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Sustainable municipal solid waste management in low income group of cities: a review

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Abstract: Low waste collection efficiency and financial constraints along with poor planning and lack of study on changing complexities of municipal waste lead to worsening of municipal solid waste related problem, which results in masking the goal of sustainable management of municipal solid waste (MSW). An integrated planning and capacity building is required backed by financial support to control the situation. Life cycle assessment, categorisation, recycling and reduction in all types of wastes and proper landfilling are required.

Resumen: Una eficacia baja en la recolección de los residuos y limitaciones financieras, junto con una planeación pobre y una carencia de estudios sobre las complejidades cambiantes de los desechos municipales, condujeron al empeoramiento del problema relacionado con los residuos sólidos municipales, lo cual opaca la meta de manejar de forma sostenible los residuos sólidos municipales (MSW, siglas en inglés). Para controlar la situación se requiere hacer una planeación integrada y construir capacidades, con suficiente apoyo financiero. Asimismo, hace falta evaluar el ciclo de vida, categorizar, reciclar y reducir todo los tipos de desechos y hacer rellenos sanitarios adecuados.

Resumo: A baixa eficiência narecolha de resíduos e as restrições financeiras, juntamente com o mau planeamento ea falta de estudo sobre as mudanças na complexidade dos resíduos urbanos contribuíram para o agravamento dos problemas relacionados com os resíduos sólidos urbanos ede que resulta na indefiniçãodo objectivo da gestão sustentável dos resíduos sólidos urbanos (RSU). Para controlar a situação requer-se um planeamento integrado assim como capacitaçãoe apoio financeiro. A avaliação do ciclo de vida, categorização, reciclagem e redução de todos os tipos de resíduos assim como adequada deposição em aterro são obrigatórios.

Key words: Landfill, low-income group cities, municipal solid waste, sustainable development.

Introduction

Disposal of solid waste is a growing environmental problem. Municipal solid waste (MSW) includes degradable (paper, textiles, food waste, straw and yard waste), partially degradable (wood, disposable napkins and sludge, sanitary residues) and non-degradable materials (leather, plastics, rubbers, metals, glass, ash from fuel burning like coal, briquettes or woods, dust and electronic waste) (Herat 2009; Jha *et al.* 2007; Tchobanoglous *et al.* 1993). MSW management is a complex issue

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Table 1. Municipal solid waste management in different income group of cities.

Parameters	Low-income	Middle-income	High-income
Per capita income (US $)	Less than 2000	2000-15000	More than 15000
MSW generation rate (kg capita^{-1} day^{-1})	0.3-0.7	0.5-1.5	> 1.0
MSW collection rate (%)	< 70	80-95	Nearly 100
Recycling agent	Informal	Formal+ Informal	Formal
End MSW disposal	Open dump	Open dump/ sustainable landfill	Sustainable landfill
Management capacity status	Poor	Need for capacity building & finance	Needs more precise measures
Planning	Lack of planning / short term planning	Short to medium term planning	Medium to long term planning
Regulation	Lack of regulation or lack of enforcement	Poor enforcement of law	Generally well monitored
Examples	Dhaka, Kathmandu, Karachi, Phnon Penh, almost all Indian, most African and South American cities	Beijing, Manila, Shanghai, Kuala Lampur,	Tokyo, Taipei, Cities of USA, UK, etc.

(Mendes & Imura 2004; IPCC 2006; World Bank 2000; OECD 2002)

due to changing lifestyle of people, rapid urbanization, and under-estimated contributors and stakeholders (Contreras *et al.* 2008; Da Zhu *et al.* 2008). Municipal bodies in low-income group of cities dispose MSW in low lying areas in the outskirt of the city and fill these areas one after the other haphazardly due to limited knowledge and awareness regarding contamination, waste reduction techniques and other aspects of MSW management (Da Zhu *et al.* 2008; Sharholy *et al.* 2008). We have attempted in this article to examine traditional practices of MSW management, constraints towards achieving sustainable MSW management in low-income group of cities and their remedial measures.

