GHG emissions with the mismanagement of municipal solid waste: case study of Bangalore, India

T.V. Ramachandra*

Energy and Wetlands Research Group,
Center for Ecological Sciences (CES),
and
Centre for Sustainable Technologies (Astra),
and
Centre for Infrastructure, Sustainable Transportation and Urban Planning (CiSTUP),
Indian Institute of Science,
Bangalore, Karnataka, 560 012, India
Email: cestvr@ces.iisc.ernet.in
Email: tvr@iisc.ac.in
*Corresponding author

Gouri Kulkarni

Energy and Wetlands Research Group,
Center for Ecological Sciences (CES),
Indian Institute of Science,
Bengaluru, Karnataka 560012, India
Email: gouri@ces.iisc.ernet.in

Bharath H. Aithal

Ranbir and Chitra Gupta School of Infrastructure Design and Management (RCGSIDM),
Indian Institute of Technology,
Kharagpur, India
Email: bhaithal@iitkgp.ac.in

Sun Sheng Han

Faculty of Architecture,
Building and Planning,
The University of Melbourne,
Parkville VIC 3010, Australia
Email: sshan@unimelb.edu.au

Abstract: Municipal solid wastes collected by the agencies dispose at identified disposal sites about 60%, while the balance are disposed-off at unauthorised disposal sites in an unacceptable manner, leading to the environmental consequences including greenhouse gas (GHG) emissions. Mitigation strategy necessitates understanding of composition of waste for its management in an environmentally sound way. The study revealed that the per capita waste generated is about 91.01 ± 45.5 g/day and household per capita waste generation was positively related with household size and income. Organic fraction in municipal solid waste based on the sample household's data is about 74.09 ± 34.94 g/person/day, which constitutes 82% with the strong recovery potential and conversion to energy or compost range. The total organic waste generated is about 231.01 Gg/year and due to mismanagement consequent emissions are about 604.80 Gg/year. Integrated solid waste management strategy is suggested to manage the organic fractions through technology interventions, which helps in mitigating GHG emissions with potential economic benefits.

Keywords: municipal solid waste; MSW; domestic sector; greater Bangalore; socio-economic factors; greenhouse gas; GHG emissions; integrated solid waste management; ISWM; India.

Reference to this paper should be made as follows: Ramachandra, T.V., Kulkarni, G., Aithal, B.H. and Han, S.S. (2017) 'GHG emissions with the mismanagement of municipal solid waste: case study of Bangalore, India', *Int. J. Environment and Waste Management*, Vol. 20, No. 4, pp.346–379.

Biographical notes: T.V. Ramachandra holds a PhD in Energy and Environment from the Indian Institute of Science. At present, he is working as Coordinator of Energy and Wetlands Research Group (EWRG), and Convener of Environmental Information System (ENVIS) at Centre for Ecological Sciences (CES), Indian Institute of Science (IISc). He has made significant contribution in the area of energy and environment. His research areas include wetlands, conservation, restoration and management of ecosystems, environmental management, GIS, remote sensing, regional planning and decision support systems. He teaches principles of remote sensing, digital image processing and natural resources management. He has published over 278 research papers in reputed peer reviewed international and national journals, 318 papers in the international and national symposiums as well as 18 books. In addition, he has delivered a number of plenary lectures at national and international conferences. He is a Fellow of Institution of Engineers (India), IEE (UK), senior member, IEEE (USA) and many similar institutions.

Gouri Kulkarni holds a Masters in Science and is currently working on spatial analysis of wetlands in Karnataka

Bharath H. Aithal is an Assistant Professor at Indian Institute of Technology Kharagpur, IIT KGP, Ranbir and Chitra Gupta School of Infrastructure Design and Management. Kharagpur. His areas of research are urban sprawl, modelling and development of algorithm for spatial planning. During the past eight years, he has published 37 journal papers (peer reviewed international journals), four book chapters, 34 conference proceedings, and 14 technical reports.

Sun Sheng Han's research and teaching expertise are in the areas of urban and regional development, strategic planning and analytical methods in urban studies. He has been working on a research agenda which links theories of the spatial organisation of urban activities with the dynamics of institutional and economic restructuring in the Pacific-Asia region. He has been active in pursuing his research agenda and successful in fund raising, graduate student supervision, research collaborations and publications.

1 Introduction

Solid wastes are any non-liquid wastes that arise from human and animal activities that are normally solid, comprising organic and inorganic waste materials such as product packaging, grass clippings, furniture, clothing, bottles, kitchen refuse, paper, appliances, paint cans, batteries, etc. produced in a society, which do not generally carry any economic benefits (Ramachandra, 2009, 2011; Getahun et al., 2012). Unplanned urban development coupled with rapid population growth and changes in the standard of living have led to the tremendous increase in the amounts of municipal solid waste (MSW) leading to mismanagement, which include mix of dry and wet wastes (due to insufficient segregation), dumping in drains and open spaces, disposal without treatment for energy or resource recovery. Municipal solid waste management (MSWM) is associated with the control of waste generation, its storage, collection, transfer and transport, processing and disposal in a manner that is in accordance with the best principles of public health, economics, engineering, conservation, aesthetics, public attitude and other environmental considerations. MSWM is considered a serious environmental challenge confronting local authorities (Ramachandra, 2011, 2012a) and current management approaches does not satisfy the objectives of sustainable development throughout the world (Thanh et al., 2011; Seo et al., 2004; Al-Khatib et al., 2010).

Major portion (70-75%) of MSW is organic (Ramachandra, 2009, 2011; Sathishkumar et al., 2001; Ramachandra et al., 2012b; Sharholy et al., 2007) and contribution of inorganic component is gradually changing and is likely to show further changes in the future. However, solid waste management (SWM) still has gaps due to lack of waste segregation at source level, treatment, re-use, recycling and appropriate disposal. Dumping of waste in open areas, roadside is also one of the common practices in developing countries. These approaches have led to public health risks, adverse environmental impacts, haphazard landfilling leads to depreciate the water quality and other socio-economic problems (Abushammala et al., 2009; Diaz et al., 1999; Chattopadhyay et al., 2007; Nickolas and Ulloa, 2007). The organic fraction of waste through treatment forms a secondary source of raw materials.

Treatment of organic fraction of waste alters its physical and chemical characteristics for energy and resource recovery. The important processing techniques include either composting (aerobic treatment) or biomethanation (anaerobic treatment). Composting through aerobic treatment produces stable product-compost which is used as manure or as soil conditioner. In metropolitan cities, compost plants are underutilised due to various reasons, most important reasons are unsegregated waste and production of poor quality of compost resulting in reduced demand from end users (Ramachandra, 2011). Vermi-composting is also practiced at few places. Biomethanation through microbial action under anaerobic conditions produces methane rich biogas. It is feasible when waste contains high moisture and high organic content. Uncontrolled and unscientific disposal of all the categories of waste including organic waste leads to the environmental problems such as contamination of land, water and soil environment due to leaching of nutrients, etc.

SWM to be effective requires separation of waste at source level with the implementation of 3Rs (reduce, reuse and recycling), treatment of organic fractions of wastes at local levels and disposal at sanitary landfills (Ramachandra, 2011; Tadesse et al., 2008). The indiscriminate dumping, inadequate treatment and poor recovery of organic fractions in urban areas have caused adverse effects on the local ecology, environment (such as air, water and land pollution) and human health (Sharholy et al., 2005; Rathi, 2006; Ray et al., 2005; Kansal et al., 1998; Jha et al., 2003, Gupta et al., 1998; Singh and Singh, 1998; Kansal, 2000). The sustained dumping of solid waste without treatment has overloaded the assimilative capacity of the surrounding environment, necessitates environment friendly treatment and management of solid waste.

Appropriate waste management policy needs to be based on the principle of sustainable development, which considers the society's refuse as a potential resource. SWM facilities are crucial for environmental management and public health in urban regions. Techniques for solving regional waste problems inevitably have a large number of possible solutions due to variable population densities, incomes, multiple (actual and potential) locations for waste management infrastructure, protected landscape areas and high value ecological sites. Due to this, MSW management have received a great deal of attention as the country produces an estimated quantity of 50–600 million tonnes of urban solid waste annually. Environmentally sound waste management depends on various site-specific factors such as the characteristic of the waste, the efficiency of the waste collection and processing systems required by different waste management practices, availability of proximity of material for recovery from the waste stream, the emission standards to which waste management facilities are designed and operated, the cost effectiveness of the environmental obtained by different management practices and social performance of the community.

Table 1 Quantity of MSW generation rate in Metro cities

Sl. no.	*Name of city*	*Waste quantity (TPD)*
1	Greater Bangalore	1,800–3,600
2	Greater Mumbai	3,200
3	Ahmadabad	1,200
4	Kanpur	2,142
5	Lucknow	600
6	Chennai	1,819
7	Pune	1,000

Sources: Ramachandra (2009, 2011, 2016) and Chanakya et al. (2007)

The waste generation quantum depends mainly on the consumption patterns, seasons, lifestyle and socio-economic factors. The per capita waste generation is expected to increase annually by 1.33% (Pappu et al., 2007; Shekdar, 1999; Bhide and Shekdar, 1998). Table 1 lists the quantity of waste generated in the metro cities of India, which highlight that the waste quantity generation is high in Chennai, Greater Bangalore and Greater Mumbai due to the standard of living and urbanisation. However, waste generated is comparatively low in the Pune and Lucknow (Ramachandra, 2009; Chanakya et al., 2007).

Quantification and assessment of characteristics of waste through door-to-door survey during two seasons (dry season and wet season) in the Can Tho city the capital of the Mekong Delta region (Thanh et al., 2010) show that an average household solid waste (HSW) generation is about 285.28 g/person/day (including 283.10 during dry season and 287.46g/person/day). Statistical analysis reveal that household quantity waste is positively correlated with the population density, urbanisation level and negatively correlated with household size. Total greenhouse gas (GHG) baseline emission by the HSW is estimated as 153.41 tons per day carbon dioxide equivalent, while compostable and recyclable accounted 80.02% and 11.73% respectively.

Ramachandra and Varghese (2003) explored the possibilities of achieving sustainable management of solid waste using Bangalore as a case study. The strategies include community participation, human resource development, legal mandates and adopting recent technologies like GIS-GPS and GIS System. Environmental audit of MSW management for Bangalore city was done by Ramachandra and Bachamanda (2007) by collecting the data from government agencies, field survey and interview with stakeholders.

