper quantification and characterization are essential. Recovery from solid waste is an important aspect where as disposal is only the final option. Recovery of methane from landfills is rarely practiced in India. Solid waste management from Rajam, a municipality in Srikakulam district , AP is considered in the present study where there is a potential for huge generation of solid waste generation but not following the proper management practices. Systematic studies are conducted in Rajam for quantification, determination of composition, study of route analysis and recovery value from solid wastes. Rajam is generating 9000 kg/day of solid waste with per capita waste generation of 0.214 kg/day, 74% food wastes with average density of 320 kg/m^3 and estimated methane gas generation of 180 m3/tonne of waste. Due to high biodegradable content (6.66 tonnes/day), compost and biogas generation options are studied. Optimum distribution of biodegradable solid waste among these two options is studied. A combination of 4.66 tonnes for composting and 2 tonnes for landfilling with net recovery of Rs 12,846 per day is suggested. The recovery value of non-biodegradable items such as paper and plastic are also studied. It is found that, Rajam can make a recovery of **Rs 53,73,165 per year** excluding the construction and operation cost incurred for establishment of compost plant and landfill biogas collection system. Improvements to the route analysis are suggested to reduce the number of trips of collection.*

Key words: *Solid waste management, Route analysis, Recovery value, Quantification, Characterisation, Composition, Rajam.*

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I. Introduction

Solid waste has emerged as one of the most serious problem being faced by urban centres all over the world. India, being the world's second highest populated country and one of the fastest urbanizing countries is facing the problem of solid waste management. Solid waste generated in India is 1,27,486 TPD or 47 million tonnes per year as per 2012 status (CPCB) and is expected to increase to 300 million tonnes to 300 million tonnes per year by 2047 (Firdaus and Ahmed, 2010). The estimated land requirement for disposal of such huge quantum of waste would be 169.6 km^2. Out of the total waste generated in the country 89,334 tonnes (70%) is collected, 15,881 tonnes (12.50%) is being treated while 22,271 tonnes (17.5%) is not being collected (CPCB). Municipal solid waste (MSW) or urban solid wastes generally composed of a spectrum of refuse categories such as food wastes, street sweepings, garden wastes, abandoned parts of vehicles and appliances and residues from small scale industries (Peavy et al., 1985). The quantity and composition of municipal solid wastes vary greatly in different Municipalities and from time to time (UNESCO, 1996) . The average collection efficiency for MSW in Indian cities is about 72.5% and around 70% of the cities lack adequate waste transport capacities (Singhal and Pandey, 2001). The Calorific value may vary from 800 kcal/kg to 1000 kcal/kg and density from 330 kg/m^3 to 560 kg/m^3 (Sharholy et al., 2008). The per capita waste generation ranges from 100 gm to 500 gm based on population of locality (Asnani, 2006). However, the range of per capita generation in India is reported (CPCB, 1999) as 0.3-0.6 kg/cap/day. The efficiency of solid waste management depends on collection, segregation and transportation of solid waste (Sridharan et al., 2006). House-to-house collection and segregation are not fully covered in most of the cities. There is a large gap in between waste collection and processing. Most of the municipalities have no sanitary landfill facility and follow dumping for disposal of MSW (CPCB). Maharashtra (19,204 TPD), West Bengal (12,557 TPD), Tamil Nadu (12,504), Uttar Pradesh (11,585 TPD), Andhra Pradesh (11,500 TPD),), Kerala (8338 TPD), Delhi (7384 TPD), Gujarat (7379 TPD) are the States in India generating major quantities of solid waste as per 2012 status (CPCB). Composting, vermicomposting, biogas plant, RDF – pelletization are the recovery techniques adopted in the country. Waste processing plants through composting and waste to energy plants are already established in the country (CPCB). Based on the studies compiled by CPCB in 2011, 59 landfills are constructed in the country, 376 landfills are planned and 1305 landfill sites are identified for future use.

Under such varying scenarios that are happening in the country, study of solid waste management practices in a small municipality would be interesting to understand the current practices and the scope for potential improvements in the area. Rajam, a small municipality town in Srikakulam district is considered in the present study.