Municipal solid waste management

MSW management encompasses planning, engineering, organization, administration, financial and legal aspects of activities associated with generation, growth, storage, collection, transport, processing and disposal in an environmentally compatible manner adopting principles of economy, aesthetics, energy and conservation (Tchobanoglous *et al.* 1993). Although population growth and waste generation are global challenges, the condition of low-income cities is of particular concern. Cities having less than $2000, $2000-$15000 and higher than $15000 per capita income are categorized as low-income, middle income and high-income cities (Mendes & Imura 2004). Although MSW generation rate is high in cities of the developed world, they are well equipped and have well-surveyed mass and material flow data from cradle to crest (Table 1), which are unavailable for low-income cities of the developing countries.

In low-income group of cities, the existing practices of MSW management and their planning are based on projection of population and per capita waste generation based on sample survey (Khatib *et al.* 2007; MOEF 2006; Shimura *et al.* 2001; Upadhyay *et al.* 2005). Comprehensive survey in winter, summer and rainy seasons for each generation source is unavailable. The seasonal variation in MSW generation is due to the fact that more biomass is burnt in winter, more scattering of MSW takes place in summer and more water soluble organic matters find way in gutters during rainy season. MSW generation also rises during festive seasons that require temporary control measures. Stakeholders of MSW generation and management need to be considered on case-to-case basis as MSW management issues are specific and localized. The first group of stakeholders is MSW generators like households, institutional areas, different groups of businesses; floating populations; health care services; etc. Second group of stake-

Table 2. Criteria indicators of MSW management and their relative importance.

Criteria indicator	Driving force of criteria indicators	Relative importance and their need
Public health*	a. Income status, density and awareness of population b. MSW generation and removal rate c. MSW composition & quantity and their seasonal variation d. Rag picker's status & awareness e. Contamination prevention facilities and infrastructure f. Potential and spread of contamination; contamination prevention, etc.	Directly related to control & prevention of contamination; aesthetics and credibility of the city-needs awareness, funds and personal protection
Environmental scenario#	a. Influence of social and economic status b. MSW generation and removal rate c. Composition and total quantum d. Resource recovery & recycling e. Decomposable matter content f. Climatic and weather set up g. Infrastructure for MSW management h. Decomposition characteristics of waste at intermediate transfer points and landfills i. MSW collection efficiency j. Leaching, air pollution & greenhouse gas emission potential k. Leveling, compaction and cover soil provision at landfill l. Percentage of MSW burning at landfill, etc.	Short term and long term influence, potential hazard and becoming bigger challenge day by day –Need better understanding & suitable management plan
Present and future cost to society**	a. Purchase capacity and awareness among stakeholders b. Employment in formal & informal sectors c. Cost of MSW management d. Composition and quantum e. Economic activity like recycling and composting and associated market f. Extent of contamination and burden on landfill g. Taxes and duty implications h. Public private participation i. Unattended and diffused waste j. Pollution and contamination load k. Economic value of waste to fuel and compost conversion, etc.	Continuous increasing management cost and can be big threat to society due to un-scientific manage-ment-needs better planning
Social aspects##	a. Social and religious behaviour b. Economic status, lifestyle and habits c. Attitude, awareness and best practice adoption, etc.	Responsible for quantum and composition, a linkage for cost due to source segregation potential-needs awareness and attitude of stakeholders

* Macawife & Su 2009; Hubbard *et al*. 2005
**World Bank 1999; Tanskanen *et al.* 1998
El-Fadel *et al.* 1997
Vlachos 1975; Sessa *et al.* 2010

holders are informal rag pickers and their vendors as well as the people who collect food wastes for their animals from households or the animals roaming around the city roads for waste food materials. Third group of stakeholders are organized bodies including municipal authorities, formal sorting activities, processors of degradable and non-degradable materials and the disposal management bodies (Sekher 2001; Taylor 1999).

