Using GIS to Locate Waste Bins: a Case Study on Kolkata City, India

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ABSTRACT

Environmentally acceptable management of Municipal Solid Waste (MSW) has become a challenge due to limited resources, increasing population and rapid urbanization. Kolkata city, with an area of 187.33 km^2 and a population of about 10 million (including a floating population of about 6 million), generates about 3,500 MT of solid waste per day. Daily disposal rate of solid waste at Dhapa exceeds 3,000 MT d^{-1} while at Garden Reach the disposal is 100-150 MT d^{-1}. Conservancy staff collects waste from households and streets and dumps them at skips/MS containers (55%) or at open vats (45%). Collected waste is transported directly to disposal ground at Dhapa by KMC departmental vehicles and KMC-hired vehicles. Lack of proper planning and inadequate data regarding solid waste generation and collection compound the solid waste management problem. GIS as a tool can recognise, correlate and analyse relationship between spatial and non-spatial data- it can thus be used as a decision support tool for efficient management of the different functional elements solid waste e.g. bin location, number of bins required, waste transportation, generating work schedules for workers and vehicles. This study examines GIS application in assisting locational analysis of waste bins in Kolkata and optimise the overall solid waste collection process.

Key words: *Municipal Solid Waste (MSW), bin location, Geographic Information System (GIS), Kolkata Municipal Corporation (KMC), Solid Waste Management (SWM)*

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INTRODUCTION

Solid waste management is a multidisciplinary field requiring information about the physical, environmental, social, and economic implications of a SWM system. Adequate, accurate and current information is necessary to support a solid waste planning and management system (*Chiueh and Yu 2006*). It is often seen in most of the local bodies that data lies in isolated, discontinuous and inaccurate form. The SWM data is often not available at one platform for arriving at proper decisions regarding planning and management. Conventional solid waste management endeavours fall short in data management, logistics management and spatial planning. The core solution for efficient delivery of municipal services lies in the linking and proper management of the available data (*Ogra 2003*). Considering the amount and complexity of such data, computer based systems should be considered to facilitate storage, retrieval and general data handling (*Toftner 1973*). GIS is one of the most sophisticated modern technologies to capture, store, manipulate, analyse display spatial data (*Chang 2008*)- thereby enabling policymakers to link disparate sources of information, perform sophisticated analysis, visualise trends and project outcomes.

Ghose, Dikshit and Sharma (*2006*) proposed three types of waste bins to be placed within the municipality area in Asansol Municipal Corporation, India. The bin sizes and clearing frequency depend on the population of the localities while fixing the location the three different types of bins was done according to road width through which the conservancy vehicles need to pass. Three different vehicle types compatible with the three bin types have been proposed for collection of waste. After fixing the location of bins, optimal routing for waste transportation has been executed using Network Analyst extension of ArcGIS. The study is more on ArcGIS application on waste transportation route optimisation and does not throw much light on GIS-assisted bin location/allocation.

Vijay et al. (*2008*) had selected a 4 km^2 study area with the objective of identifying the optimised bin locations and appropriate number of storage bins using p-median constraint model on a GIS platform. The optimized locations and the number of storage bins required are identified using *Central Public Health and Environmental Engineering Organisation (CPHEEO) Manual* (*2000*) distance guidelines. In their work, road intersections are assumed as solid waste generation demand nodes. The p-median model identifies a p-centre to locate a bin by minimising total weighted distance from p-centre to demand nodes. The waste from every demand node travels to its closest bin. The bin is located at the weighted center where the majority of the demand nodes are converging with distance being the weighting criteria. Triangulated Irregular Network (TIN) is created by joining the demand nodes to compute the command area of a particular bin. However, all bins are of uniform size and one bin is placed per location. The paper does not show computations of solid waste generated, bin size, number of handcart-trips required to clear waste in a command area and number of conservancy staff required per bin command area. Current SWM regulations in India recommends house-to-house collection and this has not been simulated in the paper.

