JOURNAL OF ENVIRON. SCIENCE & ENGG. VOL. 50, No.4, P. 319-328, October 2008

Municipal Solid Waste Management (MSWM) in India A Critical Review

SUDHA GOEL

Solid waste management (SWM) is one of the most neglected aspects of India's environment and the recent Municipal Solid Waste (Management and Handling) Rules 2000 have made it mandatory for the administrative authority of any area to undertake responsibility for all activities relating to municipal solid waste management (MSWM). A survey of MSWM practices in Indian urban local bodies (ULBs) and the literature suggest that major problems in MSWM in India are: underestimation of generation rates and therefore, underestimation of resource requirements, lack of technical and managerial inputs, and lack of reliable and updated information to the public and practitioners in the field. India is a developing country whose economy is currently growing at an extremely rapid annual growth rate of 8 to 9%. Based on trends in countries like the US, and China, and European countries, it is clear that a growing economy and population are likely to result in growth rates of 11 to 12% in MSW generation. These growth rates are much higher than the current expert estimates of 1.3 % for per capita MSW generation and 4.2% for total MSW generation. The present *ad hoc* approach to MSW collection and transport results in inefficient utilization of resources. Modern technology and tools like remote sensing, GIS and mathematical optimatization methods can be used for more efficient allocation and utilization of resources.

Key words : *Municipal solid waste management (MSWM), urban local bodies (ULBs), MSW generation rates, growth rate*

1. Solid waste management (SWM)

The term 'solid waste' includes any waste material that is neither in liquid nor gaseous state. However, containerized liquid and gaseous wastes are also included in the term solid waste. Major categories of wastes included in the term solid waste are municipal solid waste (MSW), agricultural wastes, industrial wastes, ash from thermal power plants, and hazardous wastes. The objective of this paper is to critically review the current status and problems with managing municipal solid waste (MSW) in India and to propose feasible solutions.

Integrated municipal solid waste management (MSWM) includes basic activities like generation, collection, transfer and transport, separation and recycling, and disposal that are essential components of any efficient system **(Fig 1)**. The recent Municipal Solid Waste (Management and Handling) Rules 2000 have made it mandatory for the administrative authority of any area to undertake responsibility for all activities except generation. These administrative authorities or urban local bodies (ULBs) are Municipal Corporations with jurisdiction within large cities while City Urban Development Authorities manage the suburban or peri-urban areas outside the city limits. Open dumping of urban MSW is the norm in the country and almost all unused public property (and sometimes, even private property) in urban areas become convenient dumps for neighboring waste. Given the fact that SWM is one of the most neglected aspects of the Indian environment, especially in urban areas, it becomes imperative that all resources: financial, technical and intellectual, be directed towards improving it.

2. Generation of solid waste

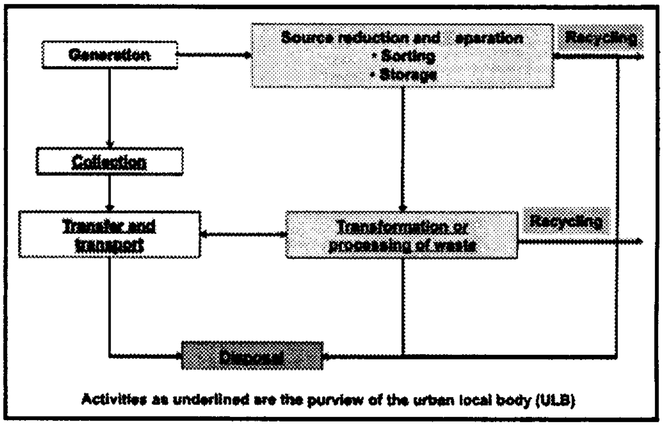


Fig. 1: Integrated solid waste management

Assistant Professor (Envionmental Engineering), Department of Civil Engineering, Indian Institute of Technology Kharagpur, Kharagpur, West Bengal, India - 721302; e-mail : sudhagoel@civil.iitkgp.ernet.in