India produces about 36.5 million tonnes of municipal waste every year. Municipal bodies spend approximately Rs. 500 to Rs. 1500 (US $ 12-36) per ton for solid waste management (Disha *et al.* 2001). About 60 - 70 % of this amount is spent on collection, 20 - 30 % on transportation and less than 5 % on final disposal (Disha *et al.* 2001). Larger funds are diverted to larger cities perhaps due to quantum of waste clubbed with prosperity. Within a city, the most sufferers are low income group people as municipal authorities allocate their limited resources to the richer areas of higher tax yields (Boadi & Kuitunen 2002; Vidanaarachchi *et al.* 2006). Generally, wealthy residents use part of their income to avoid direct exposure to the environmental problems close to their home and working place (Sarkhel & Banerjee 2009; Vidanaarachchi *et al.* 2006). Thus environmental problems at the household or neighbourhood level may recede but citywide environmental degradation either remains the same or increases. Streets are usually dirty especially near commercial centres (Sarkhel & Banerjee 2009), because the shops open in day time after street sweeping and put their sweepings on streets especially along the road.

Criteria indicators

Criteria Indicators are the elements, which identify and analyze even those elements which do not have individual direct influence on MSW management (Goran *et al.* 2008; Humphreys *et al.* 2003; Ristic 2005; Sahely *et al.* 2005). Criteria indicators of MSW management need to be identified and addressed in each city in areas such as public health, environmental scenario, cost to the society, social aspects relating to poor residents, etc. (Table 2). These elements help to assess and identify gray areas of present MSW management practices and formulate future measures to combat challenges and to achieve sustainable solid waste management.

Elements of MSW management system

Traditional system evolved to manage rural and dispersed populations have been applied to urban MSW management in low-income countries and cities (Asase *et al.* 2009; Chang & Lu 1997). This system is insufficient to tackle densely populated areas and requires better infrastructure and skill and incorporation of all major steps of management. Primary collection of MSW and its transfer to community bin or self disposal, care of transfer station, secondary collection and transport to the waste disposal site; waste reduction and disposal in designated dumping grounds is a generalized approach (Tschobanoglous *et al.* 1993). Quantum and complexity of MSW management in urban area in post economic boom period, after the year 1990, are changed (Bogner *et al.* 2007) however, municipalities have not been strengthened correspondingly. A dearth of well-defined study exists leading to primary data inadequacy (IPCC 2006). MSW records of different sources also have data mismatch and larger uncertainties, emphasizing the need of comprehensive survey with precision (Bogner *et al.* 2007). Therefore, improvement is required in demarcating elements of MSW system and their influence potential. The MSW management steps are depicted in Fig.1.

MSW generation and storage

A large number of developing countries and their cities depend on nationally projected data for formulating MSW management strategy. For example, the future management strategy in Patna is based on projected data from sample survey (Bihar Rajya Jal Parsad 2004). The quantity of waste is projected based mainly on number of trips of vehicles used to transport waste or their fuel consumption. Quantitative and qualitative data seem misleading and add large uncertainties at country level and under-estimation of impacts in and around the cities. Sometimes even in a single year different sources reported broadly same composition having different quantum. This is due to uneven distribution of survey area, statistical limitations and studies based on previous reported data due to poor records with local bodies (Bogner *et al.* 2007). It is estimated that solid waste generated in small, medium and large cities and towns in India is about 0.1 kg, 0.3 - 0.4 kg and 0.5 kg capita^{-1} day^{-1}, respectively (Sharholy *et al.* 2008). The per capita generation even reaches to 1.0 kg capita^{-1} day^{-1} in high income households in metros of developing countries especially India (World Bank 1999). According to a World Bank report, urban Asia produced about 760,000 tonnes or 2.7 million m^3 MSW per day in the year 1998-