Ahmed (*2006*) had considered the land-use of the study area (Aurangabad city, India) marking the location of schools, hospitals, cinema halls and religious buildings, natural streams. Buffers were created around schools, religious buildings, and natural streams. Commercial complexes were classified on the basis of waste generated by them- organic, recyclable and mixed. Bins were then allocated taking into consideration the buffers while maintaining a distance of 100 m from households to the nearest bin. Additional recyclable material collection bins were placed near office buildings, cinema halls, schools and shops generating recyclable wastes. The work although quite exhaustive in GIS, is weak in attribute data analysis like waste generation based on population, number of bins and their sizes, handcart-trips and manpower needed in a particular bin command area. Also, house-to-house collection has not been considered in the paper.

Illeperuma and Samarakoon (*2010*) had conducted a study for improvement of the existing SWM system in Maharagama Urban Council, Sri Lanka. They have calculated the waste generated per household and then placed bins at the centers of high waste generation areas. Further modification of bin locations was done after creating 100 m service area polygons with 100 m trim length (using Network Analyst of ArcGIS) and ensuring the entire study area is covered by the service polygons with least overlapping of the polygon areas. After locating bins, amount of waste generated within service areas of each bin is computed. Finally bin sizes were determined considering the waste collection frequency and all these data were entered in the attribute table of the ArcGIS layer. In thiscase, residents were expected to walk to the nearest bin to deposit the waste.

An ArcGIS Network Analyst model was developed by Chalkias and Lasaridi (*2009*) in order to improve the efficiency of waste collection and transportation in the Municipality of Nikea, Greece. In their study, two scenarios were simulated: S1– collection vehicle routing optimisation with the existing bin locations, and S2 – reallocation of bins and then executing route optimisation. In the S2 scenario, the number of required bins was determined and then 501 existing bins of 120 l and 240 l sizes were replaced by 162 numbers of 1100 l large size bins. A maximum travel distance of 60 m from each resident to the proposed new bin sites was allowed. The introduction of new bins with larger capacity, to accommodate for the same waste quantity, ensured the decrease of the total number of bins and collection stops. Both S1 and S2 scenarios resulted in savings compared to the existing situation in terms of collection time (3% and 17%, respectively) and travel distance (5.5% and 12.5%, respectively).

Anwar (*2004*) had attempted to locate optimised bin locations using ArcView Network Analyst for Kalabagan area of Dhaka Municipal Corporation, Bangladesh. In Kalabagan area, there were 6 bin locations (3 no. of 5 t capacity containers for wider peripheral roads, 2 no. 2 t brick-vats and 1 no. 1.5 t brick-vat for internal roads) for 1302 household points (16858 households) which were unevenly distributed over the study area. The researcher had shown that even using 200 m service area for each bin, only 351 household points were being covered in the existing system. He had then used ArcView Network Analyst to select bin locations and bin size, so as bring the entire Kalabagan area under waste collection taking into consideration landuse pattern, population density, solid waste generation and roadwidth. He has given three sets of optimum solutions (bin locations and bin sizes) considering residents convenience to walk 200 m, 100 m and 150 m from their houses to the bin locations. He proposed 16 bins (5 nos. 5 t containers and 11 nos. brick vats) for 200 m walking distance; 50 bins (13 no. 5 t containers and the rest brick vats) for 100 m distance and 24 bin locations (9 no. 5 t containers and 15 no. brick vats) for 150 m distance.

For KMC area, the vehicle and vat/container sizes are fixed and it will be economically unfeasible to propose an entire new fleet of vehicles and bins. Similarly, considering the absence of any source segregation, the idea of recyclable-material collecting bins is also redundant. The present work is unique in the sense that GIS-enabled location of bins has never been attempted previously in the KMC area. Also KMC currently organises house-to-housecollection of waste. This study took three contiguous KMC wards- 65, 66, 67 as the study area to showcase the effectiveness of GIS in bin location.

