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MUNICIPAL SOLID WASTE GENERATION, COMPOSITION AND MANAGEMENT: ISSUES AND CHALLENGES. A CASE STUDY

Khulna is the third largest metropolitan city in Bangladesh and a centre with intensive commercial and industrial activities. Rapid urbanization and increased migration of people from rural and coastal areas has put tremendous pressure on its existing solid waste management. The status of the existing municipal solid waste (MSW) management tiers such as generation, source storage, collection, on-site storage, transportation, and open dumping has been identified in this study. The daily generation of MSW is estimated as 520 Mg, of which food and vegetable wastes are the main components (79% on average). The major source of generated MSW is residential areas, which is 85.87% of total generation, whereas 11.60% in commercial areas, 1.02% in institutional areas, 0.55% in street sweeps and 0.96% in other areas. About 50% of total generated waste is disposed daily to the dumping site and the rest remains uncollected and unmanaged. Non-governmental organizations and community based organizations play an important role in primary collection, composting of organic wastes and medical waste management.

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1. INTRODUCTION

The increasing quantity of unmanageable part of municipal solid waste (MSW) is one of the most striking environmental problems faced by the city authorities of Least Developed Asian Countries (LDACs). The estimation of MSW generation and composition are the basis for the optimal planning, design and operation of the functional elements associated with the management. Managing solid waste well and affordably is one of the key challenges of the 21st century, and one of the key responsibilities of city governments. Any system for collection and disposal of the MSW has to be related to the quantity of wastes produced [1]. A comprehensive study on the issues and problems of MSW management in Asian countries was conducted [2]. The MSW management has so far been ignored and least studied environmental issues in Bangladesh, like in most developing countries, but recently the concerned stakeholders have begun to consider this area to be an inseparable component to improve public health [3]. The basic characteristics of MSW, management scenario, daily generation, recovery potential and situation of open dumping sites in a few cities of Bangladesh have been described in details [4–7]. A reliable estimate of the quantity of solid waste generation in the city is very important for proper solid waste planning and management [8].

In Khulna City, piles of garbage accumulated everyday cause enormous public health and environmental hazards. The rapid growth of Khulna City and increased migration of rural and coastal population affected by natural calamities are the driving forces behind unplanned expansion of city and deteriorating environmental condition. The results of unplanned expansion of city in the form of slums have further stretched the problems of MSW management. Composting of organic wastes and medical waste management in Khulna City were studied [9, 10]. Swapan [11] researched on the socio-economic aspects of solid waste recovery and recycling in Khulna City. He focused on the type of inorganic waste collected by the scavengers, their socio-economic status and the informal recycle chain of waste (collected by the scavengers) to be recycled. Moniruzzaman et al. [12] focused on the current recycling practices of solid waste in Khulna City.

The ecological footprint (0.088 ha/capita) was calculated to develop a sustainable waste management system by considering its existing solid waste characteristics [13]. This city faces lack of waste dumping area with its increasing urbanized wastes since it has only an ultimate disposal site (UDS), i.e. open dumping site. Therefore, it is important to find out some other sites. Seven suitable UDSs have been found by the multi-criteria evaluation method integrated with the Geographical Information System (GIS) approach in Khulna City. Each site has satisfied all the criteria adopted for highly suitable sites for MSW disposal [14].

The paper describes the amount and composition of MSW generated daily in Khulna City from various sources such as residential, commercial and institutional.

The present status of main tiers of existing MSW management was also investigated such as generation, collection, on-site storage, transportation and open disposal. In addition, the initiatives of non-governmental organizations (NGOs) and community based organizations (CBOs) in MSW management are briefly described.

2. SURVEY AND SAMPLING

Table 1 shows the basic information of Khulna City. A preliminary survey was conducted to find out 5 representative wards in the city.

Table 1

Basic information of Khulna City

Location Latitude (N) Longitude (E)	 22°30′ 89°20′
Establishment as city corporation	1990
City area, km^2	47
Population, million	1.50
No. of wards	31
Total generation of MSW, Mg/day	520
Generation rate of MSW, kg/cap/day	0.346
No. of ultimate disposal sites of MSW	1

Then, 5 different income level households were selected in each ward depending on different socio-economic statuses as shown in Table 2 (A to E in descending order).