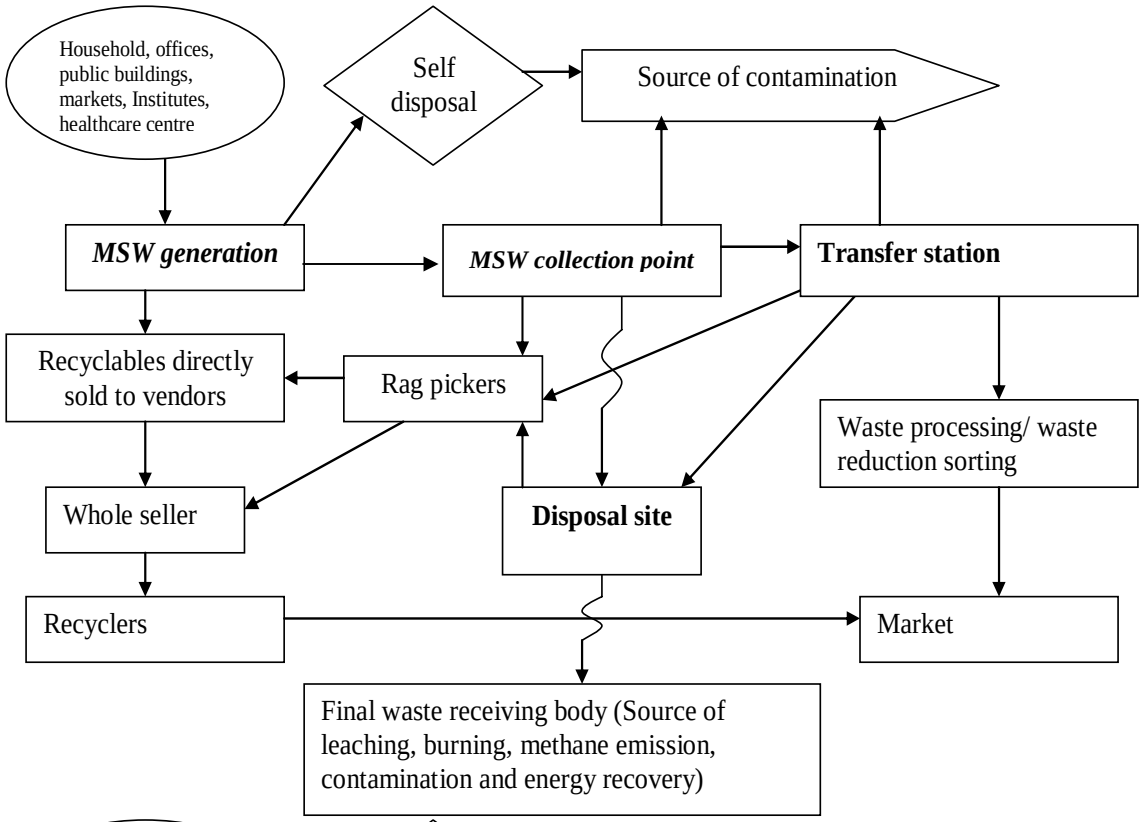

Fig. 1. Schematic flow chart of common MSW management process.

1999, and in 2025 this will increase to 1.8 million tonnes or 5.2 million m^3 per day (World Bank 1999). These estimates are somewhat conservative and the real values may be more than double of this amount. Pressure on landfills is going to be very high in future and recycling and reuse is now the need of MSW management strategy.

Collection efficiency of wastes is a tool for knowing the MSW management status. Generally collection points are open and unattended for a day or more and are clubbed with poor collection efficiency which is even less than 50 % in low income cities (Shimura *et al.* 2001). Besides vectors, stray animals pass contamination to human chain via milk and meat. Spray of disinfectants and daily collection in covered tippers and dumpers are required. Source sorting of recyclables and two covered compartments are needed at collection points for recyclable and compostable waste in case of failure of prompt waste removal. Bio-degradable fraction is high in MSW of low-income areas due to the lifestyle of inhabitants (IPCC 2006; World Bank 1999). High biodegradable fraction in tropical climatic condition warrants frequent collection and removal of refuse from the collection point (Jha *et al.* 2007) as most of the low income cities fall within this climatic regime of Asia and Africa.