MATERIALS AND METHODS

Study Area

India is fast shifting from agriculture-based nation to industrial and services-oriented country. Due to continuous migration of population from rural areas to towns and cities, in India the share of urban population has increased from 10.84% in 1901 to 26.15% in 1991 to 31.2% in 2011. There are three megacities- Greater Mumbai, Kolkata and Delhi, which have a population exceeding 10 million, 53 cities which have more than 1 million population and 415 cities whose population exceeds 100,000 (*Census 2011; Singh et al. 2011*). The urban population in India generated about 1,14,576 MT d^{-1} of MSW in 1996; 1,27,486 MT d^{-1} during 2011-12; and 1,44,165 MT d^{-1} during 2013-14 (*CPCB 2012; CPCB 2015*). Per capita waste generation in cities varies from 0.2 to 0.6 kg day^{-1} (*Dayal 1994; Department of Economic Affairs 2009*) depending upon the size of population. An assessment has been made that per capita waste generation is increasing by about 1.3% yr^{-1} (*Bhide and Shekdar 1998; Shekdar 1999; Imura et al. 2005*). Economical and infrastructural constraints, limited availability of land for disposal, lack of awareness and technical manpower, results in inefficient urban solid waste management. Although municipalities in India devote 75-95% of their financial resources towards collection and transportation of waste, yet, MSW collection efficiency ranges between 70-90% in major metro cities while it is around 50% in smaller towns- the remaining waste remains unattended in streets, dumps and low-lying areas and pollute the urban environment (*Khan 1994; Ghose, Dikshit, and Sharma 2006; Siddiqui, Siddiqui, and Khan 2006; Sharholy et al. 2008; Annepu 2012*).

Kolkata (22° 33´ N and 88° 30´ E) has an area of 187.33 km^2 and a population of about 10 million (including floating population). KMC is responsible for solid waste management within the city. In 2015, the KMC area comprises of 15 boroughs and 141 electoral wards; each borough consisting of a cluster of wards. KMC area currently generates a total of 3500 MT of solid waste d^{-1} (*Chattopadhyay, Dutta, and Ray 2007, Hazra and Goel 2009*) (**Table 1**). The collected waste has high biodegradable fraction (50.56% by wet weight), high inert content (29.6% by wet weight), high moisture content (46% by dry weight and a low calorific value of 1201 kcal kg^{-1} (*Chattopadhyay, Dutta, and Ray 2009*).

Due to the predominance of decomposable matter in the waste and climatic factors like high temperature and humidity, MSW decomposes rapidly causing odour and health problems. Hence in most areas collection needs to be done on a daily basis. Collection, transportation and disposal of MSW are the most challenging problems of the city today. At many places, household wastes are thrown haphazardly in and around roadside waste bins leading to unaesthetic, unhygienic conditions. In the absence of a proper segregation system, recovery of recyclables is almost nil. Sometimes the bins overflow, since the bin sizes were not accurately calculated taking into consideration the population of the locality and the collection frequency. The littered waste is further scattered by wind, rain and street animals. Collection, transport and disposal of MSW in Kolkata encompass an extremely complex set of operations.

Table 1. Percent distribution of KMC municipal solid waste from different sources (*KEIP 2003; Das and Bhattacharyya 2013*).

Sources of waste	Percentage
Household waste	34.20
Street sweeping	22.80
Institutional waste	6.32
Commercial and market waste	36.37

- Street sweeping and cleaning: Using a broom, shovel and handcart, municipality staff executes sweeping and cleaning of the streets in the early morning. Inert materials and solid wastes littered by citizens along roadside/low-lying areas are collected into the handcarts and deposited at the nearby vats/container points.
- Residential, slum and commercial complexes: In the early morning hours, conservancy staffs arrive at their assigned areas with handcarts and blow their whistles requesting residents to deposit wastes in their handcarts. The handcarts are then taken to the nearby vat/container locations and MSW transferred to the vats/container locations. This door-to-door collection has been successfully implemented in about 70% of KMC area and KMC proposes to increase the percentage in coming years.
- Large hotels/restaurants have their own storage containers and waste is collected by KMC on payment basis. Small enterprises, however dispose their wastes to nearby KMC vats. KMC collects wastes from vats/containers located in markets regularly and much of these wastes are putrescible.