Mismanagement of municipal solid waste is a vital source of anthropogenic GHG such as methane (CH_4), biogenic carbon dioxide (CO_2) and non-methane volatile organic compounds (NMVOCs), etc. (Ramachandra, 2009; Ramachandra et al., 2015; Thanh et al., 2010). Among these, Methane is considered as a potent

GHG having global warming potential (GWP) 25 times greater than that of carbon dioxide and concentration of atmospheric methane is annually increasing at 1–2% (Kumar et al., 2004a; IPCC, 1996). Emission of methane from landfill accounted 3–9% of the anthropogenic source in the world (IPCC, 1996; Kumar et al., 2004b).

The organic components in the waste dumps and landfills generate about 60% methane (CH_4) and 40% CO_2 together with other trace gases during anaerobic decomposition (Hegde et al., 2003; Jha et al., 2008). This would vary depending on the waste composition, age, quantity, moisture content and ratio of hydrogen/oxygen availability at the time of decomposition (Jha et al., 2008). Evaluation of the quantitative and qualitative characteristics of MSW in Allahabad city (Sharholy et al., 2007) through door-to-door survey show the average generation rate varies from 0.37kg/capita/day to 0.44kg/capita/day and the total quantity of MSW is about 500 ton/day.

Quantum of MSW has increased from 650 tonnes per day – tpd (1988) to 1,450 tpd (2000) (Ramachandra et al., 2012) and 3,000–3,600 tpd (2016) due to the increase in population with the expansion of spatial extent. The daily collection is estimated at 3,000 tpd with a per capita generation from 0.16 kg/d (1988) to 0.58 kg/d (2009). Table 2 and Table 3 list composition during different time period and physical composition at different levels. Among which, residence (household waste) is the foremost contributor to the total waste stream with a high proportion of biodegradable waste, i.e., 72%.Presently, a quasi-centralised collection system is employed in Bangalore and the waste collection system from households (HH) closely follows the MSW (handling and management) MSW (H&M) rules 2000, employing door-to-door collection. In most of residential area the provision of dustbin is removed to avoid the multiple handling of waste (Chanakya et al., 2010; TIDE, 2000).The city has been facing severe shortage of landfills to dump garbage due to unplanned urbanisation. Bruhat Bangalore Mahanagara Palike (BBMP) is responsible for management of solid waste.

Table 2 Composition of MSW generation in Bangalore

Components	*Composition (% by weight)*			
	All over Bangalore, 1988	*All over Bangalore. 2000*	*IISc, residential area. 2001, 2015*	*All over Bangalore*
Fermentable	65	72	72.5	60
Paper	8	11	18	12
Miscellaneous	12	1.9		1
Glass	6	1.4		4
Polythene/plastics	6	6.2	9.5	14
Metals	3	1		1
Dust and sweepings		6.5		

Sources: Rajabapaiah (1988), TIDE (2000), Sathishkumar et al. (2001), Ramachandra (2016) and BMP

Table 3 Physical composition of MSW in Bangalore

Waste type	*Composition*						
	Domestic	*Markets*	*Hotel and eatery*	*Trade and commercial*	*Slums*	*Street sweeping and parks*	*All sources*
Fermentable	71.5	90	76	15.6	29.9	90	72
Paper and cardboard	8.39	3	17	56.4	2.49	2	11.6
Cloth, rubber, PVC, leather	1.39		0.33	3.95	0.54	0	1.01
Glass	2.29		0.23	0.65	8.43	0	1.43
Polythene/plastics	6.94	7	2	16.6	1.72	3	6.23
Metals	0.29		0.26	0.38	0.23	0	0.23
Dust and sweeping	8.06		4	8.17	56.7	5	6.53

Sources: TIDE (2000) and Ramachandra (2009, 2016)

During the early stages, a large part of the organic fraction of city wastes were sent to a compost plant situated outside the city limits Karnataka Compost Development Corporation (KCDC). In 1988, the city was producing 650 tpd, among this about 100 tpd of market wastes were taken back for direct application on the land and another 150 tpd was handled by KCDC. A large segment of decomposable was ‘open dumped’ along the various arterial roads at outskirts of the city (Rajabapaiah, 1988). This trend of open dumping had continued beyond 2000. Today as the wastes generated has increased drastically; most wastes are being openly dumped at about 60 known dumping sites and many unrecorded sites. Composting accounts for 3.14%, but with increase in urban solid waste, the number of compost plants has not increased. Among these, more than 35 sites possess a mixture of domestic and industrial waste (Lakshmikantha, 2006). This highlights that the existing solid waste treatment methods in the city are neither efficient nor well-organised. Taking cognisance of the prevailing situation of waste mismanagement, The Government of India introduced statutory waste minimisation, treatment and environmentally sound management to address the earth's dwindling resources and the growing mountains of waste (MSWM, 2000; SWM, 2016).

Earlier studies concerning the MSW of Bangalore have mainly focused on various aspects of solid waste such as composition, generation and disposal. This includes various waste handling practices in Bangalore city (Sathishkumar et al., 2001), exploring options for handling wastes at decentralised levels (Ramachandra and Varghese 2003; Chanakya et al., 2009), comparative assessment of community bins and beneficial aspects of door to door collection systems, etc. These efforts have not captured the various factors that generate HSW, and its last stage of the life cycle. Further, the growing concern of GHG emissions necessitated the quantification of waste and GHG emissions with options to mitigate environmental implications. Estimation of the emission of methane from MSW disposal sites in India by using default, modified triangular methodology and by field investigation (Kumar et al., 2004b), show methane emission of 14.206 Gg, 7.667 Gg and 1.776 Gg respectively. The GHG emission from MSW management in Indian mega-cities, Chennai (Jha et al., 2008) based on IPPC tier I (default emission factors and other parameters as per IPCC guidelines) and tier II (applies country specific emission factors and other parameters) methods for estimating the CH4 emission for the year 2000 from Kodungaiyur (KDG) and Perungudi (PGD) landfill sites, showCH4 emission of 8.1 Gg (for KDG with the waste of 314 Gg) and 9.8 Gg (for PGD with the waste of 379 Gg) respectively. Emission fluxes were estimated by using Gas chromatography (GC-SRI, USA, Model 8610C) flame ionisation detector and with the knowledge of an area of landfills, CH_4 annual emissions of 0.12 Gg y^{-1}, N_2O emission of 1 ty^{-1} and 1.16 Gg y^{-1} CO_2 emissions.

In this regard, objectives of the current study are to

1 determine the composition of waste and the rate of generation of HSW

2 SWM being practised at household level

3 assess GHG emissions from the HSW

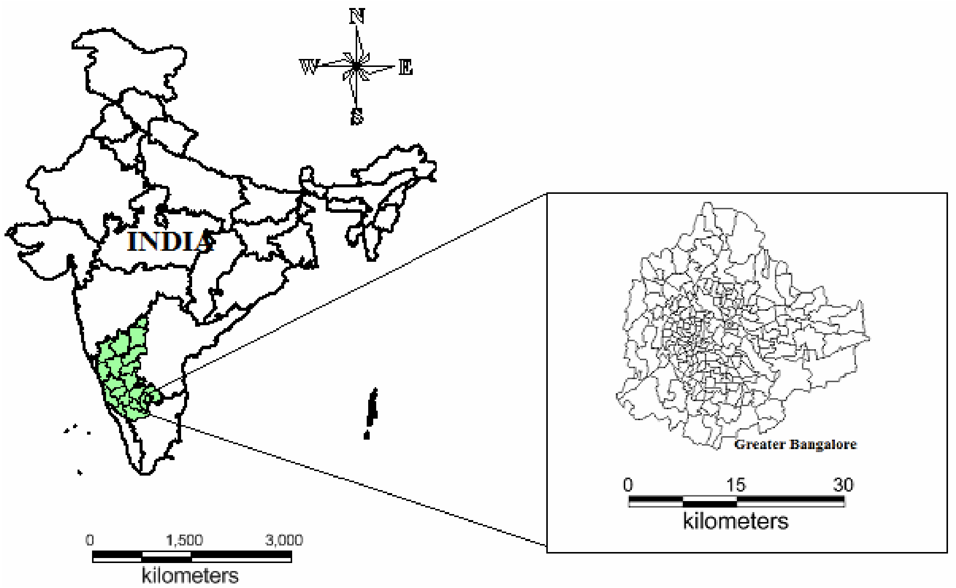
4 capture the role of various socio-economic factors that affect the generation, composition and management of solid waste.

2 Materials and methods

2.1 The study area

Bangalore is the administrative, cultural, commercial, industrial and knowledge capital of the state of Karnataka, India currently with a population of about 7 million and area of 741 sq. km. and lies between the latitude 12°39'00" to 13°13'00" N and longitude 77°22'00" to 77°52'00" E (Figure 1). It is situated at an altitude of 920 metres above the sea level where as the winter temperature ranges from 12°C–25°C, while summer temperature ranges from 18°C–38°C. Mean annual precipitation is 880 mm. (Ramachandra and Kumar, 2010, 2008; Sudhira et al., 2007).

Figure 1 Study area – greater Bangalore with the administrative wards (see online version for colours)



Bangalore city administrative jurisdiction was redefined in the year 2006 by merging the existing area of Bangalore city (221 sq. km) spatial limits with eight neighbouring urban local bodies (ULBs) and 111 Villages of Bangalore Urban District. The spatial extent of Bangalore now is 741 sq.kms with 198 administrative wards consisting of diverse economic and social back ground families (Ramachandra and Kumar, 2008, 2010; Sudhira et al., 2007). Bangalore city population has increased enormously from 65, 37, 124 (in 2001) to 95, 88, 910 (in 2011), accounting for 46.68 % growth in a decade (http://censuskarnataka.gov.in). Population density has increased from as 10,732 (in 2001) to 13,392 (in 2011) persons per sq. km. From 12st to 21st century the Bangalore grew rapidly due to intensified urbanisation coupled with improper planning and become one of the fastest growing cities in the world (Ramachandra et al., 2012).