II. Problem Formulation and Methodology

In view of the importance of the problem a systematic study of solid waste generation and characterization is necessary for planning the solid waste management facilities. Rajam, a municipality in Srikakulam district of Andhra Pradesh with a total population of 42,125 (2011 data) is considered for the study. Rajam has been selected based on (i) drastic changes in growth pattern in the past few years (ii) upgraded to Municipality from Panchayat (iii) increased growth rate of population (iv) increase in establishment of small scale industries, commercial establishments, schools and colleges (v) established market place for the surrounding villages. All these developments are leading to increased solid waste generation in Rajam.

At present no systematic procedure is being followed in the collection, recovery and disposal of solid waste generated (Reshma et al., 2014). Further, no systematic studies are available for quantification and characterization of solid waste generated in Rajam. The present study is hence taken up with the following objectives:

- Systematic study of the existing solid waste management system in Rajam
- Systematic study of quantification of solid waste
- Systematic study of characterization of solid waste
- Systematic study of collection and transport options being implemented
- Proposing better solid waste management practices for Rajam

Based on the objectives listed above, the following methodology is drawn in the present study:

- Literature review
- Primary data collection
- Collection of representative solid waste samples
- Segregation of solid waste samples into wet waste (biodegradable) and dry waste (non-biodegradable)
- Laboratory examination for physical properties such as moisture content and density
- Estimation of components in solid waste
- Determination of chemical composition of solid waste
- Quantification of solid waste
- Study of existing collection routes and improvement of the same
- Study of alternatives for waste processing and disposal facilities
- Cost estimation for the options studied

III. Results and Discussion

3.1 Study zone: Primary data is collected in Rajam (Personal Communication, 2014) to understand the existing practices of solid waste management at Rajam and the details are given in Table-1. The Rajam town is divided into 11 wards for collection of solid waste. The solid waste is collected using 17 tricycles from 11,158 households without separating wet and dry waste. The collected solid waste is being dumped into the temporary storage bins/yards with the help of tri-cycles. The solid waste is then carried by tractors and tipper to the permanent dumping yard and directly dumped at Garacheepurupalli without following any systematic disposal practices. The following observations are made during the field visit:

- No segregation of solid waste is followed at the time of collection
- Waste carriers are not properly covered leading to spillage during transportation
- Due to improper dumping at the collection points (Refer Fig.), unhygienic conditions are prevailing that causes various other problems to public during rainy season
- Improper dumping may cause contamination of ground water in the area
- No systematic disposal at final disposal point

Table-1: Details of existing SWM practices at Rajam

S No	Item particulars	Details
1	Total area	25.76 sq. Km
2	Population (2011 data)	42,125
3	Number of residences	11,158

4	Collection method	House-to-house
5	Time of collection	530 am – 1030 am
6	Number of vehicles used for collection of waste	Tricycles-17 (total volume: 8.84 m^3) Tractors-3 (Total volume: 18.31 m^3) Tippers-1 (Total volume: 4.61 m^3) 2 trips for tipper
7	Area of dumping yard at Garacheepurupalli	4.53 acres
8	Number of storage yards	6 (Ponugantivalasa, Seetharama Theatre, Saradhi theatre road, Ammavari colony, Municipal office, Cheepurupalli road)
9	Number of vegetable markets	2

Fig 1(a): Storage yard at Ponugantivalasa

Fig 1(b): Storage yard at Municipal Office

3.2 Sampling and laboratory examination

For the convenience of sampling of solid waste from households, the entire Rajam town has been divided into five number of segments as follows:

1. Dolapeta
2. Maruthi Nagar
3. Cheepurupalli Road
4. Vegetable market and Hotels
5. Ammavari Colony

Five houses from each segment are randomly selected making a total of 25 households for daily sampling during the study period. Sampling is carried out for one week to account for daily variations during one entire week. The 25 households are consulted before commencement of sampling and obtained their consent for the study purpose. Two bags are given to each of the houses, one for keeping wet waste and the other for dry waste. Solid waste samples are collected for one week during February 2014. The total samples collected during sampling are: 2 bags x 5 houses x 5 segments x 7 days = 350 comprising of 175 wet (biodegradable waste) samples, 175 dry (non-biodegradable waste) samples.

All the samples are examined in the laboratory for the determination of moisture content, density and composition. For quantification purposes, the average number of persons per house is considered as four.