In 2011, total collection points in the city was around 650 with 365 mild-steel MS skips/containers, 20 direct loading, and 265 open vat points. KMC proposes to convert open vats to closed container systems gradually (**Figure 1**). Skips/Containers are of two sizes – Normal (4.5 m^3) and Big (7 m^3) (**Table 2**).

The conservancy workers commence their work at

Figure 1. The big container (left) and one particular type of open vat (right).

Table 2. Status of collection points at Kolkata (*ADB 2005; personal communication with KMC 2011*).

Year 2005					Year 2011			
Br No.	Total collection points	Type of collection points			Total collection points	Type of collection points		
		DL[a] points	Open vat/ space	Container points (B/N[b])		DL[a] points	Open vat/ space	Container points (B/N[b])
I	58	3	35	20 (12B, 16N)	56	0	25	36 (25B, 17N)
II	19	0	12	7 (14B)	19	0	7	11 (20B)
III	33	0	16	17 (30B, 2N)	33	0	9	23 (35B, 4N)
IV	22	0	14	8 (19B)	22	0	10	13 (22B)
V	22	0	17	5 (9B)	22	0	10	8 (14B)
VI	20	1	13	6 (12B)	19	0	7	10 (19B)
VII	57	7	27	23 (34B)	56	4	17	34 (39B)
VIII	34	3	11	20 (36 B)	34	2	8	33 (50 B)
IX	53	6	31	16 (23B)	52	4	23	27 (40B)
X	81	18	53	10 (11B, 6N)	79	7	41	15 (19B, 8N)
XI	52	2	19	31 (33N)	50	1	12	47 (5B, 46N)
XII	48	5	11	32 (33N)	48	2	6	49 (5B, 45N)
XIII	63	0	43	20 (4B, 18N)	61	0	32	37 (6B, 32N)
XIV	52	1	38	13 (13B, 2N)	51	0	25	18 (19B, 4N)
XV	48	0	48	0	48	0	33	4 (2B, 2N)
	662	46	388	228 (217B, 110N)	650	20	265	365 (320B, 158N)

[a]Direct Loading; [b]Big (7 m^3)/Normal (4.5 m^3)

5:30 am and continue until 12 noon with a break of half-an-hour in between. Municipal staff carries out street sweeping and cleaning of road and pavements and dispose off the collected garbage to the assigned vats/containers. The task is completed by about 7:30 am. From 7:30 am onwards, they move on to their respective areas with their handcarts (0.9 m × 0.645 m × 0.45 m) blowing whistle, signaling the residents to deposit the garbage at their handcarts. Garbage thus collected is taken to the nearest vat/container/skips from where larger conservancy vehicles haul waste to the disposal ground. The loading of waste from the bins to the larger conservancy vehicles (either KMC-owned vehicles or hired trucks) is done manually or through pay-loaders.

In Kolkata, the major disposal ground is Dhapa (21.47 ha) located in the eastern side of the city. It receives about 3000-3200 MT of solid waste per day. Another site at Garden Reach (3.52 ha) receives only about 100-150 MT of solid waste day^{-1} (*Chattopadhyay, Dutta and Ray 2007; Hazra and Goel 2009; Das and Bhattacharyya 2013*). Waste is simply spread at the landfilling sites by the dumpers without any treatment and/or compaction. KMC spends 70 to 75% of its total SWM budgetary allocation on collection of solid waste, 25 to 30% on transportation, thus leaving a meager 5% for final disposal (*Chattopadhyay, Dutta and Ray 2009*). Thus, any increase in collection efficiency will lead to savings in the overall SWM cost.