2.1 *Waste generation rates*

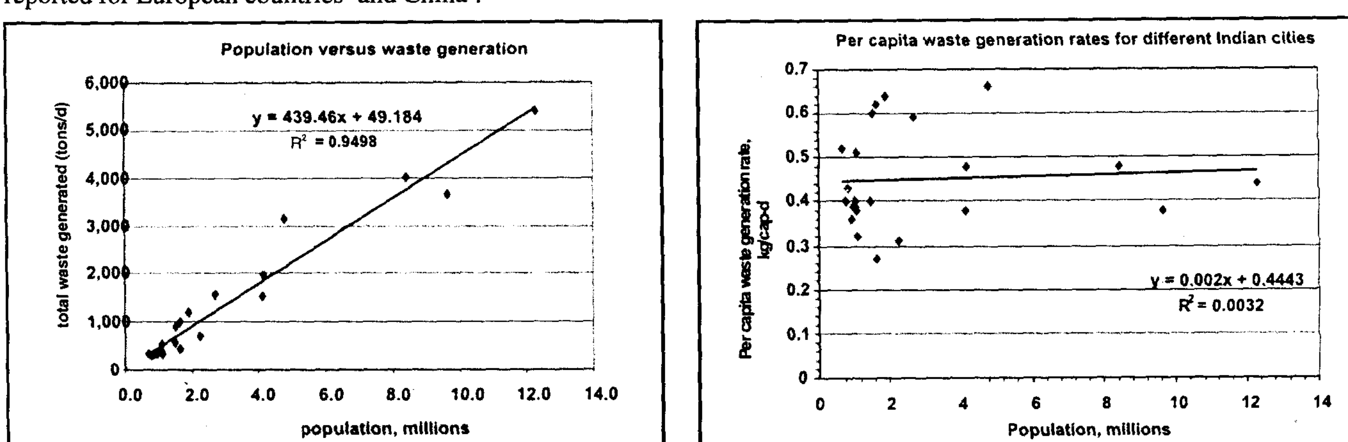
Global generation of solid wastes (SW) was 12 billion tons/y in 2002 of which 1.6 billion tons/y (13.3%) were MSW[1]. Asia alone accounts for the generation of 277.4 million tons per year (MT/y) of MSW[2]. Data for the US show that MSW constitutes only 1.5% of the total SW wastes (RCRA) generated[3], while data for India suggest that MSW constitutes 11% (48 MT/y) of the total waste generated with agriculture accounting for 35.6% and industrial activities accounting for 28.2%[1]. In general, MSW represents a very small fraction of the total SW generated in any country but tends to get more attention since more people generate it and are affected by its subsequent management or lack thereof.

2.2 *MSW generation rates: total and per capita waste generation rates*

CPCB's estimate of urban MSW generation in India in 1947 was 6 million tons/y, which increased to 48 million tons/y in 1997. This represents a 4.2% annual growth in total urban MSW generation rates. Census of India data for 1951 and 1991 were used to interpolate total populations and urban populations for 1947 and 1997[4]. Per capita urban SW generation rates in 1947 and 1997 were calculated based on these data and found to be 0.31 kg/cap-d and 0.52 kg/cap-d, respectively which amounts to a 1% growth rate. This demonstrates the increase in both, total and per capita generation rates. These increasing trends in India can be compared to those of a developed country like the US, where per capita generation increased from 1.36 kg/cap-d in 1960 to 2.05 kg/cap-d in 1990[5]. After 1990, the per capita generation rates in the US have remained almost constant and can be attributed to better public awareness about recycling and aggressive recycling campaigns by administrators. Similar trends in SW generation rates have been reported for European countries[6] and China[7].

Current per capita MSW generation rates in India for different cities range from 0.22 kg/cap-d to 0.66 kg/cap-d[2] with an average of 0.45 kg/capita-d. A NEERI[8] paper had shown that per capita SW generation rates ranged from 0.21 to 0.5 kg/capita-d, and these increased with an increase in population size for a town or city. The raw data for this relationship is not available to the public. While total tons of MSW generated/d are directly proportional to the size of the population as shown in **Fig. 2a**, per capita generation rates are not. Based on Environmental Resources Management (ERM) data, no correlation was found between population size and per capita SW generation rates and these data are shown in **Fig. 2b**. Similar results and relationships were reported for US data[9].

For greater perspective, per capita generation rates in other Asian countries can be compared to those in India; these range from 0.45 kg/capita-d for Myanmar to 5.07 kg/capita-d for Hong Kong[2]. The 5.07 kg/cap-d rate for Hong Kong is likely to be an overestimate since it includes construction and demolition waste. Another study reports Hong Kong's per capita waste generation rate as 1.01 kg/cap-d[7]. The International Bank for Reconstruction and Development (IBRD) report provides data for per capita SW generation rates for Asian countries along with GNP per capita. Per capita generation rates are related to the income levels of the country to a much greater extent than they are to population size (**Fig. 3**). Higher income countries in Asia have higher per capita SW generation rates ranging from 1.1 (Singapore) to 5.07 (Hong Kong) kg/capita-d. A survey of European nations also shows a clear relationship between increase in income levels and per capita MSW generation rates [6,10]. Viswanathan[11] similarly reports a clear linear relationship between per capita SW generation rates and income levels for Indian households.