Table 2

Household category and criteria of division

Category	Social status	Criteria of division	Income level [TK/family/month][a]
A	high	independent bungalow type of home, with at least a vehicle and parking space, at least one servant	≥30 000
B	middle high	independent home, few rooms of the building could be on rent, at least one servant	≥20 000
C	middle	family owning a flat on rent	≥10 000
D	middle low	family living a flat in cheap rent or family with a small grocery shop	≥5000
E	low	a group of workers (daily wage) sharing a single room and having a common kitchen people living in slum areas.	<5000

[a]1 US $ ≈ 70 taka (TK).

The family types based on the income level are categorized as high socio--economic, designated as level A families; middle high socio-economic, designated as level B families; middle socio-economic, designated as level C families; lower middle socio-economic, designated as level D families; and low socio-economic, designated as level E families.

3. MSW GENERATION

The MSW are the heterogeneous composition of wastes, organic and inorganic, rapidly and slowly biodegradable, fresh and putrescible, hazardous and non-hazardous, generated in various sources in urban areas due to human activities [1]. Jenson and Pipatti [15] presented a detail breakdown of all possible major types of MSW according to sources. The rates of MSW generation in residential, commercial, institutional areas and for street sweeping in Khulna City are determined. The details of MSW generation are described in the following sections.

Residential areas. Table 3 shows the waste generation rates of 25 sampled households in Khulna City. The maximum generation rate is as 0.480 kg/capita/day in ward No. 17 for a level A family and minimum is 0.101 kg/capita/day in ward number 23 for a level E family. The average highest generation rate is found as 0.356 kg/capita/day in ward No. 17 whereas average lowest generation rate is 0.223 kg/capita/day in ward No. 23.

Table 3

Rates of generation of solid waste at residential areas

Income level	Generation rate [kg/cap/day]						Standard deviation [kg/cap/day]
	Ward No.					Average	
	1	17	18	21	23		
A	0.440	0.480	0.341	0.320	0.261	0.368	0.090
B	0.384	0.371	0.349	0.254	0.306	0.333	0.053
C	0.403	0.386	0.301	0.307	0.198	0.319	0.082
D	0.278	0.320	0.257	0.216	0.251	0.264	0.038
E	0.180	0.221	0.341	0.171	0.101	0.203	0.088
Average	0.337	0.356	0.318	0.253	0.223	0.297	0.070

In high socio-economic family, daily waste generation rates are generally higher than those in lower socio-economic ones. The mean generation rate for level A families is estimated as 0.368 kg/capita/day, while the rates are 0.333, 0.319, 0.264 and 0.203 kg/capita/day for level B, level C, level D and level E families, respectively. Figure 1 shows the average per capita waste generation rates in residential areas and Fig. 2 shows the results of the multiple range test for the generation rate by income level.

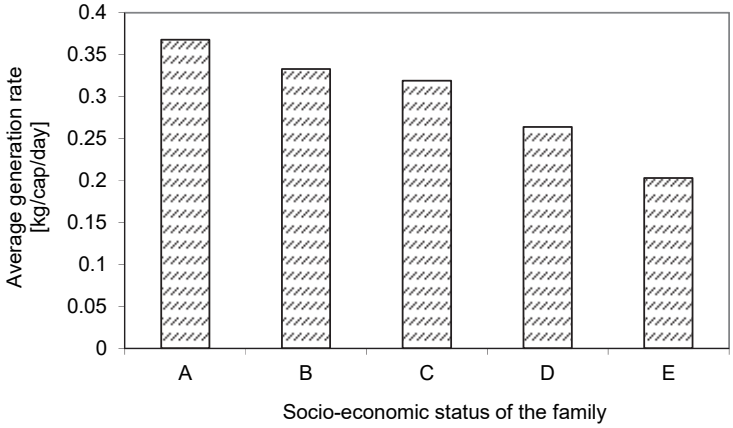

Fig. 1. Average per capita waste generation rates in residential areas: A – high class, B – middle high class, C – middle class, D – lower middle class, E – low class