2.2 Methods

Assessment of the spatial patterns in GHG emissions due to solid waste generated in the municipality involved

1 Primary survey of sample household chosen randomly through the pre-tested and validated structured questionnaire

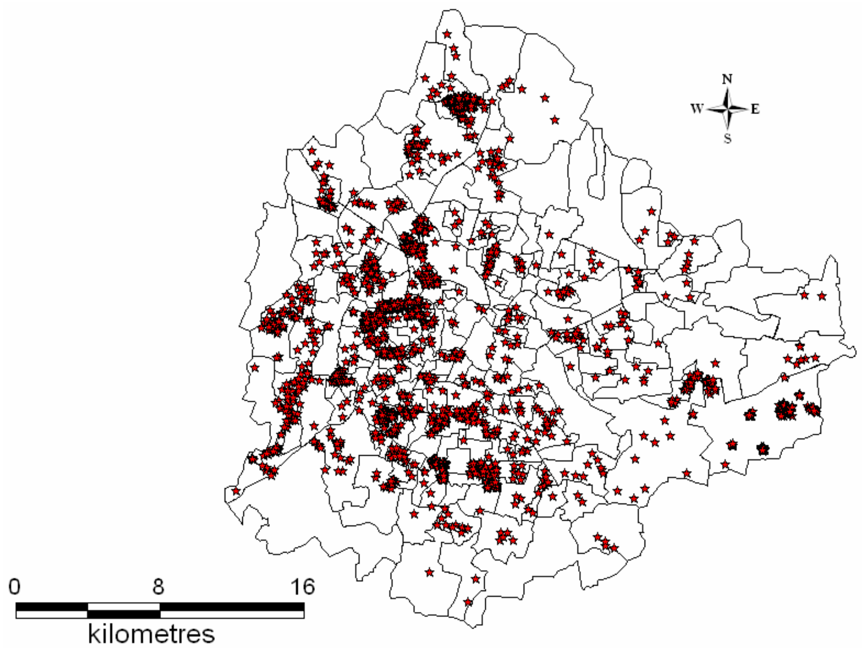
2 Compilation of ward-wise waste generation and composition data from the government agencies.

The survey at local levels (at ward levels – administrative units in a city to manage solid waste) helps to identify the problems and aid in evolving appropriate strategies for management of solid waste including the planning of household waste treatment options and its infrastructure.

3 Data collection

The structured questionnaire was designed to elicit information related to community attitude towards waste management behaviours and socio-economic factors. The questionnaire was pre-tested through a sample survey of about 60 households before taking up large scale survey. Multistage, stratified random survey of urban residences was conducted covering 1967 households during 2011–2012. These households represent heterogeneous population belonging to different income, education, and social aspects. Spatial distribution of 1967 households in eight zones (North, North East, East, South East, South, South West, West and North West) covering 138 wards is shown in Figure 2. The survey also considered parameters such as waste generation quantity, waste collection, time, frequency, number of persons involved in waste collection, collection is done, size of bin, distance of the bin from house, bin clearance time, transportation of waste, landfill site, distance of transportation of waste and socio-economic parameters such as income, household size, employment status, education level of the head of the family 1916 households responded to the quantity of solid waste generation per day.

Figure 2 Spatial distribution of residential houses in the surveyed area (see online version for colours)



4 Analysis method

Simple statistical analysis was done to assess the relationship between solid waste generation and socio-economic factors. Spatial distribution of houses and CO_2 equivalent emission from the wards of Bangalore were generated using GIS software MapInfo 7.5. In addition, the per capita generation rate was estimated using equation (1) and total quantity of waste is computed using equation (2) (Shwetmala et al., 2012; Ramachandra et al., 2015).

$$\text{Generation rate (gram/capita/day)} = \text{Quantity of household waste (gram/day)/Population} \quad (1)$$

$$\text{Total quantity of waste (gram/day)} = \text{Generation rate (gram/capita/day)} * \text{ward population} \quad (2)$$

Mismanagement of solid waste, which are rich in organic components emits GHG such as CO_2, Methane (CH_4). The overall carbon footprint is calculated in terms of CO_2 equivalent emissions. The GWPs for the relevant greenhouse gases used were: 1 (CO_2), 23 (CH_4), which are used to convert emission of different gases to carbon equivalents. CO_2 equivalent emission from the solid waste is quantified through equation (3) (Ramachandra et al., 2015).

$$CO_2 \text{ equivalent emission} = (W * EF_{CO_2}) + (W * EF_{CH_4} * GWP_{CH_4}) \quad (3)$$

Where, W is organic waste (gram/day); EF is the emission factor (0.016 Gg/Gg of waste for methane, which is equal to the EF obtained from MTM reported from landfills of Delhi (Kumar et al., 2004b) and lower than the value reported from Chennai landfill site (Jha et al., 2008) and 2.25 Gg/Gg of waste for carbon dioxide), GWPCH4 is GWP of 23 for CH4.

5 Results

5.1 Analysis of quantity of waste generation

Quantification (measured using weighing balance) of waste generated per household based on the survey of 1967 households is about 772 kg per day. Table 4 lists the per capita waste generation composition along with descriptive statistics. It reveals that the per capita waste generated is about 91.01 ± 45.5 g/day and organic fraction is 74.09 ± 34.94 g/person/day. Per capita waste generated is positively related with household size and income. Table 5 provides the waste composition, which reveals that organic fraction constitute the major share (81.96%) followed by paper (12.69%)

Zone wise analysis indicates the variability of waste generated in each zone given in Table 6. The few notable factors which are responsible for the variations are change in the food habits, affluence, income and change in lifestyle. The average organic waste ranges from 66.24 ± 36.77 g/person/day (South East) to 78.84 ± 33.02g/person/day (East) and inorganic waste contributes about 24.71 g/person/day (South, North West) to 31.13 ± 34.19 g/person/day (East). The organic fraction (kitchen) was the largest component which accounts 82% of the total, paper waste is 13% next to kitchen waste. Earlier studies have reported (Chanakya et al., 2005) a relatively lower value, indicating the increase of organic fraction from 72% (in 2005) to about 82%. Higher proportion of organic fraction in MSW and open dumping in absence of appropriate treatment leads to the release of GHG. This necessitates quantification of GHG and appropriate measures to mitigate GHG emissions through the treatment of organic fractions in MSW. Studies done in the neighbouring developing countries, show 66% (Sujauddin et al., 2008) and 90% of Organic waste (Bandara et al., 2007). Figure 3 illustrates the spatial distribution of per capita waste generation per day. It indicates that majority of households, i.e., 926 households generates 50 to 100 g of waste. 497 households generates 100 to 150 g followed by 214 households generates less than 50 g and 155 households generates 150 to 200 g. Table 7 compares city wise the physical composition of household waste, which reveals that MSW in Bangalore has a higher share of organic fractions compared to other cities. The most apt way to treat the waste rich in organic fractions is decentralised systems of either bio-methanation or composting.

Figure 3 Spatial distribution of per capita waste generation of sample (see online version for colours)

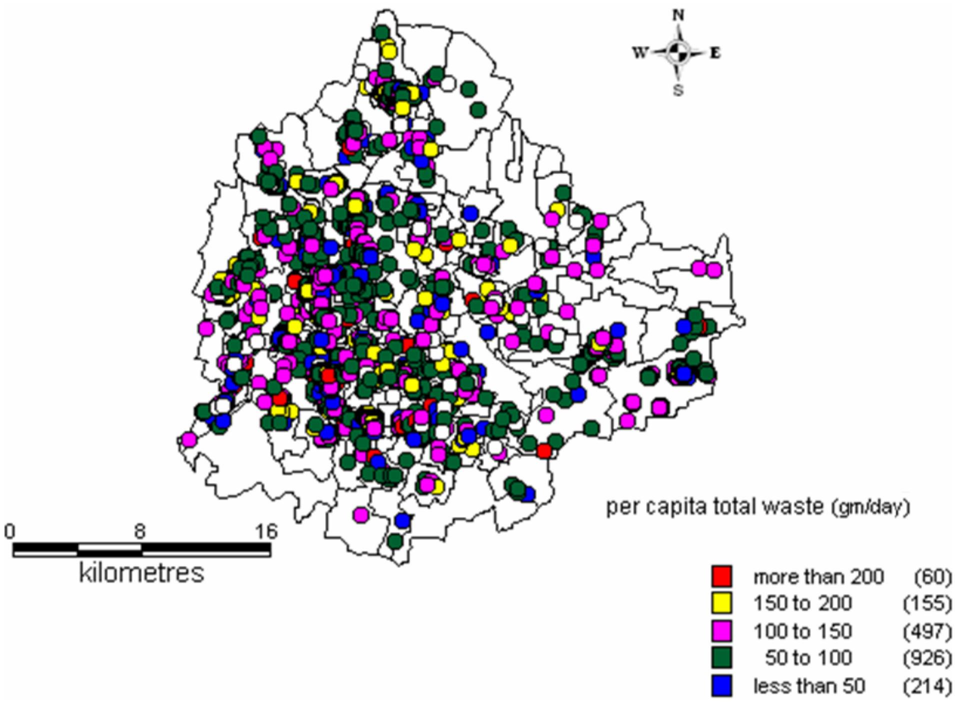


Table 4 Waste generation (g/capita/day)

	Mean	*Skewness*	*Std error*
Organic	74.09 ± 34.94	0.72	0.81
Paper	19.18 ± 22.22	2.88	0.65
Metal	10.66 ± 11.87	1.94	0.71
Glass	6.8 ± 5.01	0.69	0.39
Others	4.53 ± 1.74	5.11	0.04

Table 5 Percentage of composition of waste from surveyed area

Composition of waste	*Percentage of waste composition*
Organic	81.96
Paper	12.69
Metal	1.67
Glass	0.65
Others	3.02

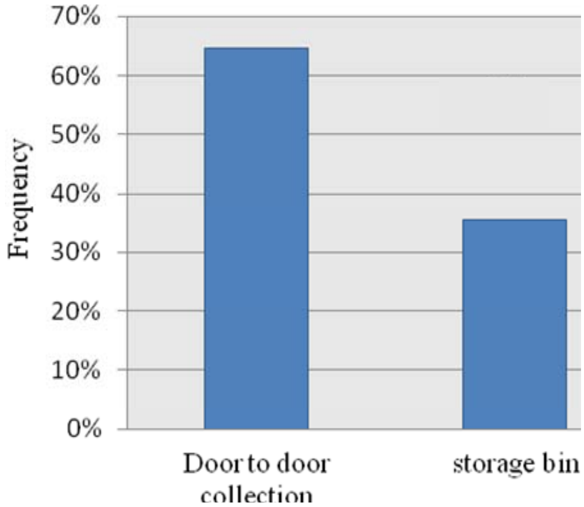
Table 6 Statistical analysis of waste generation (g/capita/day) across the zone

Zones	*Parameters*	*Mean*	*Minimum*	*Maximum*	*SD*	*Skewness*	*Std error*
East	Organic	78.84	4.67	187.50	33.02	0.55	2.03
	Inorganic	31.13	0.63	173.33	34.19	2.25	2.73
NE	Organic	78.70	12.50	150.00	31.60	0.27	6.20
	Inorganic	29.98	2.50	125.00	33.35	1.78	8.34
North	Organic	71.76	6.67	250.00	35.33	0.87	2.07
	Inorganic	24.82	1.00	186.67	29.07	2.63	2.09
NW	Organic	69.14	10.00	200.00	32.51	0.87	2.09
	Inorganic	24.71	0.83	200.00	30.88	2.76	2.40
SE	Organic	66.24	12.00	166.67	36.77	0.73	5.61
	Inorganic	29.70	2.00	166.67	39.85	2.28	7.67
South	Organic	74.22	12.00	250.00	37.39	0.88	2.20
	Inorganic	24.71	1.25	137.50	26.36	2.01	1.93
SW	Organic	74.38	11.11	175.00	34.22	0.48	2.17
	Inorganic	26.56	1.25	187.50	29.85	2.26	2.42
West	Organic	75.74	4.17	222.22	35.52	0.70	1.69
	Inorganic	27.37	1.00	208.33	32.66	2.28	1.88