(a) Based on ERM India, 1995 data (b)

Fig. 2 : Waste generation rates and population size in India

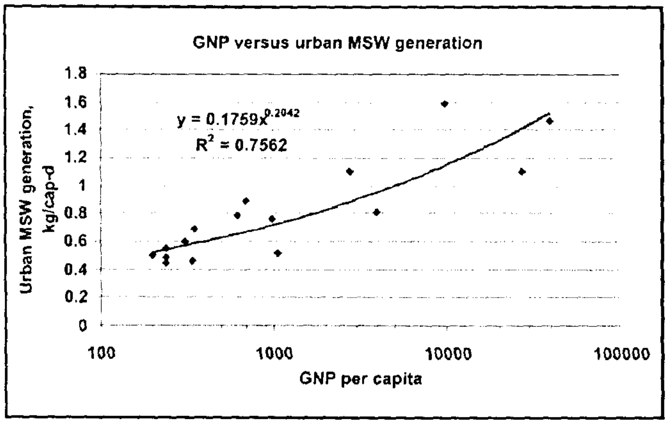


Fig. 3 : GNP/cap versus per capita urban SW generation rates for different countries

2.3 *Forecasting MSW generation rates*

The total population growth rate in India based on census data from 1921 to 2001 is 1.82%[12]. Along with rapid exponential growth in total population comes an even more rapid increase in the rate of urbanization in India with the urban population growing at a 3.0% annual growth rate from 1921 to 2001. CPCB's estimates of the growth rate for total urban MSW generation of 4.2% is likely to be based on the urban population growth rate and per capita MSW generation rate. A recent publication used a growth rate of 1.33% for forecasting per capita MSW generation[13]. It is likely that these MSW generation rates grossly underestimate the growing magnitude of the problem.

India is a growing economy with a GDP growth rate of 9.2% or higher, which implies that the rate of resource consumption is increasing rapidly. In general, total consumer expenditure (TCE) is proportional to the country's GDP[10]. As GDP or TCE increases, it implies an increase in resource consumption, and therefore an increase in the generation of MSW. Trends in India are likely to follow those of other countries, and it is likely that MSW generation rates will increase to levels similar to developed countries in the near future. China is a good example of this phenomenon; China's average annual GDP growth rate was 10.5%[14]. Per capita SW generation rates for a large Chinese city (Guangzhou) grew by 9.5% per annum (from 1983 to 1990) while their total SW generation rate increased by 10% per annum over the same period[7]. The rates of increase were slower from 1990 to 1996 as total MSW generation increased by 6.6% per annum and per capita MSW generation increased by 5%. Currently, per capita SW generation rates in Guangzhou (1.09 kg/capita-d) are comparable to Hong Kong (1.01 kg/capita-d). Per capita SW generation rates in Hong Kong have not changed significantly over the same period (1990-1996). Even European nations with much slower economic growth rates have seen a net increase in per capita MSW generation rates over the last two decades[6].

Based on the above data, two major points can be made:

1. India's per capita MSW generation rates are likely to keep pace with economic growth rates, which currently range from 9 to 10%, and if the urban population growth rate of 3% continues in the near future (most experts expect urbanization rates to increase as well), then the total urban MSW generation rate is likely to increase by 12 to 13%.

2. Per capita generation rates are likely to rise steeply before they plateau at levels close to 1.0 to 2.0 kg/cap-d, as has been the case with the US, China, Hong Kong and Europe.

These data also point to the need for detailed monitoring of MSW generation rates in urban areas to ensure that forecasting is based on 'real' data rather than assumptions based on data from other countries.

2.4 *Composition of SW*

Differences in GNP or GDP result not only in sharp differences in total and per capita SW generation rates, but also in the composition of the waste generated. As income levels rise, the percent organic content (mainly food content) decreases while the content of recyclables like paper, plastic, metals and glass increases[15,2].

Another aspect of SWM that is increasing in importance and generally not factored in is electrical and electronic waste (e-waste), especially from discarded household appliances. A survey in China highlights the problems associated with increasing quantities and toxicities of e-waste[16], and India is heading towards similar crises (in some cities like Bangalore, this is already the case). Efficient options for handling discarded e-waste include buy-back or return policies of the manufacturers, reuse of useful components and their reassembly, and recycling of key materials like metals and plastics. Other less efficient options that are currently in use in the absence of more desirable ones are direct discarding or storage of e-waste.

3. Source reduction and implementation of the 4Rs

The 4Rs, Reduce, Reuse, Recycle and Recover, are the first principles of SW reduction that are an integral part of the ethos of a developing or poor country like India. Incentives to implement the 4Rs are much greater in poor economies, where conserving resources implies money saved! This ethos is often lost as the economy improves and consumer spending and resource consumption increase. In richer economies where resource consumption is much higher, public awareness and education can improve implementation of the 4Rs, but financial driving forces remain far more potent than voluntary action and goodwill. Cultural values and industrial activities may also be significant factors. Rich economies like Hong Kong and Singapore have maintained their per capita MSW generation levels at around 1.0 kg/capita-d in the last decade, while EU and the US had per capita generation levels between 1.5 and 2.0 kg/capita-d during the same period[6,10].

The 4 Rs of SWM are described here with some examples of current practices and some that should be introduced.