Reuse and recycling at the source

Sorting and recycling at generation source initiated at various places are encouraging activity (Elango *et al.* 2009; Ziadat & Henry 2005). However, this is mainly done for valuable materials. Most recycling in low-income countries is by informal sectors for livelihood and import of material for recycling. However, in high-income countries, recycling technology is intensive and organized for long term market interest (Lavee 2007).

Informal rag picking is prominent and is not only limited to rag pickers but also at source by lowest grade municipal workers for extra income (Zia & Devdas 2008; Vidanaarachchi *et al.* 2006). Sorting at collection points should be discouraged to avoid litter and contamination spread. Moreover waste picking is born out of desperation and has

low social acceptance and hence cannot be a sustainable solution. Two bin systems can support the formal way of sorting of materials and commercialization rather than fugitive rag picking where wastes are even burnt to get easy detection of metals, polluting thus the environment. Rag pickers should be organized and either diverted to dumping ground or to transfer station till alternate income option is worked out.

Flow of recyclable materials to market should be regulated with fixed pricing to encourage adequate sorting as opportunity in recycling is high. For example, in India, the plastic demand growth is about 22 % per annum having present consumption rate of about 2 kg capita^{-1} yr^{-1} against Asian average of about 10 kg. India recycles about 29 % of its waste paper against global average of 36 %. The recovery rate is about 14 % against global average of 37 % (Upadhyay *et al.* 2005). Waste recycling rate is 10 - 15 % of apparent consumption in low-income countries against 30 to 75 % in OECD countries (OECD 2002).

Composting is a feasible option when degradable and non-degradable wastes are handled separately (Sharholy *et al.* 2008; Slater & Frederickson 2001). High biogedradable fraction in low and medium income group countries and cities specifically from households, temples, vegetable market, etc. make composting viable. In low income countries, composting is rarely done whereas in developed countries it is a popular tool at backyard and large facilities **(**Elango *et al.* 2009). Under aerobic process, organic portion of the waste is decomposed and compost having high N, P, K values and C/N ratio is produced (Sharholy *et al.* 2008; Shiralipour *et al.* 1992). The biodegradable materials are source of methane and hence harnessing of energy at landfill is also possible. Electronic waste is increasing that requires proper dismantling, resource recovery and sanitary landfilling due to hazardous constituents.

Disposal/ dumping

MSW disposal sites are generally selected on the basis of their closeness to the collection areas. In India, Dozers are generally used for MSW leveling and not compaction excepting megacities similar to other low-income countries (Khatib *et al.* 2007; Vidanaarachchri *et al.* 2006). Majority of MSW disposal sites in developing countries especially in Asia and Africa are open dumping ground where insufficient or no cover soil is provided (Jha *et al.* 2007; Kurian 2002). In India, 70 - 90 % of landfilling is open dumping (Kurian 2002) and several of Class II and Class III cities have only option of illegal dumping in the absence of facility. Such dumping grounds have poor or no foundation, liners, leveling, cover soil, leachate management, leak detection, gas collection and treatment facility and designated lifetime of dumping ground **(**Fadel *et al.* 1997). These types of dumping ground are not sustainable landfills. In high income society of low income group of cities the lifestyle and resource use is comparable to the developed countries (Kim *et al.* 2004), which indicates that quantity and complexity of MSW will continue to increase in future. Waste disposal methods, incineration or landfilling have advantages and disadvantages from waste management perspective, but the choice of management methods have important implication on public, environment and climate (Finnveden *et al.* 1995; Hubbard *et al.* 2005; Jha *et al.* 2007; Kumar *et al.* 2004).