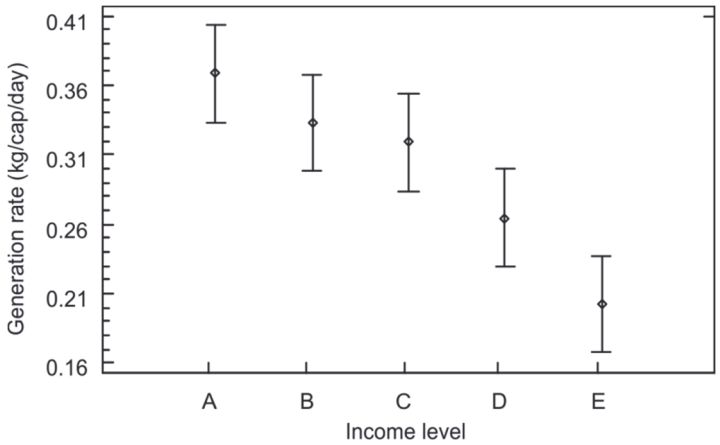

Fig. 2. Multiple range tests for generation rate by income level (means and 95% LSD intervals)

The mean generation rate is estimated as 0.297 kg/capita/day, obtained from direct survey conducted in 25 households of different income levels with different living standards. The population of Khulna City is about 1.5 millions. Therefore, it is estimated that the total MSW generated from residential areas is about 445.50 Mg/day.

Statistical analysis. The multifactor ANOVA (analysis of variance) analysis was carried out to decompose the variability of waste generation rate due to the contribution of two important factors (income level and location) using the software Statgraphics Centurion XVII. Figure 3 shows the graphical ANOVA for waste generation rate. As seen, both factors have significant effect on the waste generation rate at probability, $P < 0.05$.

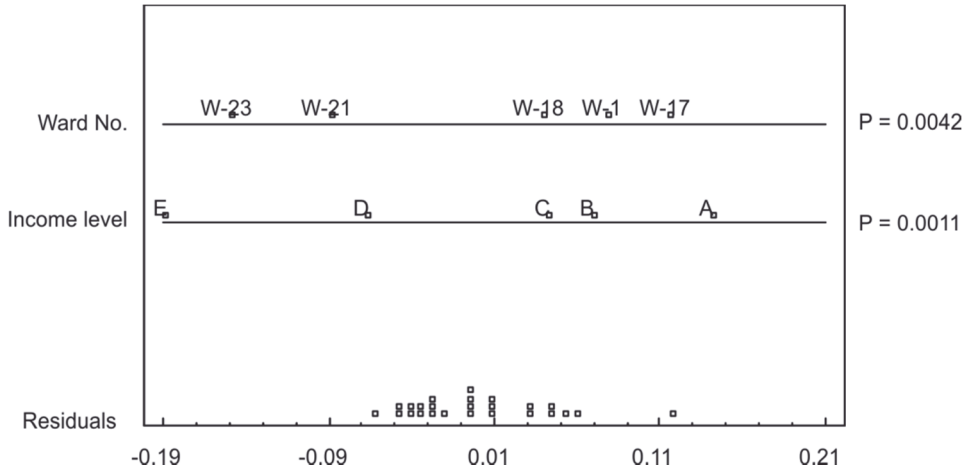

Fig. 3. Graphical ANOVA for waste generation rate (kg/cap/day)

Fisher's least significant difference (LSD) procedure was used to determine which statistical means significantly differ from others. Waste generations by the people having income of level A are significantly different from that of D and E. Contributions to the waste generation by B and C group people were also significantly different from that of E. However, other pairs did not contribute significantly to the waste generation. On the other hand, people living in wards 21 and 23 are significantly different from that of in wards 1, 17 and 18 concerning the waste generation (Fig. 3).

Commercial areas. The generation rate for wet market is estimated as 3.09 kg/stall/day whereas 1.57 kg/stall/day for shopping complex. There are 18 vegetable markets, 45 shopping complexes with different types of trade license shops, 750 restaurants (small and big) and 95 hotels/guest houses within the city area. The estimated MSW generation from commercial areas is about 60.14 Mg/day as shown in Table 4.

Table 4

Generation of MSW at commercial areas

Source	Total generation [Mg/day]	Percent of generation
Shopping complex	27.48	45.69
Wet market	19.16	31.86
Restaurants	9.75	16.21
Hotel/guest houses	0.76	1.26
Other (station, etc.)	3.00	4.99
Total	60.14	100

Institutional areas. It is estimated that the generation rate in an institute is 0.012 kg/student/day. Sampling has been done in the institute, which classes usually worked from 8:00 AM to 5:00 PM (9 h). Total number of students in the Khulna City areas is about 254 868. It can be estimated that the MSW generated from educational institutions is about 3.06 Mg/day.