3.3 Component separation and quantification

The total weight of the waste collected is noted down as W. Components of the waste such as plastic, cardboard, paper etc. are separated from solid waste (Refer Fig.2). They are collected in a container of empty weight W1. The weight of container along with individual component is measured as W2. The individual weight of the component Wc = W2-W1, is thus calculated. The percentage of each component is calculated using the formula:

% of the component = (Wc/W) x 100

The component of solid waste is collected in a container and is dried in oven at 105 C for 24 hours. The wet weight (Ww) and dry weight (Wd) are determined to calculate the moisture content using the formula (Peavy et al., 1985):

$$MoistureContent\ (\%) = \frac{W_w - W_d}{W_w} x100$$

Fig. 2(a) Component separation of solid waste | **Fig. 2 (b) Quantification of solid waste**

3.4 Calculation of composition and characteristic properties of solid waste

The data obtained from the laboratory is consolidated for each segment and the average values are obtained. The chemical composition, energy content, air requirement for composting and quantity of methane produced from landfill are calculated from the procedure outlined by Peavy et al (1985). The consolidated results are given in Table-2. The food wastes are 74% of the total solid waste and are on higher side compared to the data available (41.80%) for major Indian cities (CPCB, 2000). This may be attributed to the rural background of the study area as against the urban areas that are considered for determining average value. The values of the other parameters are also different to that of Visakhapatnam, the nearest city considered by CPCB (2000) for the study. It only shows that the characteristics vary based on several aspects such as location, income, habits, customs, season, socio-economic status etc. (Sridharan et al., 2006). The computation for air requirement for composting is essential when air is supplied through air compressors in windrows method of composting the solid waste.

Table-2: Composition and characteristics of solid waste in Rajam

S No	Item particulars	Values
1	Moisture content	53.4%
2	Average density, kg/m3	320
3	Component (average) • Paper 10.3 • Plastic 3.8 • Metals 0.73 • Food waste 74 • Miscellaneous 11.17	% by weight
4	Chemical Composition	$C_{35} H_{181} O_{81} N$
5	Energy content	1900 kcal/kg
6	Air requirement for composting	1200 m^3/tonne of waste
7	Methane produced in landfill	180 m^3/tonne of waste

3.5 Quantification of solid waste generated

The samples are collected daily for one week and the quantity of solid waste samples are determined. The daily data is consolidated for each of the five routes and finally for the entire Rajam town. The results are as follows. Suitable assumptions are made wherever actual data measurement is not possible in computing the quantities.

Quantification based on samples collected

Residential waste = 562 g/house
Vegetable market = 6.05 kg/shop
Hotels = 8.64 kg/hotel
Shops = 0.832 kg/shop
Commercial establishments = 1 kg/shop

Total residential waste		= (number of houses x waste generated from house)
		= 11,158 x 0.562 = 6304.27 kg/day
Commercial waste		= (number of units x waste generated per unit)
-	Vegetable markets	= 40 x 6.05 = 242 kg/d
-	Hotels	= 30 x 8.640 = 259.20 kg/day
-	Shops	= 100 x 0.832 = 83.2 kg/day
-	Commercial units	= 500 x 1 = 500 kg/day
Total solid waste		= 7150 kg/day

Add 25% for unaccounted = 1.25 x 7150 = **9000 kg/day** (rounded)

Quantification based on vehicle capacities

Quantity carried by each vehicle = volume of vehicle x average density of solid waste
= (8,84+18.31+4.61x2) x 320 = 8815 kg/day ~ **9000 kg/day**

3.6 Calculation of per capita solid waste generation

Per capita solid waste generation = (9000 kg/d)/(42,125) = 0.214 kg/cap/day

The per capita generation for population 0.1-0.5 million in India is 0.21 kg/cap/day (Asnani, 2006). The obtained value is in agreement with the national average values.

3.7 Route analysis

The number of trips taken for each tricycle to carry solid waste is calculated. Steps to reduce the number of trips by increasing the volume and compaction factor are also calculated.