Reduce: The first principle is to reduce the amount of material required to deliver one unit product without sacrificing its utility or quality. Examples include the use of refills instead of new containers for food packaging, spray painting instead of brush or roller painting of surfaces, use of rechargeable batteries instead of disposable batteries, and use of plastic tubes without additional packaging instead of aluminum tubes packaged in paper cartons. This principle also includes using materials that have a longer lifetime (reducing the use and need for disposables). Examples of this practice would include using plastic furniture rather than cheap wood furniture, and synthetic fabrics instead of natural fabrics. Another method of implementing this principle would be to eliminate or reduce the need for certain products. Examples include substituting print media for electronic media, and using gas pipelines instead of cylinders. It must be recognized that this concept needs to be implemented intelligently. Very often the use of disposables is necessary for convenience and maintaining quality. An example of this is the use of disposable needles and syringes for medical purposes. Even though, disposables result in an enormous increase in resource consumption and waste generation, their use is often necessary in many situations.

Reuse: The monetary incentives in implementing this principle are self-evident. Frugality usually makes most people reuse containers of cardboard, plastic, metal, and glass for storage and other purposes in homes, offices and business establishments. Packaging materials are similarly easy to reuse.

Recycle: Recycling involves separating different components of waste and reprocessing them into new products. Plastics, paper, steel and aluminum cans, glass bottles, and yard waste (composting) are examples of MSW components that can be recycled to create new products.

Recover: In general, recyclables should be separated at source. However, often refuse that is collected is unsegregated and desired materials have to be separated (recovered) at a central facility. Even though the bulk of recyclable materials are separated at source, it is becoming increasingly evident that some amounts of paper cartons, plastic, foil wrappers, household hazardous items like batteries, tube lights, thermometers, etc. are left in the mixed waste. A materials recovery facility where these materials can be separated from more benign materials like soil and organic matter is essential, especially if the waste is to be composted.

Recyclables like paper, plastic, metals and glass have significant resale value in India, and these materials are either collected from house-to-house by recyclists or from open dumps by 'ragpickers'. The economic incentives for both generators and collectors of these waste components make it possible for ragpickers and recyclists to make a living from collecting recyclables. Surveys in Delhi and Jaipur found around 90,000 ragpickers in Delhi and around 50,000-80,000 ragpickers in Jaipur[17,18]. A survey of 'ragpicking' activities in Delhi found that 17% of the trash that is dumped in containers or open dump sites is brought to recycling units by a hierarchy of recyclists (including ragpickers) and recyclables dealers[17]. People involved in these activities are part of the informal sector but form a well-organized network of small and big dealers that transfer waste components to recycling units.

An additional MSW fraction that can also be separated at source is kitchen and garden waste, to be used for composting later. Both, home composting and large-scale composting have proved successful all over the world. In India, home composting is not as popular as large-scale composting, unlike in developed countries. Composting requires some amount of information and skill, and has not become a popular waste management strategy for householders in India as in the West.

As economic levels improve, the formal and informal collection systems for recyclables are likely to become non-existent as has happened in developed countries. These systems will have to be replaced by large, mechanized materials separation facilities. Since the amounts of waste generated are enormous in large Indian cities, economies-of-scale may make large materials recovery facilities a viable option even in developing countries like India.

4. Collection of SW

a. Collection efficiency

For SWM to be effective, infrastructural collection capacities have to be greater than or equal to SW generation rates. However in India, collection capacity provided is generally less than the actual waste generated and is one of the biggest problems in SWM. The result of this gap is visible in the form of open dumps that are never collected from because they have no 'official' existence, and overflowing SW containers at 'official' dumpsites due to a less-than-required cleaning frequency or underestimated SW generation rates in that area. Municipal systems are generally designed on the basis of underestimated generation rates, and therefore, underestimated financial, infrastructural and labor resource requirements. Inefficient management also results in inequitable distribution of these resources, creating a bigger than necessary burden for some parts of a city and greater inefficiency in all aspects of SWM.

A nation-wide survey of Indian cities was conducted by Operations Research Group (ORG) in 1989 and collection efficiencies were found to range from a poor 19.2 % in Salem to 97% in Mumbai. National Institute of Urban Affairs (NIUA) also conducted a survey of 159 cities in 1989 and found poor collection efficiencies ranging from 66 to 77%. Deficiencies in waste collection were found to be mainly due to shortfalls in manpower and transportation facilities.

b. Resources

In general, most cities or ULBs suffer from lack of resources, i.e. inadequate containers, vehicles and manpower.

Containers: In India, waste is generally dumped on open land and most waste storage sites do not have containers. While ULBs are now aware of the need to containerize waste, the numbers, capacities, and locations of containers remain major issues of SWM.

a. Number of storage sites with containers: Each city has a number of official and 'unofficial' sites for storage of waste. All unofficial and most official sites do not have containers; which means that waste is often left lying around and subject to scattering by wind, stray animals, and ragpickers. Data were collected from several ULBs in the country (shown in **Table 1**), and the number of sites that had containers for waste collection ranged from 41% in Ahmedabad to 100% in Hyderabad and Vishakhapatnam.