Building of Network Dataset

Paper maps were scanned, georeferenced and digitised in ArcGIS environment using WGS 1984 UTM Zone 45 N projected coordinate system. Shapefiles for road network (Roads.shp), important landmarks, railway-lines, ward boundaries were extracted for our study area. Update of road networks was done directly in Google Earth and then added it to ArcMap. The Roads.shp was checked for topology errors after incorporating it into a Routes.mdb personal geodatabase and 'Roads' feature dataset. Thus, all overlap and gap errors were eliminated using topology rules; the corrected line geodatabase feature class was named 'Streets_Corr' and stored within the 'Roads' feature dataset.

In 2005, under Asian Development Bank (ADB) financially assisted Kolkata Environmental Improvement Project (KEIP), a master-plan on MSW management was drawn up to improve the environmental conditions in Kolkata city. Guided by ADB 2005 survey data addresses of location of open vats/containers within the study area, the researchers visited the container/vat locations with GPS set and recorded the lat/long of the vats/containers. A few vats/containers were found to be relocated while some were non-existent. It is a matter of concern, that with increase in population in KMC area, residents are exerting pressure on KMC to shift vats/containers from their backyards. KMC allocates a particular vat/container to a particular type of vehicle; big containers are hauled by KMC-owned Dumper-Placers, while open vats/open areas are catered to by privately owned lorries / manually loaded KMC Tipper Truck/Payloader loaded Tipper Truck. A shapefile layer, Vat_Container_Locations.shp, showing the location of vats and containers was created with all details fed into the attribute table.

Similarly, the 'Streets_Corr' layer was integrated with a set of attribute data so that Network Analyst extension of ArcGIS is later able to simulate the real-life situation accurately (**Figure 2**). Attribute fields of 'Streets_Corr' layer were developed (**Table 3**).

Service areas for existing open vats/ containers

The *CPHEEO Manual* (*2000*) suggests that in thickly populated areas, 250-350 m of running road length along with adjoining houses may be given to each sweeper, whereas in less congested areas 400-600 m of road length with adjoining houses may be given to each sweeper. In low density areas, 650-750 m of road length and houses can be allotted. The *CPHEEO Manual* (*2000*) also stipulates that the distance between two bins should not exceed 500 m. The existing bin locations within the study area were loaded