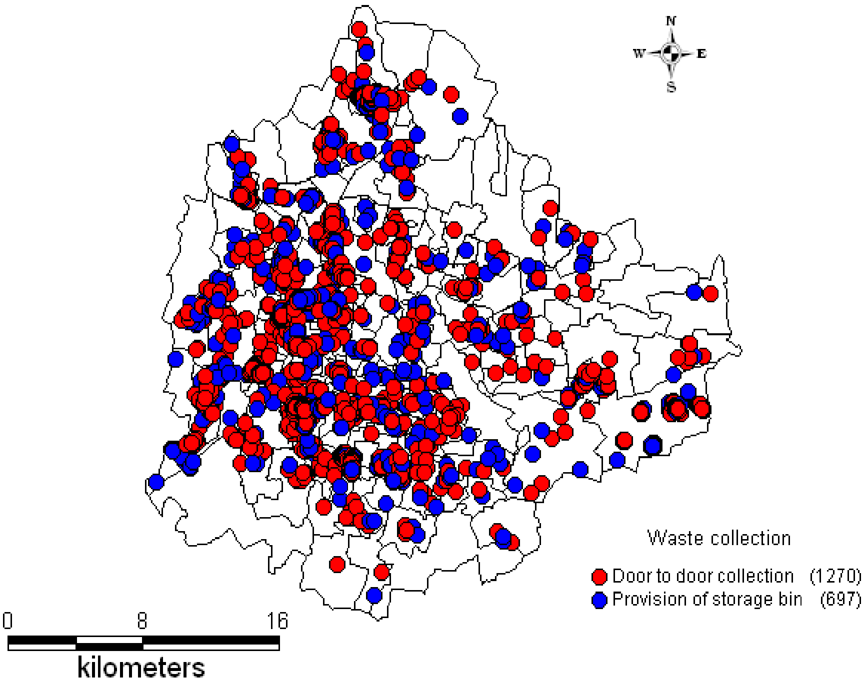
5.2 SWM at household level in greater Bangalore

The collection, transportation and disposal of MSW are significant aspects of waste management. Waste collection [Figure 4(a)] is done either through door-to-door collection systems (64.57%) or through community bins (35.43%). Wards in Bangalore has both community bin and door to door collection system (ex., Bellandru, Varthur, Yelahanka Satellite Town, Vidyaranyapura and Arekere). Households are served with door-to-door collection system [Figure 4(b)] in majority of the wards (Sunkenahalli, Kormangala, Malleshwaram). In Bangalore city, the waste collection is done by the BBMP or outsourced agencies. Swachha Bangalore (or clean Bangalore) a novel initiative was launched in 2003 by the city municipality to manage the waste effectively through door to door collection, segregation at source, etc.

Figure 4 Waste collection (see online version for colours)



(a)



(b)

In majority of wards (64%) the waste is collected in the morning (6.00 am to 11.30 am) and only in 21 households [Figure 5(a)] from surveyed area the waste is collected in the evening mainly in the part of Yelahanka Satellite Town and Herohalli and in 0.36% households [Figure 5(b)], waste is collected in the afternoon.

Figure 5 Time of waste collection (see online version for colours)

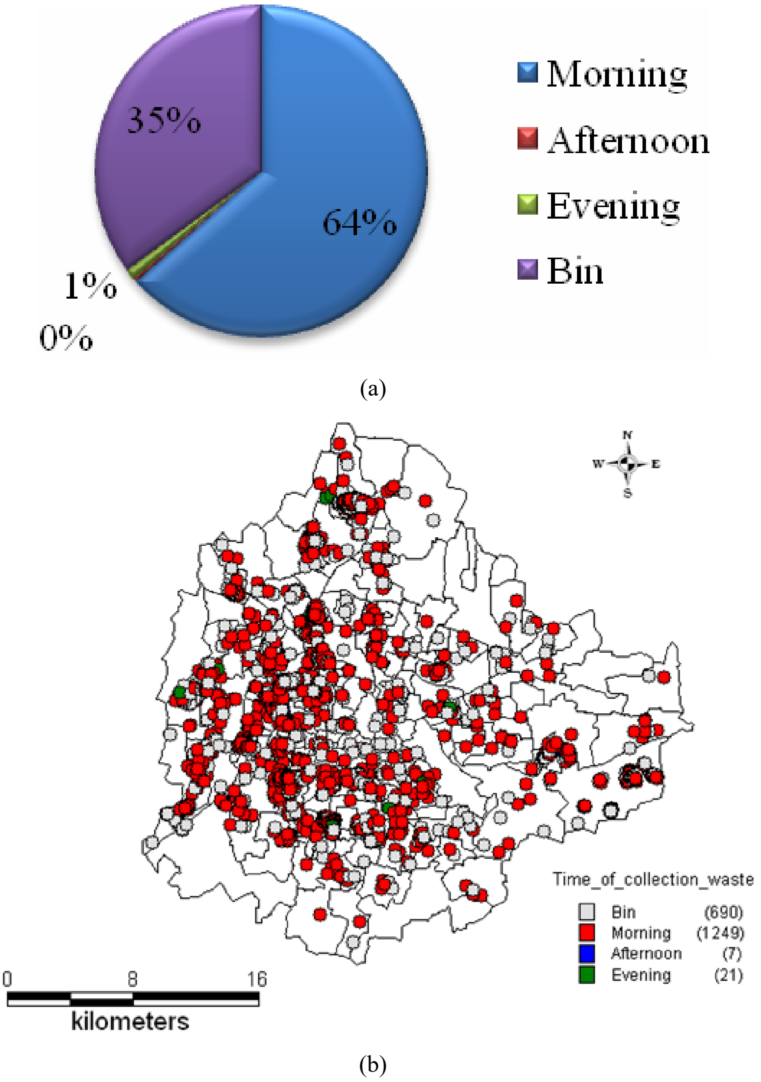
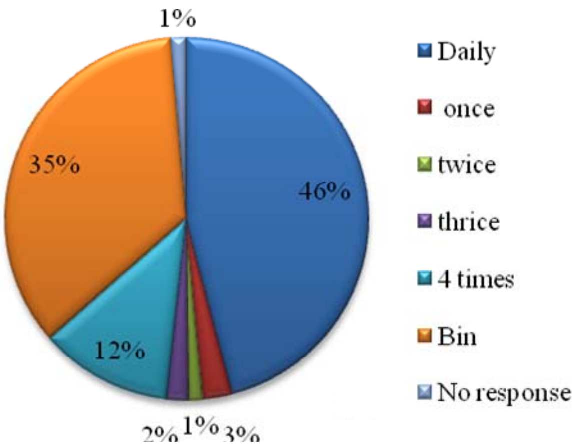


Table 7 Comparison of Household waste generation in different cities (as percentage)

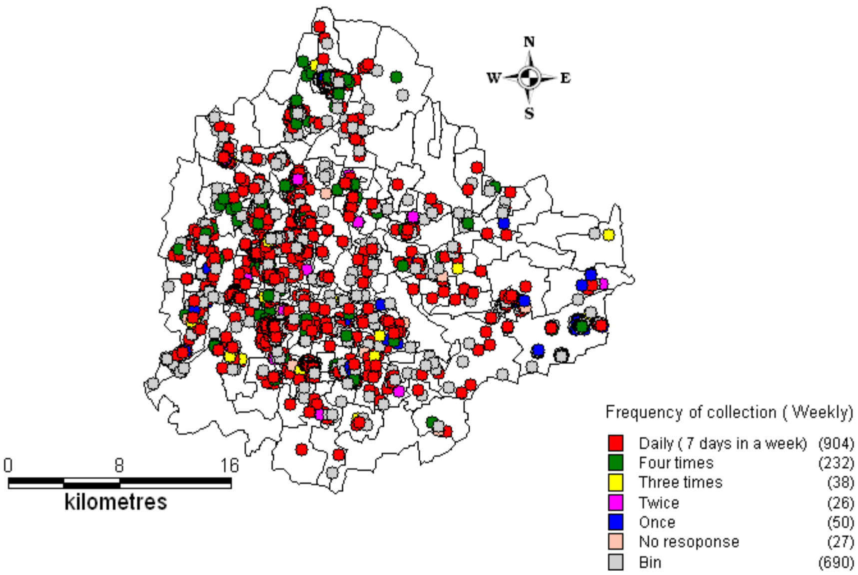
City	*Organic*	*Paper*	*Plastics*	*Metal*	*Glass*	*Textile*	*Wood*	*Others*
Bangalore (India)	84	12	-	1	1	-	-	2
Bejing (China)	69.3	10.3	9.8	0.8	0.6	1.3	2.7	-
Cape Haitian (Republic of Haitian)	65.5	9.0	9.2	2.6	5.8	-	-	7.9
Chittagong (Bangalesh)	62	3	2	-	5	1	3	-

Source: Qu et al. (2009), Philippe and Culot (2009) and Sujauddin et al. (2008)

Figure 6 Frequency of collection (see online version for colours)



(a)

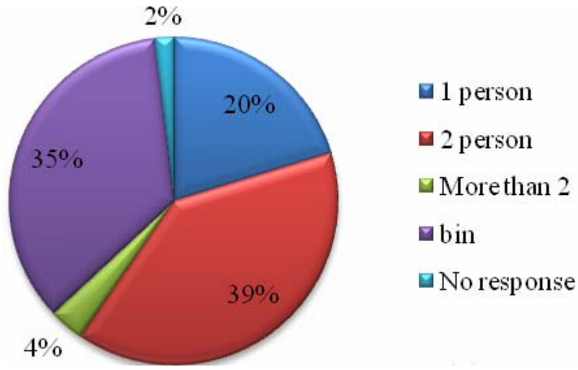


(b)