There are more than 129 hospitals, private clinics and pathological laboratories in the city. 5 are government hospitals, 59 are private clinics with more than 2000 beds, and 65 are different types of pathological laboratories and diagnostic centers. It is estimated that the generation rate for medical waste is 0.87 kg/bed/day and the total generated amount is about 2200 kg/day. Therefore, the estimated MSW generation from institutional areas is about 5.26 Mg/day (3.06 Mg/day in educational institutions and 2.20 Mg/day in health care centers).

Street sweeping. The length of total paved road is 160 km in Khulna City Corporation (KCC). On an average 50 km length of road are swept daily. It is estimated that the waste generated from sweeping of road is 2860 kg/day.

Others. It is assumed that about 5 Mg of MSW are generated daily within the city area from other sources such as public halls, community centers, motels, campgrounds and slaughterhouses.

Total amount of MSW generation. Table 5 indicates that the daily MSW generation which is estimated as 518.75 Mg, rounded, as 520 Mg within the Khulna City whereas the volume of generated wastes is 1038 m^3. Note that the specific weight is considered as 0.5 Mg/m^3 and some data for this waste generation calculations are assumed. The major source of generated MSW is residential areas, which is 85.87% of total generated MSW whereas 11.60% in commercial areas, 1.02% in institutional areas, 0.55% in street sweeps and 0.96% in other areas.

Table 5

Total generation of MSW in Khulna City

Source of generation	Total generation [Mg/day]	Percent of total generation
Residential areas	455.50	85.87
Commercial areas	60.14	11.60
Institutional areas	5.26	1.02
Street sweeps	2.86	0.55
Other	5.00	0.96
Total	518.75 ≈ 520	100

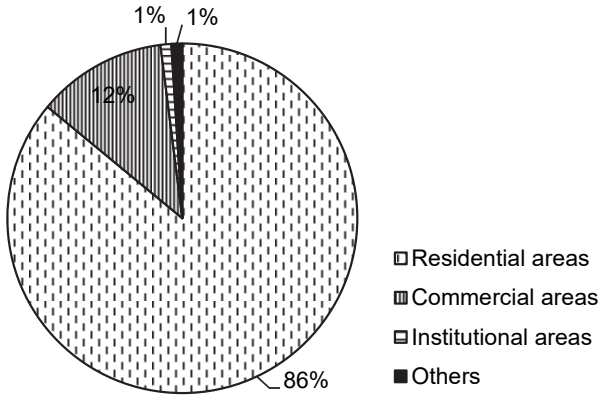

Fig. 4. Generation of MSW from different sources

Figure 4 shows the percentages of MSW generation from different sources in Khulna City.

Rate of generation. The daily-generated MSW within the city is about 520 Mg and the population of Khulna City is about 1.5 million, therefore, the MSW generation rate is estimated as 0.346 kg/capita/day.

4. COMPARISON WITH PREVIOUS STUDIES

Table 6 shows the comparison of MSW generation with previous studies in Khulna City. It implies that the waste generation increases due to the increase of population and improve in living standard.

Table 6

Comparison of MSW generation in Khulna with previous data

Year	Population [million]	MSW [Mg/day]	Per capita generation [kg/day]	Reference
2000	9.09	201	0.22	[16]
2004	1.30	300	0.23	[17]
This study	1.50	520	0.35	–

Table 7 presents the comparison of MSW generation sources with previous study in Khulna.

Table 7

Comparison of MSW generation sources in Khulna with previous data [%]

Source of generation	2005 [18]	This study
Residential areas	79	85.87
Commercial areas	10	11.60
Institutional areas	5	1.02
Street sweeps	1	0.55
Others	5	0.96
Total	100	100

Table 8 shows the comparison of MSW composition with data from previous studies. Unfortunately, there is little published information in the literature regarding the waste generation and composition in Khulna. Therefore, critical comparison analysis and discussion are not appropriate.

Table 8

Comparison of MSW composition in Khulna [%] with previous data

MSW composition	1998[a]	2006[b]	This study
Food and vegetables	90	74	78.9
Paper and paper products	–	13	9.5
Polythene and plastics	6	5	3.1
Textile and woods	–	–	1.3
Rubber and leather	–	–	0.5
Metal and tins	–	3	1.1
Glass and ceramics	4	5	0.5
Brick, concrete and stone	–	–	0.1
Dust, ash and mud products	–	–	3.7
Others (e.g. bone and rope)	–	–	1.2
Total	100.0	100.0	100.0

[a]Composition divided into organics, inorganics hazardous and inorganics non-hazardous [19].