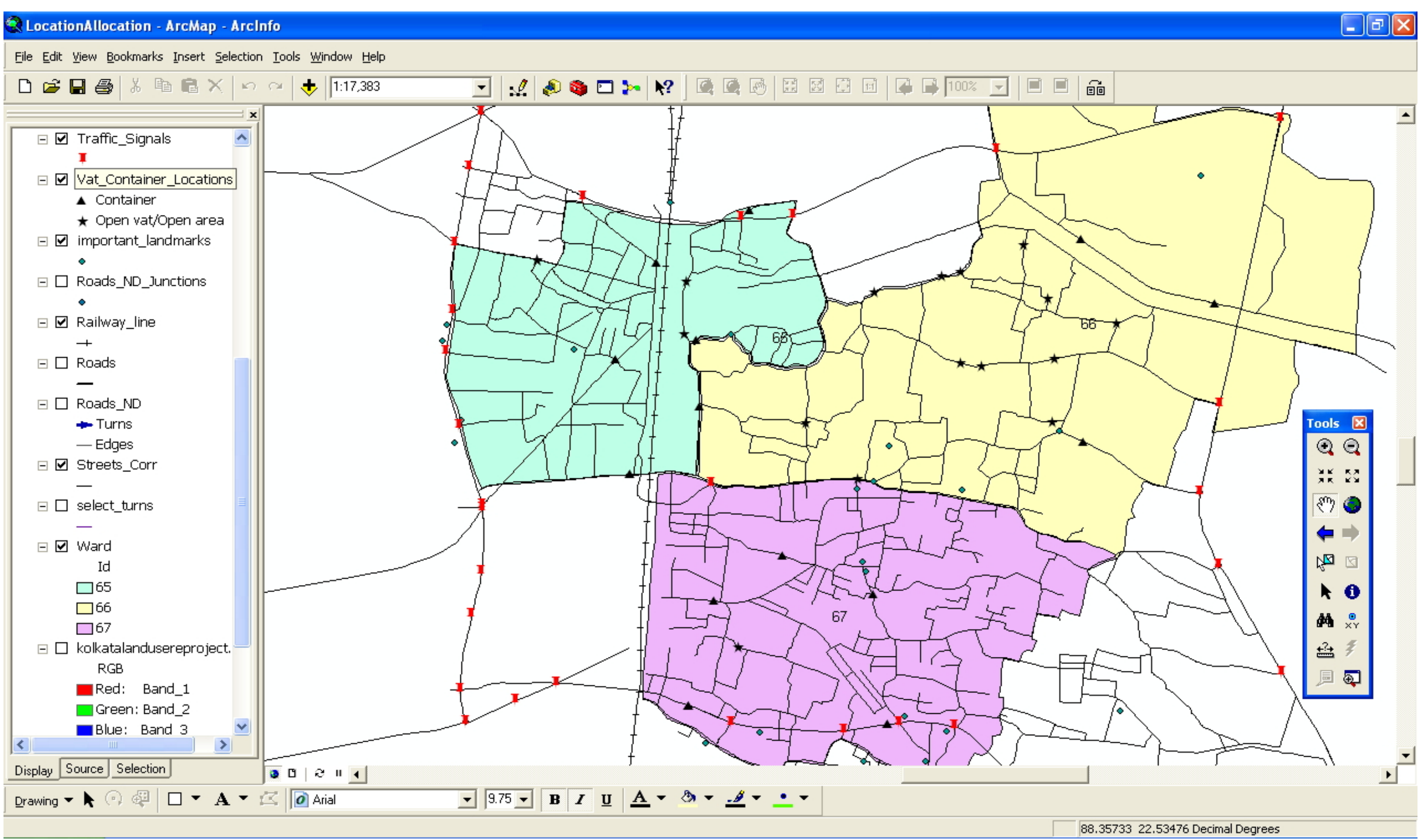

Figure 2 ArcMap file (Location_Allocation.mxd) showing different layers and the study area.

Table 3. The different fields created in Streets_Corr layer.

Name of field	Source & Purpose
OBJECTID	ArcGIS automatically assigns a particular ID to each street polyline during digitisation.
Road_Name	Name of the roads are assigned in this field.
Shape_Length	This field updates automatically during digitization of streets polylines. It stores the length of each road segment in meters.
FENAME	Same as Road_Name. This field is used during building the Network dataset.
FETYPE	Whether the street segment is Avenue/Road/Highway/Flyover/Lane.
FROM_NODE TO_NODE	These two fields store the from- and to-nodes for each road segment. This was generated automatically using ArcHydro. These two fields were used in generating turntables.
METERS	Same values as in Shape_Length field in meters.
F_ELEV T_ELEV	These fields simulate the non-planar, non-intersection of two intersecting roads, in case of a bridge/flyover.

in ArcGIS Network Analyst extension as 'Facilities'. It is assumed that each sweeper will be assigned one road of 500 m length along with adjoining houses and that houses located along both sides of the road upto a width of 250 m will be able to deposit the waste into the handcart as it whistles and passes along the road. Thus, in the Service Area Properties, Breaks were taken as 500 m and Trim Polygon length as 250 m. Network Analyst does not simply make a circular buffer of 500 m around each bin; rather it follows a road length of 500 m. This is quite justifiable, since the conservancy workers along with handcarts will be traveling along the roads only.

Service areas for corrected location of open vats/ containers

To make all the parts of the study area serviceable,some of the bins need to be relocated, or deleted while a few new container locations need to be added. Since KMC currently wants to convert open vat points to containers, the researchers have assumed all new bin locations as containers. Also, preference has been given to existing vat/container locations as it is, without shifting them- since, the existing location is assumed to be convenient to both municipal staff as well as local residents. However, a few vats/containers have been shifted so as to optimise and economise the overall process. During the analysis, it was ensured that the entire study area is covered by the service area of the minimum number of bin locations as far as possible- even if it implies that two neighbouring service area polygons overlap at certain places.