Table 1: Storage sites with containers and percent containerization

City	Number of storage sites	Sites with containers	% containerized
Ahmedabad	708	297.00	41.95
Hyderabad	1,434	1,434	100.00
Vishakhapatnam	1,680	1,680	100.00
Itanagar	46	35.00	76.09
Anantapur	116	106	91.38
Midnapur	513	513	100.00
Ambajogai, Maharashtra	335	335	100.00

b. Location and accessibility of containers: Containers are often placed in inappropriate locations where collection vehicles cannot access them as easily or as frequently as desired. These areas are also frequented by stray animals, which add to the prevailing chaos in terms of accessibility. Also, containers are often unlidded or left open, allowing stray animals to get in and pull waste out of the containers into the streets and open areas.

c. Container capacity and numbers: Underestimates of generation rates result in less than adequate numbers of containers and less than required collection capacity. A simple calculation will show why the present collection capacities (or container volumes) are inadequate. If we assume an average per capita SW generation rate of 0.5 kg/ cap-d and an average density of 400 kg/m^3, then the design volumetric capacity for collection and transport per million people should be 1250 m^3/d. For an efficiently designed system, a per capita generation rate at the higher end (0.7 kg/cap-d, current maxima) and a low density (250 kg/m^3) should be assumed. This would result in a required collection (or storage) capacity for every million people of 2800 m^3/d, if collection is done daily. Collection frequency is generally either daily or weekly[13,19]. In case of weekly collection, storage capacity should be available for 7 days/week resulting in a requirement of 19,600 m^3/week. A literature survey of SWM case studies showed no reports of collection capacities provided by the municipalities. A survey of municipalities in India was done and total container capacities provided per million people in different cities were calculated and are summarized in **Table 2**.

Container capacities provided in these cities ranged from 523 m^3 to 14776 m^3. Based on these data, it is evident that collection requirements are generally underestimated in Indian cities.

Table 2: Population and container capacities provided in different Indian cities

City	Population millions	Container capacity, m^3	Capacity per million, m^3/ million popul.
Itanagar	0.04	517.50	14776.43
Midnapur	0.25	147.75	591.00
Anantapur	0.09	106.25	1180.56
Bhilai	0.25	1113.70	4454.80
Warangal	0.58	301.50	523.44
Allahabad	1.10	623.40	566.73
Vishakhapatnam	1.90	1022.00	537.89
Hyderabad	4.30	2266.00	526.98
Ahmedabad	4.52	2564.50	567.37

Vehicles : Problems with vehicles include inadequate numbers and capacities of vehicles, lack of maintenance, and vehicle breakdown. The numbers of collection vehicles required are also grossly underestimated and breakdown, repair and other off-route time is not included when budgeting for the transport system for MSW collection. At any given point in time, the number of vehicles available from the total fleet ranged from 51% for Kolkata to 71% for Ahmedabad. Many of the unused vehicles are in "repair and maintenance". A shortfall of manpower (drivers) for driving these vehicles may be another reason for inefficiency in vehicle usage.

Labor : Manpower allocated for SWM ranges from 0.9 workers/ 1000 people in Kharagpur to 3.5 workers/ 1000 population in Delhi[20], which again seems grossly inadequate. A benchmark that many Indian experts agree on is 3.5 workers/ 1000 population[21]. However, no basis for deriving this benchmark was found in the literature. Given the lack of resources, and the lack of adequate numbers of workers, the pressures on the system make it impossible to operate efficiently and meet requirements. These pressures also cause MSW workers to have high rates of absenteeism due ostensibly to reasons like indiscipline, injury, disease and lack of motivation. However, a major fact that needs to be recognized is that human resources can never be efficiently utilized if a system is deficient in terms of material resources. Besides a shortfall in manpower, another major problem is the inequitable distribution of manpower in a city[13,19]. Often, employees prefer to be allotted 'beats' in high-income neighborhoods rather than in low-income areas, which results in more sweepers or employees allocated to high-income neighborhoods and less to low-income areas.

Budget allocation: In a state-wise survey of municipal expenditures on core services, per capita expenditure on conservancy and sanitation (solid waste and sewerage) averaged 21.5% of the total expenditure[22]. The lowest budgetary allocations were in Madhya Pradesh and Maharashtra at around 11%, and the highest allocations were in Uttar Pradesh at 50% of the total expenditure. Many municipal corporations including Kharagpur do not have a separate department or section for handling solid waste management, thus highlighting the lack of priority this issue has received until recently.