Sustainable MSW management

Sustainable MSW management requires rich understanding of waste streams, material balance and flow along with the proper knowledge and willingness of the stakeholders (Vidanaarachchi *et al.* 2006). Some of the concepts that need incorporation are discussed below:

Life cycle assessment

Life cycle assessment (LCA) is an objective process to evaluate the environmental burdens associated with a product, process or activity, by identifying and quantifying energy and materials used and waste released to the environment, and to evaluate and implement opportunities to effect environmental improvements. LCA covers full "cradle to grave" impacts of a product or service (Barton *et al.* 1996; UNEP 1999). It consists of four stages (Barton *et al.* 1996; Finnveden *et al.* 1995). These are:

(1) Goal definition and scoping, (2) Inventory of the materials and energy used during all stages in the life of a product or process and inventory of environmental overburden throughout the product life cycle, (3) Impact assessment to examine potential and actual ill-effects related to the use of resources and environmental releases, and (4) Assessment of the change that is needed to bring about environmental improvements in the product or processes.

LCA methodology could be applied to assist decision makers in waste management. This requires waste management activities to be defined as generic unit operations independent of the specific characteristics of the waste processed which can be used to find material flow and material balance of the specific system to identify the burdens independent of the waste (Barton *et al.* 1996). LCA can be helpful in identifying options for waste reduction and resource recovery in all types of waste.

Characterization of waste stream

Characterization of waste stream can help to find out the suitable strategy for waste recycling, reduction, elemental flow, waste to energy plan, composting, volume reduction, required void space, etc. Chemical and physical properties at generation source, transfer stations and disposal sites can significantly change due to poor management practices (IPCC 2006). Material balance may identify where material gets detached from the main stream. This is relatively smaller option than life cycle assessment but can identify the gap areas in various steps.

Capacity building

Capacity building is enabling the stakeholders with awareness, skill, education and research to tackle any crisis in the target area (World Bank 1999). Institutional framework involving municipal authorities, administration, corporate bodies, non-government organizations (NGO) and educational institutes, is necessary. Government and administration should pay attention to environmentally sustainable landfilling, skilled nodal agency and supportive functionaries (World Bank 2000), awareness, polluters pay principle, practice of waste minimization, prevention of malfunctioning and investigating the gap areas. Corporate bodies may contribute in recycling, waste to energy plan and advancement of existing MSW management. Private party participation can ensure better services, efficient operation and maintenance for better management of prevailing condition but need involvement in waste stream management beyond collection and disposal contracts. NGOs and educational institutes should be involved in awareness, knowledge sharing, options for waste management and prevention of pollution along with quality improvement and review of the functioning. Techno-economic feasible program is needed to monitor the impacts of MSW disposal and to provide local decision-makers with the options to implement environmentally sustainable waste management.

Bridging the gap between problem areas

There is large gap between existing conditions and administrative perception. Existing conditions are generally depicted based on older data, however, complexity of problem unfolds by increasing urbanization, changing lifestyle of people, changing waste composition, etc. (Da Zhu *et al.* 2008; Khatib *et al.* 2007; Upadhyay *et al.* 2005; World Bank 1999). In many cases, MSW problems are recognized but gap between demand and supply of funds, manpower and proper methods become a limitation. It is believed that income has direct relation with waste generation but in many low funded cities income is also related to MSW collection rate. The real cost of waste disposal should be implemented in complete landfill budget to sustain the better management practices. Key success factors should be identified and incorporated in management strategy for bridging the gap.

Conclusions

There are wide variations in magnitude of MSW management problems between cities with similar income levels. A well-managed city with medium or low income may be significantly different from a similar city with poor urban MSW management. Waste stream analysis, material balance and lifecycle assessment may be helpful in sustainable landfill management. Sustainable landfill management may not be possible in absence of complete understanding and required capacity enhancement along with financial support. Efforts should also be made to break the linkage of prosperity to waste generation.

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