The following attribute data were then attached to the optimised vat location polygon layer to link spatial data with non-spatial attributes (**Table 4**).

RESULTS AND DISCUSSION

A large portion of the study area remains unserviced under the existing system (**Figure 3**). It revealed that the vat /container locations are non-uniformly spaced; some of them are very close to each other, while some are considerable distances apart. This has resulted in under-utilisation of some bins, overflowing in others, while some portions of the study area were found to be beyond the service of waste bins and handcarts.

Service Area analysis by Network Analyst shows that the entire study area can be brought under the service of conservancy staff, with the increase in the number of bin locations from 35 to just 36. 16 of these are new container locations, while some existing locations need to be closed. The modified vat/container location facilities and the service areas of each has been found out - the optimised locations identified abides by the *CPHEEO* (*2000*) manual (**Figure 4**). It depicts the service area polygon for each vat/container location that has to be serviced by a conservancy staff or a group of conservancy crews. This will increase collection efficiency, prevent over/under- utilisation of waste bins and help in optimum use of available manpower. An enhanced collection efficiency of solid waste will ameliorate the environmental conditions of the city.

The locational analysis of waste bins depicts that 16 new bin locations have been added while 15 locations (mostly vats/open areas) have been closed (**Table 5**). The Service areas of three bins have changed during optimisation process. Similarly, number of bins/containers required at each location has been reworked so as to cater to the waste generation potential of their respective service areas. Sizes of skip/container to be placed at the new locations may be finalised keeping in mind the haulage (haulage of the container to landfill site) frequency of the respective bins. A few open vats in Ghulam Gilani Khan Road – Topsia area are recommended to be kept as it is, keeping in view of the narrow roads in those areas, which deter movement of Dumper-Placers used for transporting skips/containers. As has been correctly pointed out by *Hazra and Goel* (*2009*), the final bin locations are to be decided considering vehicle

Table 4. Attribute data generated in attribute table after analysing and optimising bin locations.

Name	Address of the vat/container location.
Area_sqm	ArcGIS calculates the areas of each service area polygon.
Ward_no	Ward no. of each container location is input.
was_sqm	Waste generated per day in KMC area at present (year 2014) is assumed as 0.491 kg capita^{-1} d^{-1} (*Paul, Dutta and Krishna 2014*). Population of wards 65, 66, 67 are 80098, 70179, 54380 respectively (*Census 2001*) and area of wards 65, 66, 67 are 1352051.92181 m^2, 3398330.31364 m^2 and 1836720.48955 m^2 respectively. From these data, waste generated (in kg) m^{-2} d^{-1} (was_sqm) has been calculated.
cum_waste	Cumulative waste (in tons d^{-1}) generated in each polygon area. This is calculated by multiplying was_sqm by respective polygon area.
correc_cum	correct_cum values are adjusted cum_waste values considering each polygon has area(s) overlapped with the neighbouring polygon(s). Simultaneously, actual waste generation rates in each bin as per 2005 KMC records (*ADB 2005*) were also taken into consideration. Predicting the corrected values of solid waste generated (correc_cum) in each polygon area is a challenging task, since certain areas in wards 65, 67 have low population density while some pockets in ward 66 have high population density. Also, socio-economic condition in the study area varies throughout. Thus, solid waste generation rates vary sharply throughout the study area in particular, and KMC area, in general, and mathematically-predicted values may be wide off the mark. Generation of solid wastes is relatively less in residential areas while it shoots up in market and commercial areas. An idea of solid waste generation rates in a particular locality can only be made once municipality records are perused.
Tripsperd	Density of waste in the handcarts has been taken as 600 kg m^{-3}. Knowing the dimension of the handcarts, total weight of solid wastes transferred to the bins per trip can be determined. Number of trips required per day (Tripsperd) was then calculated by dividing correc_cum by the weight of solid waste that can be transferred to the bin per trip. Based on this value, municipality engineers can decide on the number of conservancy workers needed to be attached to a particular bin location.