[b]MSW found in household bins [13].

Table 9 provides the waste generation data in the capital cities of some Asian countries for comparison. There exists a wide variation in the per capita solid waste generation in the Asian countries due to geographical locations, climate factors, economic disparity and consumption pattern. Population is a great concern in waste gen-

eration; therefore, a comparison would be more plausible when the comparable cities have the identical population.

Table 9

MSW generation in Khulna and some capital cities of Asian countries

City	Year	Population [million]	MSW [Mg/day]	Per capita generation [kg/day]	Reference
Jakarta	1986	7.3	4,930	0.68	[20]
Tokyo	1987	8.6	12,305	1.44	[3]
Singapore	1987	2.6	5,132	1.96	
Bangkok	1990	5.7	5,043	0.88	[20]
Kuala Lumpur	1993	1.2	1,913	1.55	[21]
Manila	1997	9.5	5,345	0.57	[20]
Hanoi	2000	1.3	1,752	1.33	
Kathmandu	2000	0.7	212	0.30	[22]
Yangon	2000	5.7	3,000	0.52	[23]
Beijing	2002	12.9	12,181	0.94	[2]
Colombo	2002	2.4	2,927	1.22	
Delhi	2002	8.4	4,000	0.48	
Khulna	2005	1.5	520	0.35	this study

Table 10

MSW composition in Khulna and capital cities of some developed and developing countries

City	Year	Composition (% by wet weight)								Reference
		Food waste	Paper	Plastic	Textile, wood	Rubber, leather	Metal	Glass	Others	
Manila	1985	45.50	14.50	8.60[a]	1.30	–	4.90	2.70	31.10	[24]
Paris	1994	16.30	40.90	8.40[a]	4.40	–	3.20	9.40	25.80	
Vienna	1994	23.30	33.60	7.00[a]	3.10	–	3.70	10.4	25.90	
Seoul	1985	22.30	16.20	9.60[a]	3.80	–	4.10	10.60	43.00	
Mexico	1992	59.80[b]	11.90	3.50[a]	0.40	–	1.10	3.30	83.30	
Kuala Lumpur	1993	32.50	28.40	17.70	9.80	0.30	3.30	2.20	5.80	[21]
Kathmandu	2000	69.80	8.50	9.17	3.20	0.66	0.87	2.5	5.30	[22]
Yangon	2000	58.00	1.00	4.00	–	–	–	–	3.70	[23]
Beijing	2002	50.79	4.91	5.88	3.43	–	0.04	0.74	34.21	[2]
Delhi	2002	31.78	6.60	1.50	4.00	0.60	2.50	1.20	51.82	
Colombo	2002	68.15	5.99	6.69	5.02	–	1.85	1.64	10.66	
Khulna	2005	78.90	9.50	3.10	1.30	0.50	1.10	0.50	5.10	this study

[a]Value for plastic, rubber and leather.
[b]Small amounts of wood, hay and straw included.

Table 10 indicates the composition of MSW in capital cities of some developed and developing countries. The major portions of the MSW stream in the cities of Asian countries are dominated by organic wastes generated from households, markets and other places. Food wastes are the major portion of organic fraction. However, in developed cities like Paris, New York and Vienna, paper and paper products fraction are dominated and food waste portion are largely lower than paper due to various reasons persisting in the developed city.

5. PHYSICAL COMPOSITION

A complete picture about the composition of MSW is an essential part for selection of the appropriate type of storage and transport system, determination of the potential resource recovery, choice of a suitable method of disposal, and the determination of the environmental impact exerted by MSW [1]. The MSW composition for this city is estimated by the ratio of waste generation to each source. In Khulna City, the total MSW generation is about 520 Mg/day, in which residential is 85.9%, commercial – 11.6% and institutional and other – 2.5%. Each component of MSW for Khulna City is estimated as:

$$W = 0.859R + 0.116C + 0.025I$$

where: W is the particular component for the city, %, R – average value of particular component from residential areas, %, C – average value of particular component from commercial areas, %, I – average value of particular component from institutional and other areas, %.