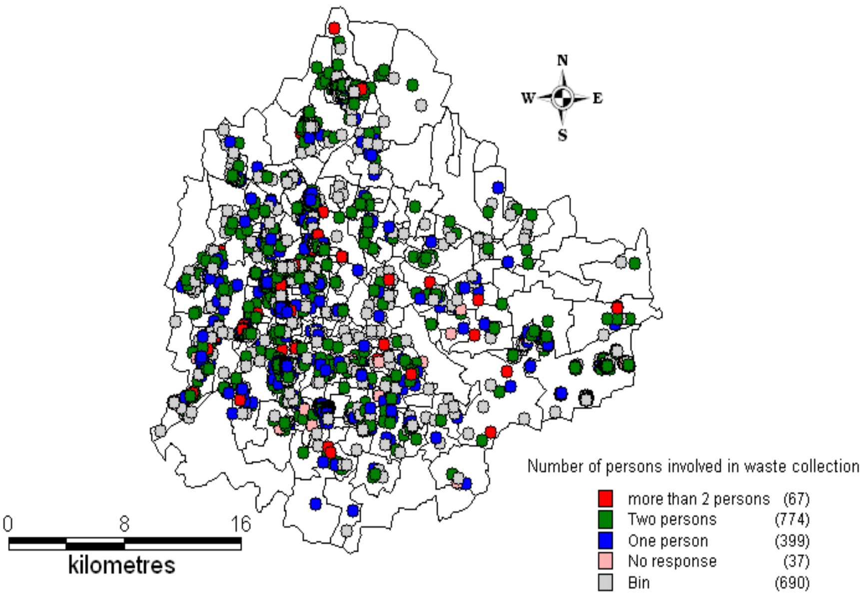
The frequency of collection of waste from door-to-door given in Figure 6a, which highlights of daily waste collection in 46% wards (ex., Sampangiram Nagar at centre of the city, Raja Rajeshwari, Malleshwaram, Rajajinagar, Jayanagar, Bellendur), while weekly four times in 12% wards (ex. Varthur, Hagadur, Kadugodi, Singasandra), thrice a week in 2% wards, twice a week in about 1% wards, once a week in 3% wards. Remaining 1% of the population did not respond to the question [Figure 6(b)].

Number of persons involved in door to door collection of waste was also surveyed and is represented in Figures 7(a) and 7(b) respectively. In most of the wards two persons were involved in collecting the waste (39%) followed by one person (20% of the total area). Figure 8(a) illustrates that 35% area have the facility of community bin and 37 households did not respond to the question [Figure 8(b)]. Municipalityis engaged in waste collection from households to final dumping sites in most (90%) parts of the city. In few areas, 8%private contractor and 2% NGO's (Swabhimana, Swachha Bangalore, Shuchi Mitras) are involved in waste collection.

Figure 7 Persons involved in door to door collection (see online version for colours)



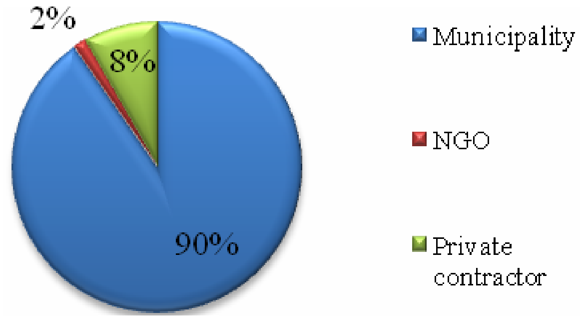
(a)



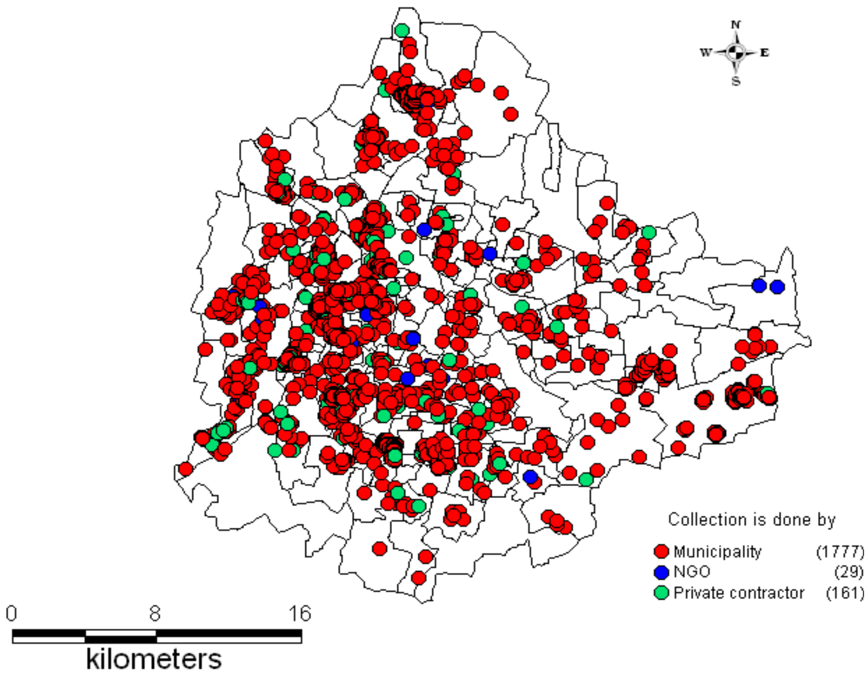
(b)

The analysis of distance of community bin from the households as represented in Figures 9(a) and 9(b), show that the dustbin is within 100 metre in 23% of the surveyed area, while in 11% area, bins is in the range of 100–500 metre away and ten household did not respond to the question. Remaining houses are served with the door to door collection system. Figure 10(a) and 10(b) reveals that bin size of 1 m^3 accounts 13.5% whereas in 7% area has less than 1 m^3 bin, and majority households (64%) have the facility of door to door collection system of waste. Depending on the local culture, tradition and attitudes towards waste, the bins are allocated and there are two types of storage bins; stationary bin and hauled bin.

Figure 8 Collection of waste (see online version for colours)



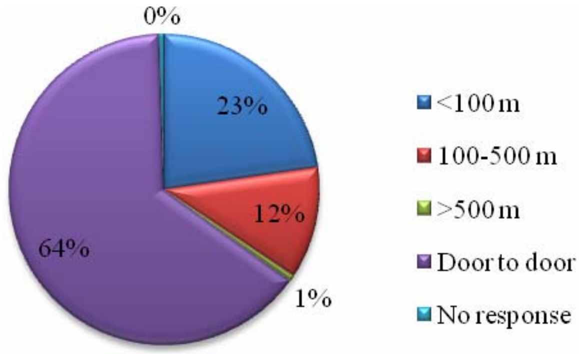
(a)



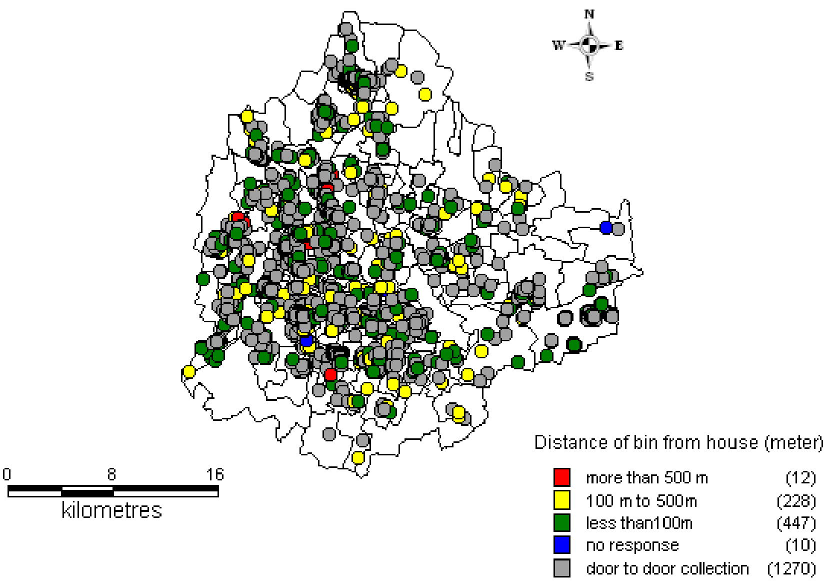
(b)

Analyses of the source segregation given in Figures 11(a) and 11(b) respectively, highlight that about 78.34% households do not segregate the waste before dumping into dustbin because of lack of awareness and general attitude of public towards segregation of solid waste, while 21.66% segregate the waste into organic and inorganic waste or dry and wet waste in the south part of Bangalore (ex., Varthur, Dodda Nekundi, HBR layout, Basavanagudi, etc.). Street bin is cleared of litter by the municipality in the locality show that in majority of wards the bin is cleared weekly which accounts 45% while in other wards bin is cleared daily and 2/3 days once were 42% and 13% respectively [Figures 12(a) and 12(b)].

Figure 9 Distance of the bin from house (in metre) (see online version for colours)



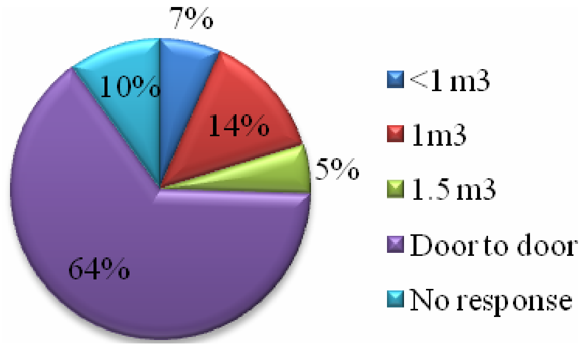
(a)



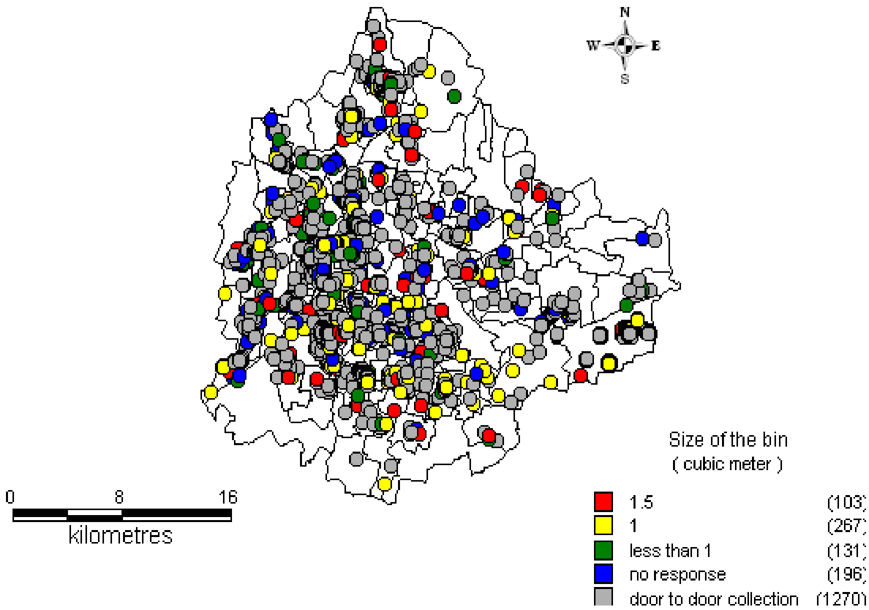
(b)

Finally transportation of waste plays an important role in waste management of the city. The transportation of waste and distance of transportation of waste are illustrated in Figures 13(a), 13(b), 14(a) and 14(b) respectively. About 85% of households are not aware about the final destination of transported waste (final dumping site) and only 205 households were aware about the transportation of waste. Among 205 households, 9% stated that the waste is transported between the range of 10–100 km where as 4% stated less than 10 km and 1% stated that waste is transported greater than 100 km and 28 households did not respond to the question. Figures 15(a) and 15(b) reveal that of 71% of the region has no provision of landfill site, while landfill exists only in 28% area mainly in the north-east and west part of the outskirts in the Bangalore.