In a recent survey of 25 major Indian cities by[20], annual per capita expenditure on MSW management ranged from Rs. 258 in Ludhiana to Rs 431 in Delhi. One author suggests that ULBs in India spend 5 to 25% of their total budget on SWM, which amounts to Rs. 75 to 250 per capita annually[23]. Globally, % GNP spent on SWM ranges from 0.16% (Romania) to 0.8% (Vietnam) while per capita expenditures range from 0.66 USD (Ghana) to 106 USD (New York, US)[2]. India's current per capita GNP is USD 797 (2004 Estimate, Wikipedia), which is approximately equal to Rs. 31400 at current conversion rates of Rs 39.4 to USD 1. Despite Indian ULBs spending around 0.78 to 1.3% of the per capita GNP on SWM, the results leave a lot to be desired. These data are also indicative of the fact that ULB spending levels have increased only after regulations have been put in place, i.e. in the last decade or so. As infrastructure improves, the same level of spending will show better results.

At present, most cities rely on an *ad hoc* approach to collection and transfer of waste to disposal sites. With availability of tools like Remote Sensing and GIS[24], and mathematical optimization techniques[25-27], more rational, consistent and efficient methods can be utilized for managing collection activities like determining optimum bin locations, optimal allocation of waste to multiple disposal sites and optimizing collection routes. More generous budget allocations and better estimates of system requirements are essential for better functioning. Hiring more workers and ensuring that they are well trained are other areas that can be improved.

c. *Public versus private sector management*

Until recently, Urban Local Bodies (ULBs) were striving hard to meet the needs of MSWM on their own. However, the last decade has found more and more ULBs relying on private operators to manage MSW. A recent survey by

FICCI found that 23 out of 25 cities in the country have engaged private sector companies to carry out at least part of the ULB's responsibilities[20]. The most common activities that have been sub-contracted to the private sector are sweeping, collection and transportation. The major advantage for these public-private partnerships (PPP) is that private operators can provide services at lower costs and with greater efficiency compared to public sector companies. ULBs in Navi Mumbai and Rajkot found that PPPs resulted in 40% and 23% cost reductions, respectively[28]. Navi Mumbai also found that 450-500 sanitation workers were redundant after hiring private contractors to do sweeping and waste transport. While most private operators provide collection and transportation services, a few private operators have been providing treatment and disposal services.

Again, it is important to note that most reports about PPPs demonstrate their successes, while there are some ULB experiences that deserve attention despite their lack of success. Rajkot, for example, found that it was essential for the ULB to retain control over providing an essential service like MSWM when private contractors went on strike during the monsoon asking for a hike in fees. Rajkot Municipal Corporation has been maintaining its own fleet of vehicles since then[28].

5. Treatment issues

The objective of treating MSW is to reduce the weight and volume of waste that has to be disposed of in a landfill. Treatment processes for MSW include physical processes for separation of different fractions, chemical processes like combustion and biological processes like composting and biofuel generation. The choice of treatment process depends on many factors including the amount and composition of the waste. Most large cities in developed countries have solid waste treatment facilities where the waste is processed prior to disposal. Similar facilities have been setup in India, with 21 out of 25 cities having some kind of treatment facilities, and many more with treatment facilities in the planning stage[20].

5.1 *Physical treatment (processing)*: The main objective of physical treatment (processing) of waste is to separate different components from waste for recycling, reuse or recovery. Other objectives include homogenization of waste and reduction in volume for subsequent storage, transportation, and treatment. Examples of physical treatment processes include shredding, grinding, screening, magnetic separation, air classification, and densification.

Separation of waste components in India is done manually at source by the generators or by ragpickers after the waste has been dumped. Some degree of pre-treatment, which includes separation of contaminating materials from waste, is done at composting plants prior to composting. However, no large-scale materials recovery facility for mechanized separation of waste has been setup in India as yet.

5.2 *Chemical treatment:* Oxidation of MSW by combustion is a common process. Traditionally, rural residents and very poor urban residents have utilized agricultural waste as supplemental fuel for household purposes. Uncontrolled burning or incineration of waste is also common practice in the country. Generally, people are unaware of the dangers of uncontrolled incineration.

Large-scale combustion of MSW is feasible. When large amounts of waste are combusted in an incinerator, adequate air pollution control equipment becomes essential and that results in high combustion costs. This makes large-scale combustion an unattractive option for most Indian ULBs. Waste-to-energy (WTE) combustion is an attractive proposition (second only to composting), provided sufficient energy can be obtained from the waste. Again, in developing countries, where the bulk of the waste is biodegradable with high moisture content, WTE is feasible only after the biodegradable fraction has been separated.

Popular WTE treatment methods include incineration, biomethanation, pelletization, bioethanol or biodiesel generation and gasification. There is a minimum amount of waste required to ensure the success of WTE facilities and 300 tons/d is often assumed as a minimum[29]. At least 5-6 ULBs in India had setup WTE facilities like incineration, or pelletization, without long-term success. Several ULBs continue to plan and setup WTE projects[20], undeterred by the lack of success of other WTEs. At this stage in India, it is worthwhile for policy makers to review the deficiencies in the existing WTE systems (defunct and functioning) and publish or make these reviews available to the public, or at least practitioners in the field.