Table 11

Physical composition of MSW [wet weight %]

MSW component	Residential area	Commercial area	Institutional area	Whole city
Food and vegetables	86.0	40.1	16.0	78.9
Paper and paper products	6.0	27.2	48.0	9.5
Polythene and plastics	2.0	9.1	14.0	3.1
Textile and woods	1.0	3.3	3.0	1.3
Rubber and leathers	0.5	0.8	0.0	0.5
Metal and tins	1.0	1.6	2.0	1.1
Glass and ceramics	0.5	0.6	0.0	0.5
Brick, concrete and stone	0.5	1.0	1.0	0.1
Dust, ash and mud products	2.0	13.9	14.0	3.7
Others (e.g. bone and rope)	0.5	2.4	2.0	1.2
Total	100.0	100.0	100.0	100.0

The values of *R*, *C*, *I* and *W* in wet weight basis and composition of MSW in school areas is considered as the composition in institutional areas for simplicity. Table 11 represents the percentage of different components of MSW based on generation sources. Food and vegetable wastes are 78.9%, paper and paper products are 9.5%, which is much lower than food and vegetable wastes. Plastics are 3.1%, indicating that packaging materials are not densely related to the daily life. Metal components are only 1.1%, which is very low quantity and its major portion comes from soft drink cans. The dust and ashes are 3.7% resulting from the daily street, house and yard sweepings.

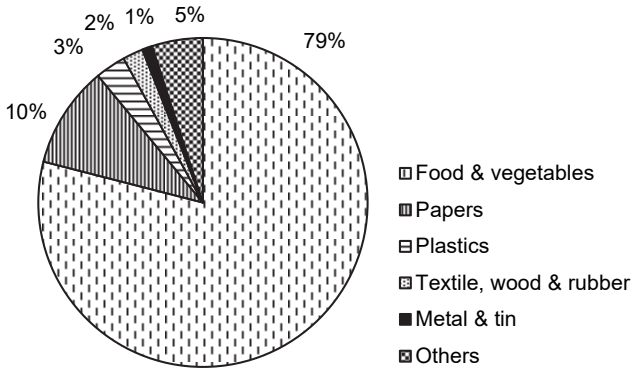

Fig. 5. Physical composition of MSW

Figure 5 shows that the food and vegetable wastes are the predominant components in the waste stream, which is about 79%. The habit of fresh food consumption is common and important in the city. Therefore, it is necessary to collect (from sources) and dispose the MSW generated (to the landfill) in daily basis to reduce the possible environmental hazards.

6. MSW MANAGEMENT

Collection from sources. Door-to-door collection system is adopted by NGOs and CBOs and then dispose major portion of it to the nearest secondary disposal site (SDS). About 71 non-motorized Rickshaw vans are operated by NGOs and CBOs. KCC has 266 non-motorized vehicles, which are used to transfer wastes from community bins to SDS. Total numbers of households are 172 000 in Khulna City [25], while NGOs and CBOs are responsible for collecting the wastes from approximately 24 000 households, i.e. only about 14% is covered under their collection system. There is no collection system for the remaining houses (about 86%) where dwellers dispose the wastes to the nearest SDS. This study reveals that no segregation of wastes takes place at the household level. Generally, wastes are collected in a single bin and the collec-

tion van also has a single compartment, therefore, the waste gets mixed. This makes the segregation of materials for recovery and recycling a daunting task. Moreover, due to lack of motivation, awareness and commitment, half of wastes are never disposed in the designated places for ultimate disposal. The scattered wastes often blocks the roadside drains creating foul odor and nuisance which possess a serious health threat and risks to the surrounding environment.

Roadside storage. There is no transfer station and handover point in Khulna (i.e. Bangladesh). SDS may be an unused open space, low-lying areas or roadside accumulation of solid wastes where any concrete/brick/masonry bins or any demountable steel haul containers (DSHCs) or any types of storage facilities are available.

Fig. 6. Primary collection through door-to-door system (left), and brick masonry dustbin in a roadside (right)

Figure 6 shows the MSW collection from generation sources and present situation of roadside storage in Khulna City. More than 60 SDSs are available. About 28 DSHCs are placed in SDSs of different wards within the city. The city authorities are solely responsible to provide SDS, to collect wastes from SDS and to transfer for final disposal as per existing city corporation act. These sites are located in selected places based on population density, space availability and accessibility. The MSW are disposed to SDSs by the generators, city dwellers, NGOs, CBOs and city authorities. Around 1200 community bins are located on the roadsides at irregular intervals within the city. The MSW from community bins are transferred to SDSs mostly by city authorities through non-motorized Rickshaw van and hand trolley.