Figure 10 Size of the bin (see online version for colours)



(a)



(b)

5.3 *Survey of socio-economic factors*

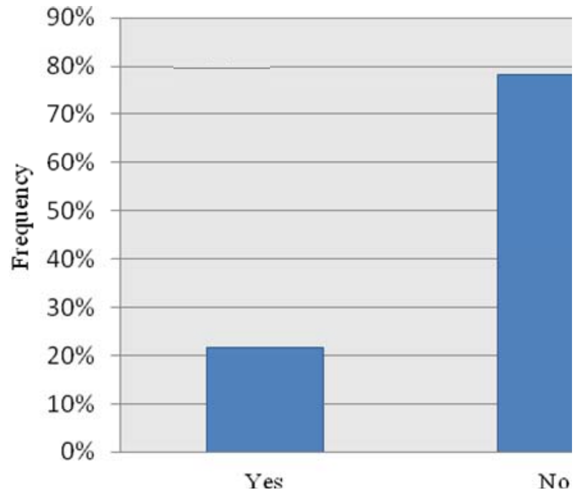
A number of socio-economic parameters such as household size, income, employment status and education status influence the quantum of solid waste generated. Table 8 shows the frequency, percentage and cumulative percentage of the socio-economic factors of households. It indicates the average household size is 4.5 ± 1.74 persons/hh. Majority of the households have four (45.86%) persons, followed by five persons

(19.2%), three persons (15%), six persons (13.9%), greater than six (5.4%), etc. The education and employment status mainly influence the food habits, materials consumed and waste generation. Graduates constitute 36.71% followed by high school educated (24.66%). The average monthly income INR 35,563.63 ± 77,851, which is similar to earlier studies (Sankoh et al., 2012; Getahun et al., 2012; Dennison et al., 1996).

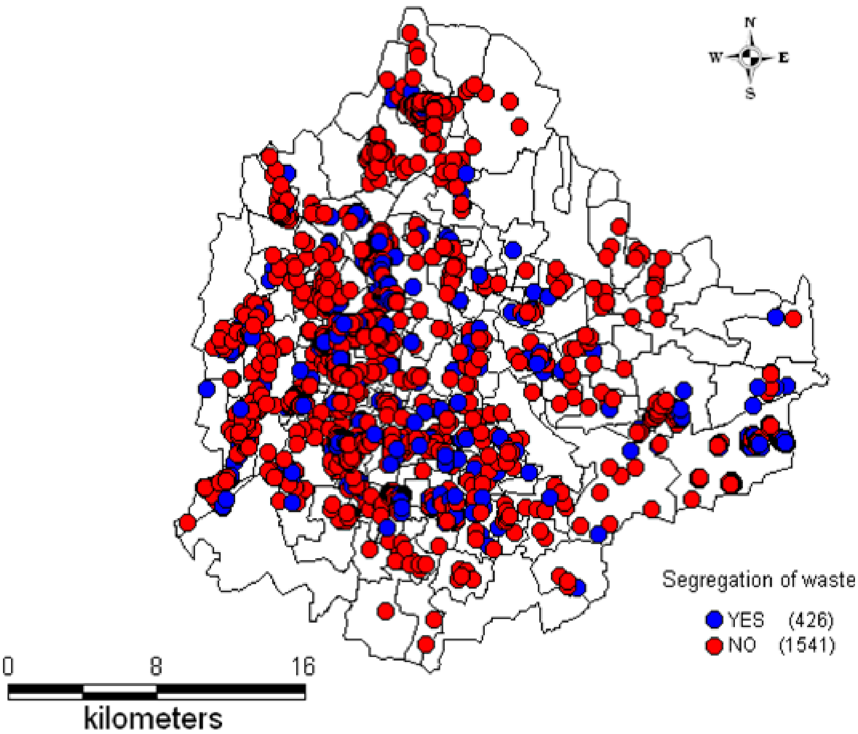
Table 8 Frequency, percentage and cumulative percentage of the socio-economic factors

Variables name		*Frequency*	*%*	*Cumulative %*
1	Family size			
	2	20	1.02	1.02
	3	286	14.54	15.56
	4	902	45.86	61.41
	5	378	19.22	80.63
	6	146	7.42	88.05
	More than 6	128	6.51	94.56
	No response	107	5.44	100.00
2	Education status			
	Middle school or lower	134	6.81	6.81
	High school	485	24.66	31.47
	Technical school	278	14.13	45.60
	Universities	722	36.71	82.31
	Masters	269	13.68	95.98
	PhD	79	4.02	100.00
3	Employment status			
	Government institution	460	23.39	23.39
	School/hospital/research or design institute	83	4.22	27.61
	Foreign corporation	113	5.74	33.35
	Local company	235	11.95	45.30
	State corporation	67	3.41	48.70
	Business institute	391	19.88	68.58
	Others	587	29.84	98.42
	No response	31	1.58	100.00
4	Monthly income			
	< 10,000	509	25.88	25.88
	0000–50,000	1192	60.60	86.48
	50,000–100,000	183	9.30	95.78
	>100,000	83	4.22	100.00

Figure 11 Segregation of waste (see online version for colours)

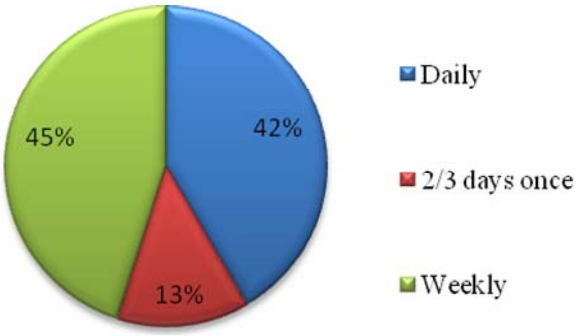


(a)

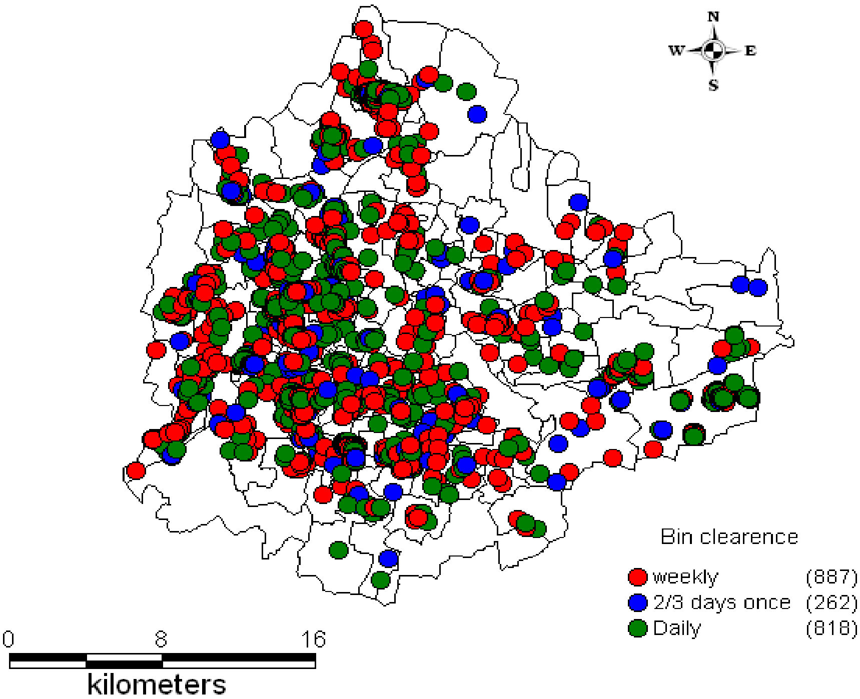


(b)

Figure 12 Bin clearance (see online version for colours)



(a)



(b)

5.4 Relationship between the quantity of HSW generated and socio-economic factors

Family size is an important factor in the household waste generation and Figure 16(a) reveals that the household size was positively related to the daily per capita waste generation. As the family size increases, the total waste generation of household increases and per capita waste generation decrease gradually similar to the earlier reports (Jones et al. 2009; Hockett and Lober, 1995) indicating smaller household size produced more per capita waste than the larger household size. Figure 16b indicate that family with an income >100,000 produces more per capita waste compared to the other families. The relationship between family income and per capita waste quantity was found to be significant, i.e., as the family income increases the consumption pattern and purchase trend increases which in turn leads generation of more solid waste quantity, comparable to the earlier reports (Sujauddin et al., 2008; Dennison et al., 1996) highlighting that family income is positively related to the waste generation rate. The education levels of the family were not found to be significantly [Figure 16(c)] related with per capita waste generation. Families with the education level of masters produces more per capita waste compared to the families with higher levels of education (persons with PhD). In this study the employment status is not significantly relatedto the waste generation [Figure 16(d)]. The head of the family who are in the business produces more waste than the families who are working in the other sectors. The total waste generation from the household increases as the income increases is depicted in Figure 16(e). Table 9 lists the descriptive statistics on the physical composition of household waste with different socio-economic groups. This indicates that organic waste is the prominent component in the solid waste composition in all the socio-economic groups. It is also evident that as the income level increases the organic waste composition decreases with the increase in the proportion of paper, metal, glass and others. The organic waste generated from household varies from 80–82% in the surveyed area. Among them, the high income family group (annual income > 1,000,000 INR) produces the lowest (80.31%) organic waste and low income family group (< 100,000 INR) produces the highest organic waste (85.52%). The organic waste generation was found to be increasing from high income family group to low income family group. The opposite trend is observed for the paper, glass and others.