5.3 *Biological treatment*: The dominant fraction of MSW (50 to 60%) in India is biodegradable (with high organic and moisture content) making composting an optimal initial treatment strategy. Composting, which is a traditional technique, and vermicomposting, which is done by utilizing earthworms, are two biological processes that can be used to treat the biodegradable fraction of solid waste. Composting can be carried out aerobically or under a combination of aerobic and anaerobic conditions with compost as the end product. This is a popular treatment method and 15 out of 25 cities in the FICCI survey have composting or vermicomposting facilities. Compost is useful as a fertilizer supplement, and as a soil conditioner. As income levels increase, the non-biodegradable content increases, and composting requires separation of kitchen and yard waste from all other components prior to treatment. Separation of wet and dry waste at source is an option that should be considered in residential areas, and will require public awareness campaigns to make this a successful option.

Other biological processes include biofuel generation (generation of ethanol, diesel or methane) under anaerobic conditions and are being setup in India.

6. Disposal issues

In general, waste that cannot be recycled, reused or treated ends up in an open dump or landfill. Landfills can be designed as bioreactors as is done in many European countries and the US, or they can be used for disposal of non-biological materials as recommended in the Indian regulations. Higher income countries with large areas of land that are easily available tend to prefer landfilling as against other options like composting and combustion. Extreme examples of this preference include Australia and Canada. Where land availability is low and real estate prices extremely high, combustion becomes the method of choice for disposal as in Japan. However, combustion requires air pollution control, which makes the cost of combustion prohibitively expensive for low- and middle-income countries.

7. Information generation and dissemination

One of the most common problems in India is the lack of reliable and regular data collection and its lack of availability to the public and practitioners in the field. A lot of work has been done by ULBs in the last decade. While many ULBs are providing relevant information to the public through their websites as well as on request, there are many that have not made their experiences, successful or not, public. Currently, practitioners in the field have to rely on assumptions while designing a system and not 'real' data applicable to the actual site. It is therefore, essential that regular monitoring of MSW generation, treatment and disposal is done and the data made available to the public. A centralized database that provides information in the form of data, reports, papers, webpages, etc. about ULB experiences would go a long way towards improving SWM design and practices in the country.

8. Summary and conclusions

India is a developing country whose economy is currently growing at an extremely rapid annual growth rate of 9 to 10%. A growing economy and population imply that resource consumption and waste generation will follow similar or higher rates of growth. For a country that has paid little attention to the issue of SWM, it becomes imperative to recognize the extent of the problem and its growing magnitude.

There are inherent flaws in current MSWM design and practice in India and solutions are proposed for addressing them.

a. MSW generation rates: Forecasting of MSW generation rates and estimates of resource and manpower requirements need to be more realistic. In general, these are underestimated by most ULBs and consequently systems designed with these data are always stressed and unable to meet performance standards

b. Collection and transport systems: At present, most cities rely on an *ad hoc* approach to collection and transfer of waste to disposal sites. Even though this section of SWM gets the largest share of any ULB's budget, almost every aspect of waste collection is inefficient due to lack of resources (data, labor, equipment, money) and skills, mainly technical and managerial. With availability of tools like remote sensing and GIS and mathematical optimization techniques, more rational, consistent and efficient methods can be devised for managing collection activities. More generous budget allocations and better estimates of system requirements are essential for better functioning. Hiring more workers and ensuring that they are well-trained are other areas for improvement

c. Treatment: Of the 25 cities surveyed by FICCI, 21 have some waste treatment facility[20]. Most of these facilities have been put in place in the last decade. Composting is the most popular treatment method followed by vermi-composting, incineration, pelletization and biomethanation. Mechanized separation of MSW fractions and/or source separation are essential for ensuring that treatment methods like composting are successful.

d. Disposal: There are very few engineered landfills in the country and little information is available about those that have been constructed. In general, MSW continues to be dumped on open land without any regard to design, operation and monitoring guidelines despite regulations to this effect.

e. Information dissemination: Regular monitoring and data collection are essential for designing an efficient system. A centralized database that provides information in the form of data, reports, papers, webpages, etc. about ULB experiences in SWM would go a long way towards improving SWM practices in the country.

Acknowledgements

The author is grateful to the following students of the Civil Eng. Dept. in IIT Kharagpur for collecting data from the respective ULBs: SSR Murthy for Vishakhapatnam, Aviram Lamdoh for Itanagar, K Vidyasagar for Warangal, Parthasarathi Roy for Kharagpur, TT More for Ambajogai, N. Sanjeev Kumar for Midnapore, K. Thanmayi for Anantapur, H. Reddy for Kurnool, P. Suma for Nellore, T. Hazra for Kolkata, and Naresh Kumar for Hyderabad.