Transport to landfill. KCC has 32 motorized vehicles that are used for collection of wastes from SDS and then transfer to the ultimate disposal site (UDS). The collection/transfer vehicles are categorized as dump truck, normal truck, open truck, tractor with trolley, tipping truck (container carrier), de-sledging vacuum tanker with tractor, power tiller with trolley. DSHCs are only hauled by tipping truck and no workers are

required for collection and disposal, however, their numbers are limited. Wastes are mostly collected during morning often obstructing the movement of pedestrians and traffics. It creates nuisance and pollution due to over heaped, uncovered and leakage of liquid from waste carrying vehicles.

Crude open dumping. There is no controlled/engineered/sanitary landfill in Khulna. The existing landfilling system is the crude open dumping where there are no provisions for the leachate collection and treatment, for the groundwater/surface water pollution control (i.e. no liners and fences are used), and for the biogas management and utilization. Although recycling and composting can divert a little portion of MSW, a large amount of waste still needs to be placed in landfill. In Khulna City, the only UDS is situated outside the city in low-lying lands at Rajbandha, 7 km far away from the city center. The amount of wastes daily transfer and open dump to the UDS is about 260 Mg, which is about 50% of the total waste generation. All types of solid wastes are disposed together including some portions of industrial and construction wastes. Crude open dumping of MSW are practiced, i.e. level 0 according to landfill definition which always incompatible with the surroundings. Neither planning nor proper operation of dumping waste is followed at the dumping site. Wind blows litters and the waste spreads all over the site, and even to the surrounding ponds.

Fig. 7. MSW transport to landfill site (left), and crude open dumping near surface water (right)

Figure 7 shows the scenarios of MSW transferring and crude open dumping near the surface water in Khulna City. Hand pumps/tube-wells are very near to the UDS (about 300 m) and people use the groundwater for drinking, bathing and washing purposes. The leachate may contaminate the groundwater resources in that region.

NGOs and CBOs involvement in MSW management. More than 22 NGOs and CBOs are involved in MSW management in cooperation with the city authority and respective ward commissioner. Prodipan and PRISM Bangladesh, are the two national

NGOs initiated MSW management at Khulna City and provide financial support to other small NGOs and CBOs. Presently, these two NGOs are not directly involved in waste collection. Their works are distributed to partner NGOs and CBOs. In general, NGOs are mainly involved in the collection of wastes from point of generation, composting of organic wastes and medical waste management, while the CBOs are only involved in collection from sources. Three NGOs are involved for composting of organic wastes through six composting plants situated in and around the city areas. Among them PRISM Bangladesh operates four while Prodipan and RUSTIC each operates a single composting plant. The amount of organic wastes consumed in these six plants is about 5 Mg/day. The compost is used for agricultural purposes.

Prodipan initiated medical waste management project in 2000. Now 47 institutes are under their services. Among them 2 are government hospitals, 35 are private clinics and 10 are different types of pathological laboratories. The waste collection from these institutes is 700 kg/day, while the total generated medical waste is 2200 kg/day. Only 32% of total generated medical wastes are collected and managed by Prodipan. The collected hazardous medical wastes are then sent to the burning unit installed at the UDS to burn up them.

Fees and regulations. The city dwellers pay a tiny amount (e.g. <1 US$/month /house) to the NGOs/CBOs who collected the wastes from houses. However, the city authority does not take any fees from the city dwellers for transferring the wastes to the UDS from the SDSs. The city dwellers usually pay taxes yearly to the city corporation.

An act to provide for conservation of the environment, improvement of environmental standards and control, and mitigation of environmental pollution was published in the Bangladesh Gazette, extra-ordinary issue of 16-2-1995 (The Bangladesh Environment Conservation Act, 1995; Act No. 1 of 1995) and amended by Acts Nos. 12 of 2000 and 9 of 2002.

7. CONCLUSIONS

The amount and composition of MSW generated daily in Khulna City from various sources such as residential, commercial and institutional have been analyzed. The daily generation of MSW is estimated as 520 Mg and the major portion (85.87%) is generated from residential areas whereas 11.60% from commercial areas, 1.02% from institutional areas, 0.55% from street sweeps and 0.96% from other areas. It is observed that the food and vegetable wastes are the predominant components in the waste stream (79% on average). The habit of fresh food consumption is quite common and important in the city. The status of the existing MSW management tiers such as generation, source storage, collection, on-site storage, transportation, and open dump-

ing is identified and found that the present scenario of MSW management in Khulna is not quite satisfactory.

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