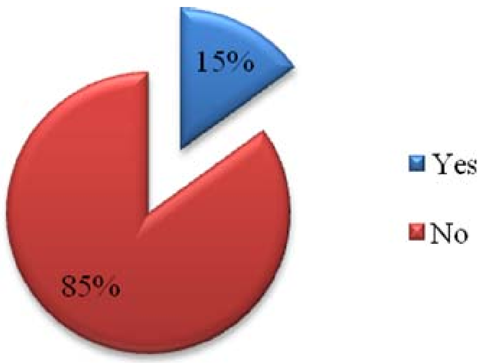
Table 9 Descriptive statistics of physical composition of household waste generated with different socio-economic groups (as a percentage)

Annual income	*Organic*	*Paper*	*Metal*	*Glass*	*Others*
< 100,000	85.52	11.62	1.20	0.52	1.14
100,000–500,000	84.09	11.35	1.51	0.58	2.47
500,000–1,000,000	82.99	13.50	1.22	0.58	1.72
> 1,000,000	80.31	14.72	1.73	0.63	2.61

5.5 Carbon dioxide emissions from household waste

Mismanaged municipal solid waste is the significant contributor to the greenhouse gases such as methane and carbon dioxide in the atmosphere. CO_2 equivalent emission from organic waste generated at household is calculated by using the equation (3). According to this study, the total organic waste generated from surveyed houses was 231.01 tons/year and total emission is about 604.80 tons/year. Table 10 lists zone wise CO_2 equivalent emission (Gg/year) from solid waste generated in Bangalore. The Mean ward wise CO_2 emission varies from 2.59 (North) to 3.23 Gg/year (South West). The CO_2 equivalent emission from solid waste generated at household (kg/capita/day) is depicted in Table 11. It reveals that the average CO_2 equivalent emission is low in South East (0.17 kg/capita/day) and highest in East and North East zones (0.21 kg/capita/day). Figure 17 reveals the per capita CO_2 equivalent emission from households in the surveyed area. 926 households emits 50–100 kg/person/year, 624 households emits less than 50 kg/person/year, 247 households emits 100–150 kg/person/year and only 46 households emits more than 150 kg/person /year. Quantification of GHG emissions from all the wards of Bangalore, reveal that the average ward-wise CO_2 equivalent emission is 2.93 ± 0.91 Gg/year. 47 wards emits in the range of 3 to 3.5Gg/year while 46 wards emits more than 3.5 Gg/year. Forty-five wards emit in the range of 2 to 2.5 Gg/year, 39 wards 2.5 to 3 Gg/year and 18 wards emits in the range of 1.5 to 2 Gg/year. Remaining seven wards emits less than 1.5 Gg/year.

Figure 13 Transportation of waste (see online version for colours)



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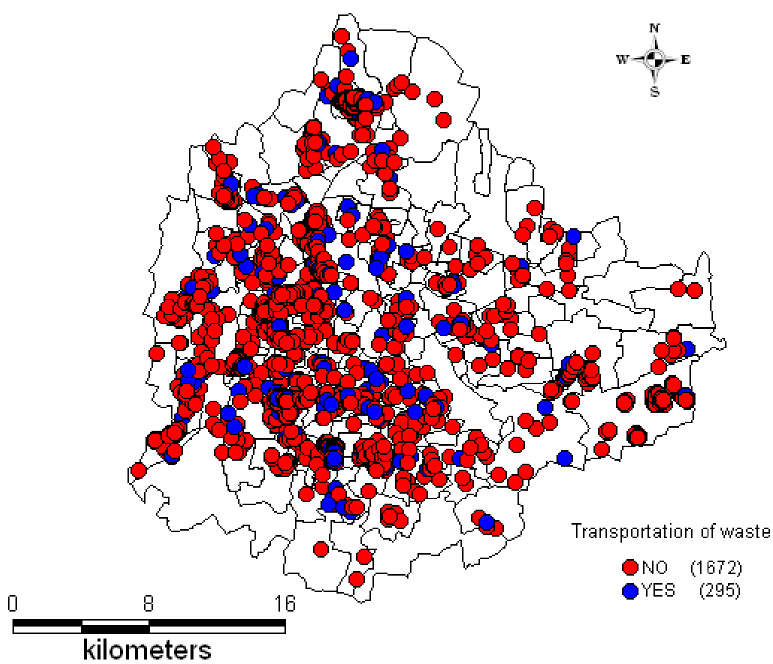
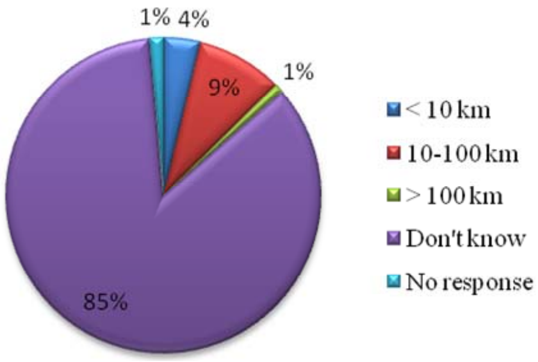


(b)

Figure 14 Distance of the waste transportation (see online version for colours)



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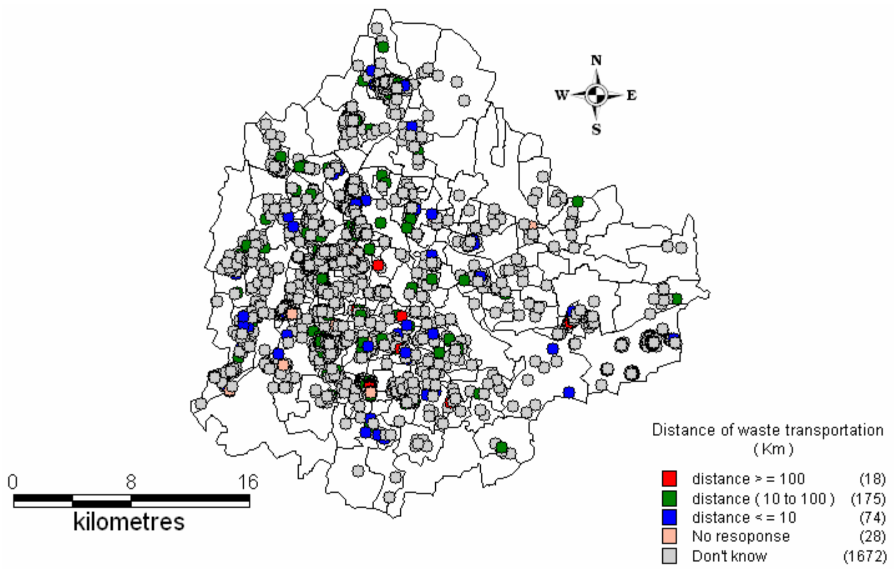
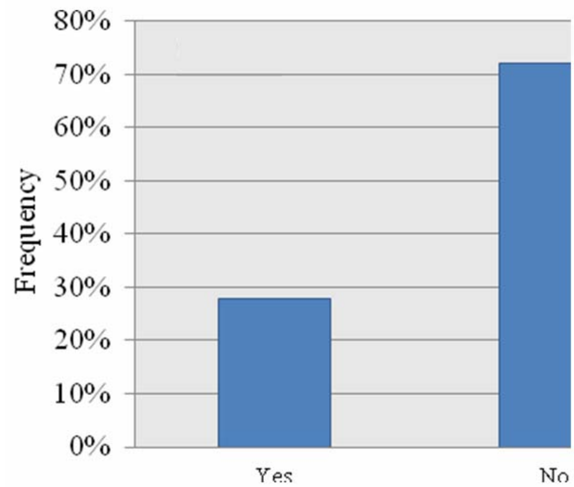


(b)

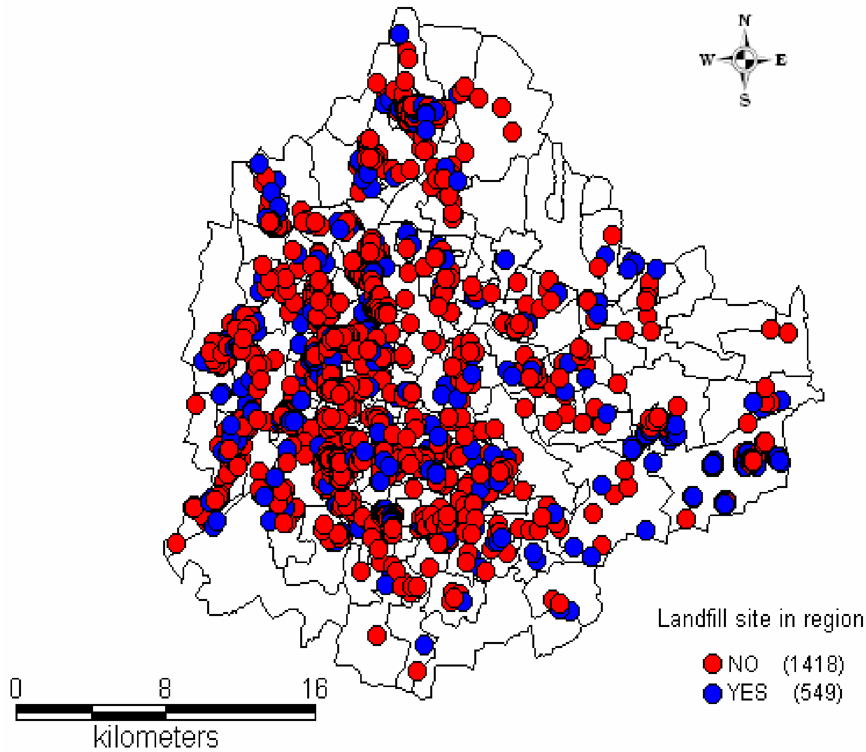
Table 10 CO_2 equivalent emission from solid waste in Bangalore (Gg/year) across the zone

Zone	*Mean*	*Min*	*Max*	*Sum*	*SD*
East	3.11	0.49	5.37	62.21	1.21
North East	2.89	1.66	4.70	57.87	0.80
North	2.59	0.60	5.58	54.41	1.01
North West	3.05	1.99	3.75	70.15	0.50
South East	2.72	0.59	6.25	32.62	1.47
South	2.62	1.01	4.69	83.93	0.80
South West	3.23	2.00	6.25	96.90	0.82
West	3.10	1.76	4.84	102.18	0.78

Figure 15 Landfill site in the region (see online version for colours)

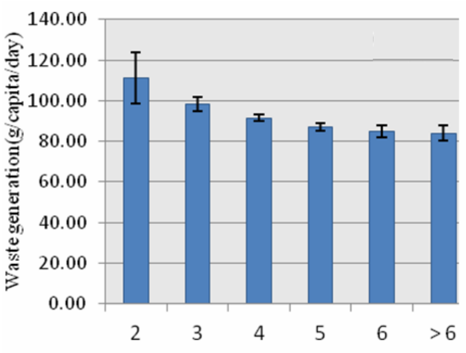


(a)