References

1. Pappu A, Saxena M and Asolekar S, Solid wastes generation in India and their recycling potential in building materials, *Building and Environment*, **42**, 2311-2320 (2007)

2. IBRD-World Bank, What a Waste: Solid Waste Management in Asia. Available from web.mit.edu/ urbanupgrading/ urbanenvironment/ resources/ references/pdfs/ WhatAWasteAsia.pdf (1999)

3. Masters GM, Chapter on Solid Waste Management in Introduction to Environmental Engineering and Science, Prentice Hall, USA (1998)

4. Registrar General of India Census of India. Downloaded from http://www.censusindia.net/2005

5. US Environmental Protection Agency (USEPA) Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2003. Downloaded from www.usepa.gov.

6. Matsunaga K and Themelis NJ, Effects of affluence and population density on waste generation and disposal of municipal solid wastes. http://www.seas.columbia.edu/ earth/ wtert/waste-affluence-paper.pdf (2002)

7. Chung S S, and Poon C S, A comparison of waste management in Guangzhou and Hong Kong, *Resources, Conservation and Recycling*, **22**, 203-216 (1998)

8. National Environmental Engineering Research Institute (NEERI) strategy paper on 'Solid Waste Management in India', NEERI (1996)

9. Vesilind PA, Worrell W and Reinhart D, Municipal Solid Waste Characteristics and Quantities in Solid Waste Engineering, Thomson Learning Inc., Singapore (2002)

10. Daskalopoulos E, Badr O and Probert SD, Municipal solid waste: A prediction methodology for the generation rate and composition in the European Union countries and the United States of America, *Resources, Conservation and Recycling*, **24**, 155-166 (1998)

11. Viswanathan C, Domestic Solid Waste Management in South Asia, Downloaded from http:// www.faculty.ait.ac.th/ visu/. (2006)

12. Malayala Manorama, Population data for India. In *Manorama Yearbook 2006*, Malayala Manorama, Kottayam (2006)

13. Sharholy M, Ahmad K, Vaishya RC and Gupta RD, Municipal solid waste characteristics and management in Allahabad, India, *Waste Management*, **27**, 490-496 (2007)

14. Wikipedia, Economy_of_ Mainland_ China – 2007. Downloaded from http://en.wikipedia.org/wiki/

15. Tchobanoglous G, Theisen H and Vigil S, Integrated Solid Waste Management: Engineering Principles and Management Issues. McGraw Hill International Ed. Civil Eng Series Singapore (1993)

16. Liu X, Tanaka M and Matsui Y, Electrical and electronic waste management in China: Progress and barriers to overcome, *Waste Management and Research*, **24**, 92-101 (2006)

17. Agarwal A, Singhmar A, Kulshrestha M and Mittal AK, Municipal solid waste recycling and associated markets in Delhi, India, *Resources, Conservation and Recycling*, **44**, 73-90 (2005)

18. Khwairakpam M, Bhrigu U and Bhargava R, Financial aspects of solid waste management in Jaipur city – A case study. Downloaded from the Internet (2006)

19. Desai A, Present status and alternatives for SWM in Ahmedabad City. Bachelor's Thesis submitted to School of Building Science Technology, CEPT, Ahmedabad (2000)

20. Federation of Indian Chambers of Commerce and Industry (FICCI) Huge Scope for Privatisation of Solid Waste Management. Downloaded from the Internet (2007)

21. Gupta S, Mohan K, Prasad R, Gupta S and Kansal A, Solid waste management in India: Options and opportunities, *Resources, Conservation and Recycling*, **24**, 137-154 (1998)

22. Mathur O.P, Sengupta P. and Bhaduri A, Option for closing the revenue gap of municipalities, 2000/01 to 2004/05, prepared by National Institute of Public Finance and Policy (NIPFP), New Delhi

23. Kumar S, Municipal solid waste management in India: Present practices and future challenge, Downloaded from http://www.adb.org/Documents/Events/2005/Sanitation-Wastewater-Management/ paper-kumar.pdf (2005)

24. Ghose MK, Dikshit AK and Sharma SK, A GIS based transportation model for solid waste disposal – A case study on Asansol municipality, *Waste Management*, **26**, 1287-1293 (2006)

25. Ahluwalia PK and Nema AK, Multi-objective reverse logistics model for integrated computer waste management, *Waste Manage Res*, **24**, 514–527 (2006)

26. Revelle C, Research challenges in environmental management, *European Journal of Operations Research*, 218-231 (2000)

27. Shmelev SE and Powell JR, Ecological-economic modeling for strategic regional waste management systems, *Ecological Economics*, **59**, 115-130 (2006)

28. FIRE(D) Project Notes: Innovative approaches to solid waste management in India: Focus on private sector participation. Indo-US Financial Institutions Reform and Expansion Project – Debt Market Component [FIRE(D)].. Project Notes (1997)

29. Devi K, Project Notes: Emerging private sector participation arrangements for solid waste management in India. Indo-US Financial Institutions Reform and Expansion Project – Debt Market Component. Project Notes (2001)