Capacity of 1 tricycle = 0.52 m^3 and it can carry 167 kg (=320 x 0.52) of solid waste.
Number of trips taken by tricycle = (total residential waste/amount of waste carried by each tricycle) = 6304/167 = 38 trips
Required trips for each zone = (38/17) = 2.3 or nearly 2-3 trips
From field observations, it is noted that 2-3 trips are made in each area.

If the height of tricycle storage is increased to 0.8m from the existing height, then the tricycle can accommodate 0.86 m^3 volume ie., 65% increase and can carry 275 kg of solid waste.
Number of trips that can be taken by the tricycle = (6304)/(275) = 23 trips
Required trips for each zone = 23/17 = 1.7 or nearly 2 trips from existing 2-3 trips per day.

Hence, if we increase the volume of tricycle, the number of trips can be reduced which is economical.

Compaction of solid waste:

It should be noted that in the above analysis the compaction of solid waste is not considered and is taken as unity ie., carrying the solid waste as it is in collection vehicle without any compaction.
The compaction factor can be calculated as follows (Peavy et al., 1985):

Solid waste carried by all tricycles = 17 x 275 = 4675 kg
Compaction factor = (6304 kg/d)/(4675 kg) = 1.35 ~ 1.5 (rounded)
If solid waste is compacted to 1.5 times at the time of collection, the number of trips can be reduced to 1 instead of 2 as calculated above (with increased storage volume).

If increase of storage volume is not considered and follow the existing practices, the solid waste carried by all tricycles in 1 trip = 17 x 167 = 2839 kg
Compaction factor = (6304/2839) ~ 2.25
To continue the existing practices, compacting the solid waste at the time of collection to 2.25 times can reduce the number of trips to 1 (from prevailing 2-3 trips) and can be made economical.

3.8 Estimation of methane production

The recovery product from landfills is methane. This is useful in estimating the recovery value of methane from landfill emissions. Methane production from landfills is estimated based on chemical composition of solid waste from Rajam using the procedure outlined by Peavy et al. (1985).
Methane produced per tonne per day = 180 m^3/tonne

3.9 Recovery of total solid waste generated per day

The recovery values of the plastic, paper and compost are noted down based on personal interactions with vendors at Rajam. The details are given below:

3.9.1 Recovery value of biogas

1 m^3 of biogas can generate 1.25 kW/hour electricity or 200 m3 of biogas can generate 1.25 x 180 = 225 kW/hour electricity.
Assuming 1 kW/hour costs Rs 5 (residential uses), amount that can be recovered from 1 tonne of solid waste = 5 x 225 = 1125 per day.

3.9.2 Recovery value of compost and methane from landfill

Total solid waste generated per day = 9000 kg/day
Biodegradable waste = 6660 kg/day (@ 74%)
This can be used for composting as well as in landfill. Assuming 5 tonnes of solid waste is used for composting and remaining 1.66 tonnes for landfilling, the calculations that can be made are-

Compost:
Recovery value of compost: 25-50% (Richard, 2016, Adamu et al., 2015). Assume as 35% for calculation purposes.
Compost recovered = 5 x 0.35 = 1.75 Tonnes per day.
Recovery value @ Rs 6000 per tonne (Agricultural Information, 2016) = 1.75 x 6000 = Rs 10,500

Biogas from Landfill
Biogas generation = 1.66 x 180 = 299 m^3 per day
Assuming cost of 1 m3 of biogas (IIT-Delhi, 2016) = 1.7 x 150/30 = Rs 8.5 per day
Recovery value = 299 x 8.5 = Rs 2,541 per day.

The detailed breakup of recovery values for different combinations of solid waste used for composting and landfilling are computed to study the best combination that can be used and is given in Table-3.

Table 3: Recovery value options for different combinations of biodegradable solid waste for composting and landfilling

S No	Solid waste for compost (Tonnes)	Recovery value (Rs)	Solid waste for landfill (Tonnes)	Biogas generated (m^3)	Recovery value (Rs)	Total Value (Rs)
1	6.66	13,986	0	0	0	13,986
2	5.66	11,886	1	180	1,530	13,416
3	4.66	9,786	2	360	3,060	12,846
4	3.66	7,686	3	540	4,590	12,276
5	2.66	5,586	4	720	6,120	11,706
6	1.66	3,486	5	900	7,650	11,136
7	0.66	1,386	6	1080	9,180	10,566

The optimum combination for the compost and biogas mix proportion From Fig. 3 is 2.66 tonnes for compost and 4 tonnes for landfilling bringing an optimum revenue of Rs 11,706. However, this is Rs 2,280 less than the best combination (#1). Further, more solid waste for landfilling means it requires additional land for disposal. The best combination would be to minimize the solid waste for landfilling and make better use of solid waste for recovery as compost as it would help bring direct revenue and improve crop productivity as well. Hence a combination of 4.66 tonnes for composting and 2 tonnes for landfilling with net recovery of Rs 12,846 per day may be adopted.