(b)

Figure 16 Relationship of per capita waste generation with socio-economic factors, (a) household size (b) 100,000, 4: >100,000 (c) educational level (d) occupation (e) annual income (see online version for colours)



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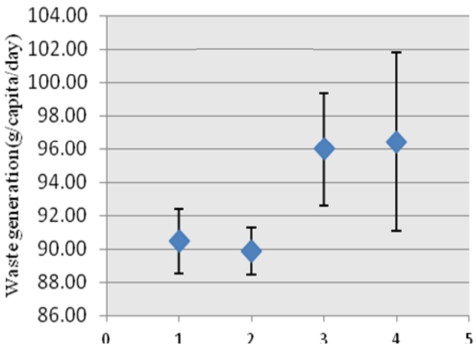

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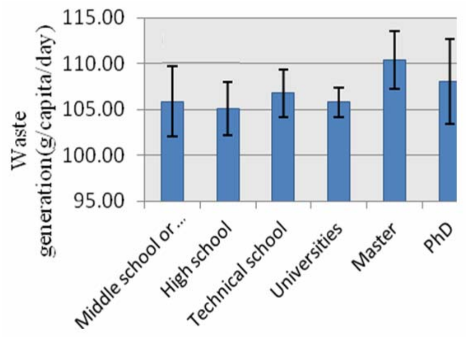

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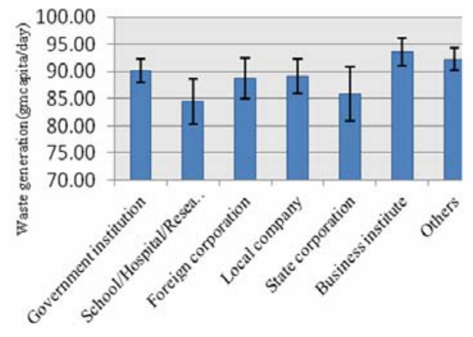
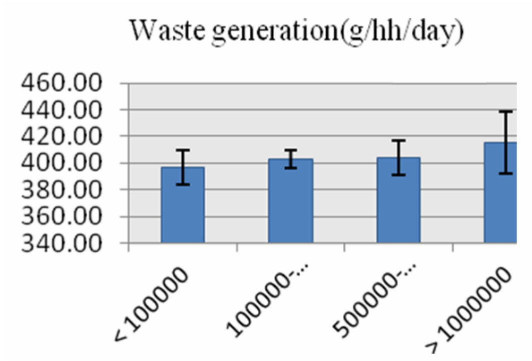


(d)



(e)

Figure 17 Per capita CO_2 equivalent emission from HSW generated (see online version for colours)

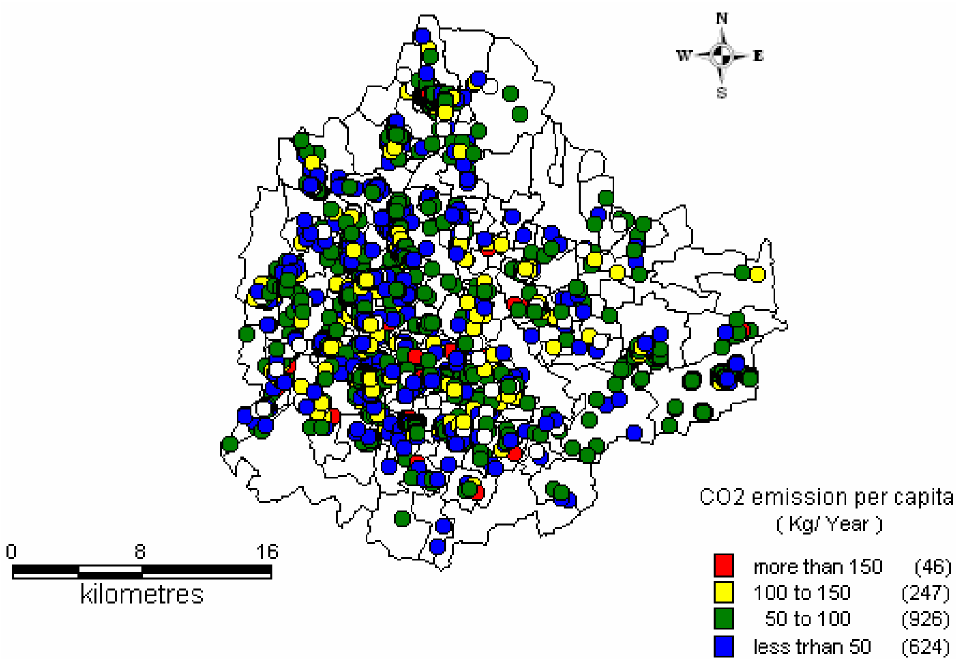


Table 11 CO_2 equivalent emission from solid waste generated at household (kg/capita/day) across zone

Zone	*Mean*	*Sum*	*Minimum*	*Maximum*	*SD*
East	0.21	54.49	0.01	0.49	0.09
North East	0.21	5.36	0.03	0.39	0.08
North	0.19	54.67	0.02	0.65	0.09
North West	0.18	43.81	0.03	0.52	0.09
South East	0.17	7.46	0.03	0.44	0.10
South	0.19	56.15	0.03	0.65	0.10
South West	0.19	48.30	0.03	0.46	0.09
West	0.20	87.25	0.01	0.58	0.09

5.6 Mitigation of GHG emissions

Scope for mitigation of GHG emission is through the recovery and conversion of organic component (which constitute 82%) to energy or compost. Policy interventions for the adoption of integrated solid waste management (ISWM) through the incorporation of the waste management hierarchy considering direct impacts (transportation, collection, treatment and disposal of waste) and indirect impacts (use of waste materials and energy outside the waste management system) would reduce the carbon footprint due to mismanagement of waste (Ramachandra, 2011). ISWM framework optimises the existing systems and implements new waste management systems. In addition to climate concern, the recycling and energy recovery enriches the resource efficiency and reduce the environmental impacts from GHG emission. The strategy includes:

- Door to door collection of waste with incentive based mechanism to enhance segregation at source: This entails
  1. Deploying appropriate mobile collection vans (for each locality) with an option to store segregated and unsegregated wastes
  2. Incentive of Rs 1 per kg of segregated organic waste and payment directly to the respective household account through direct bank transfer
  3. Disincentive to unsegregated waste individuals who refuse to segregate needs to pay Rs 5 per kg of unsegregated waste. Revenue generation would encourage many households to switch over to segregation.
- Segregation of waste at source. The biodegradable organic waste bring a dominant component in MSW, treatment of organic fractions through appropriate technologies helps in the resource recovery while addressing its negative impact on the environment and potential economic benefits.
- A waste stream with a high biodegradable organic content can be processed to produce high-quality compost which avoids land filling and enables the provision of manure to enrich nutrients in the soil. The biodegradable fraction has the appropriate moisture content for composting.
- Promotion of recycling or reuse of segregated material reduces the quantity of waste and the burden on landfills, and provides raw materials for manufacturers.
- Improved storage containers for the storage of biodegradable / wet wastes.
- Setting up transfer stations taking in to account local situations to improve the efficiency of waste collection, especially in narrow roads and slums,. This will ensure the proper handling of wastes and the reduction of transportation costs.
- Primary collection of waste stored in various locations on a daily basis through active public participation
- Improved collection vehicle design to increase capacity and ergonomic efficiency.
- A helpline to tackle various issues such as road sweeping, open dump, open burning, garbage collection, etc.
- Garbage tax to be levied to the large and small generators for the disposal of wastes.
- Adequate training to all the levels of staff engaged in SWM to handle respective functional aspects (collection, generation, storage, segregation of waste, etc.).
- Adoption of technological solutions such as bio-gas recovery, composting, etc. for affecting improved recovery and disposal of waste.
- Collection trucks to have global positioning system (GPS) which would help in online tracking and also in reducing malpractices associated with waste management.

- Transparency in the administration though online availability of spatial information system, accessible to all including public. Adoption of geographic information system (GIS) with GPS would streamline collection of waste garbage and improves efficiency.
- Constitution of citizen forum in each corporation ward involving local people, NGO's and concerned authorities to ensure close monitoring and supervision of waste management practices regularly.
- Taking into account the bulk wastes to be handled every day, sanitary landfill sites have to be set up to dispose of the rejects after composting and landfilling.
- Regular monitoring of sanitary landfill sites involving local people in the team along with sanitary authorities.
- Administrative restructuring of the urban local bodies to discharge more efficiently specific responsibilities. This requires structural changes within the administration aimed at decentralising authority and responsibilities. This also includes periodic meetings among the staff and between the executives and elected wing of the corporation.
- Encouraging the involvement of local NGO's in working on various environmental awareness programmes and areas related to waste management including educating the public about the importance and necessity of better waste management.

6 Conclusions

GHG emissions in the municipal waste sector are quantified based on the sampling of 1967 households in Greater Bangalore chosen through multistage, stratified random sampling. The outcome of the analysis showed the daily solid waste generation from 1967 residential households in surveyed area of Greater Bangalore was about 772.2 kg and the per capita of 91.01 ± 45.52 g/day. The analysis revealed that the organic fraction (82%) constitute a major portion of household wastes. The total organic waste is 632.92 ± 0.210 kg/day with the per capita organic waste generation of 74 ± 35 g/person/day. This emphasise the need for appropriate treatment option to minimise GHG emissions.

Most of the households (64%) in the study area have the facility of door to door collection of solid waste and about 78.34% of city population do not segregate the waste at source (household level). The decision makers should bring awareness among citizens and pourakarmikas (BMP staff) through capacity building workshops highlighting the importance of segregation at source level and promotion of recycling and reuse methods. This will reduce the quantity of waste and burden on landfills while ensuring the sustainability of natural resources. Further the study has revealed the relationship between waste generation and socio-economic factors. The family income and family size are positively related and the education status is negatively related with per capita waste generation at household level. The average carbon dioxide equivalent emission from household is 307.50 ± 205.51 kg/year and per capita emission is 66.33 ± 36.61kg/year. Further research is necessary to evaluate the seasonal variation in solid waste generation and composition as well as relationship between household waste generation and socio-economic factors at household level during different time period. The implementation of functional elements (such as segregation at source, storage, treatment of organic fractions, etc.) would aid in reducing GHG emissions.

Acknowledgements

We thank BMP (Bangalore Mahanagara Palike) for providing zone-wise data. Student volunteers assisted us in compiling the data from households. We are grateful to the Asia-Pacific Network for Global Change Research (APN) for its financial support (ARCP2011-07CMY-Han) to this research.

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