3.9.3 Recovery value for Paper and Plastic

Non-biodegradable solid waste = 9000 x 0.26 = 2340 kg/day

Recovery for paper:
Amount of paper : 10.3 x 2340/100 = 241 kg/day
Assuming 50% is not recoverable = 120 kg/day.
Recovery value @ Rs 10 per kg of paper = 120 x 10 = Rs 1200 per day

Recovery for Plastic
Amount of plastic = 3.8 x 234/100 = 89 kg/day
Assuming 50% is not recoverable = 45 kg/day
Recovery value @ Rs 15 per kg of plastic = Rs 675 per day

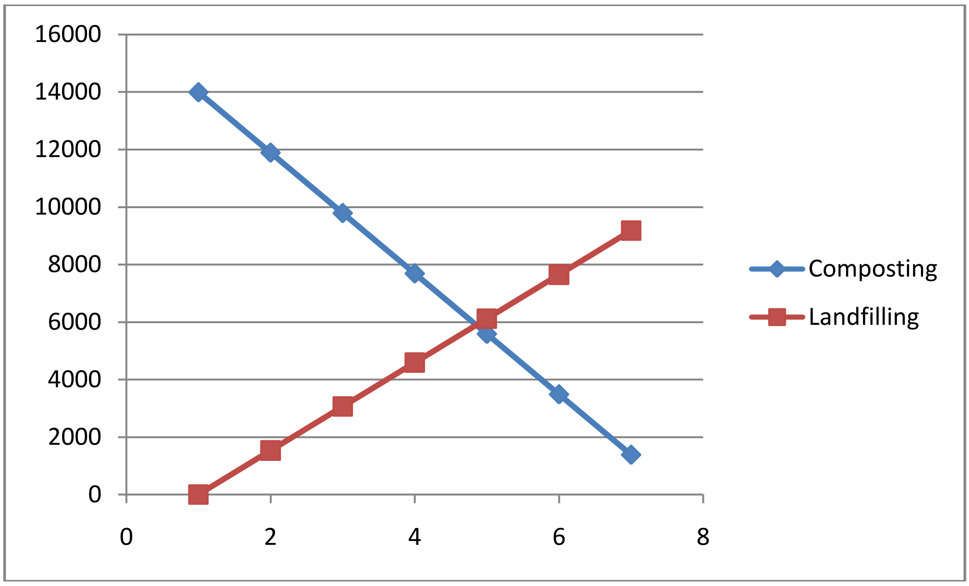

Figure 3: Recovery value (Rs) comparison between Composting and Landfilling options

3.9.4 Total recovery value from solid waste

The total recovery value from solid waste = Recovery value from bio degradable waste + Recovery value from non-bio degradable waste

The total recovery value from solid waste = 12,846 + 1200 + 675 = Rs 14,721 per day or **Rs 53,73,165 per year**. However, it should be noted that construction and operation costs for composting and landfilling are not included. Since it is an investment, it can be recovered quickly in a few years from the operation. It should be noted that, the recovery value is maximum (87%) from biodegradable waste and hence waste recovery practices should be followed. Moreover, recovery value of paper and plastics (13%) is possible only when segregation of these components is made at the source of generation. Contamination of these components may lead to higher side of non-recoverable portion and the recovery value will be reduced further.

IV. Summary and Conclusions

Solid waste management practices at Rajam, in Srikakulam District, Andhra Pradesh is studied. Currently no systematic practices are being followed except collection of solid waste from houses and dumping at far off place. Systematic studies are made and computations are done for determination of composition, characterization, quantification, route analysis and recovery value of the solid waste. Few suggestions are floated in this regard.

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