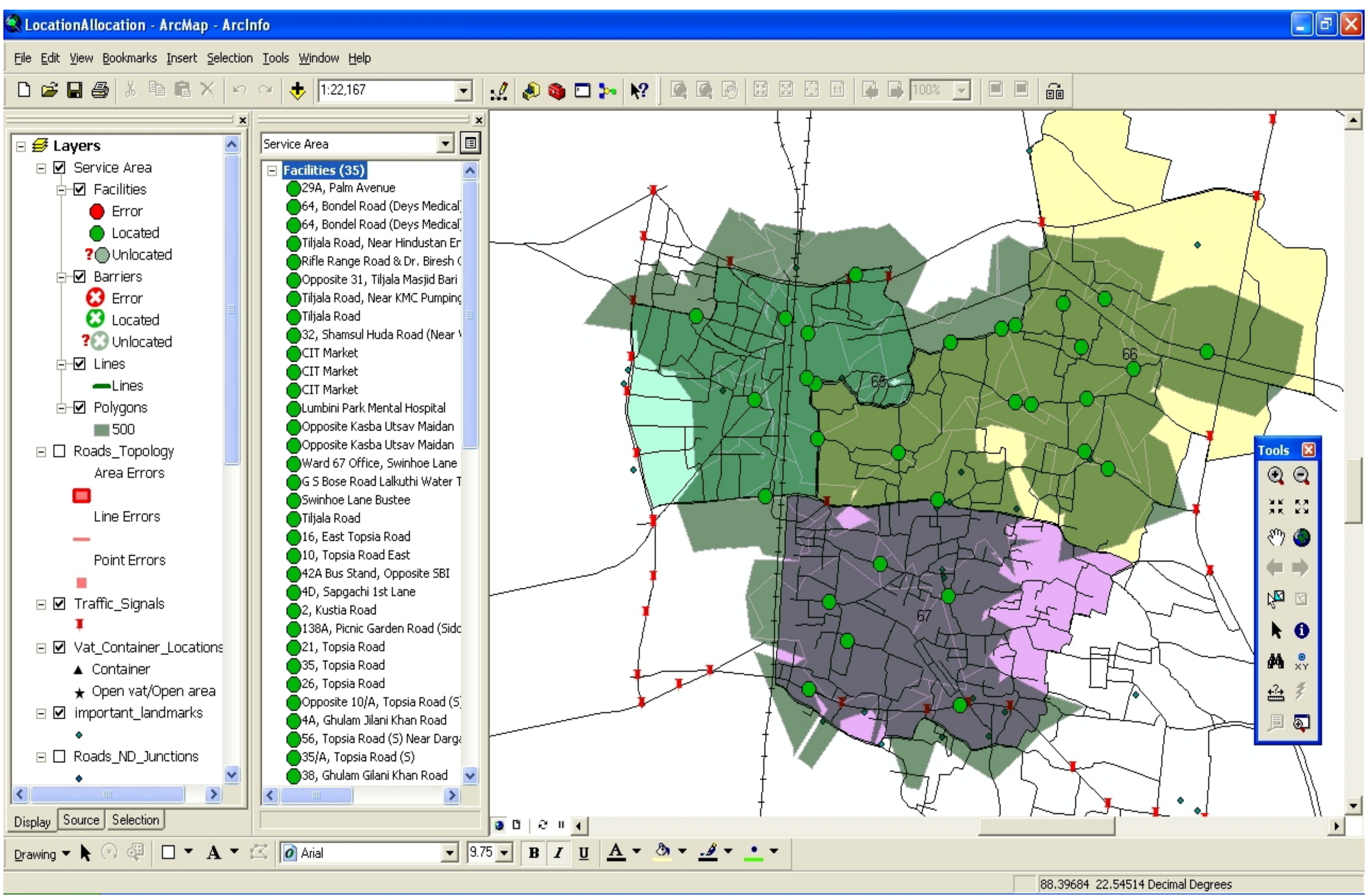

Figure 3. The Service Area (Command Area) of each container/vat location.

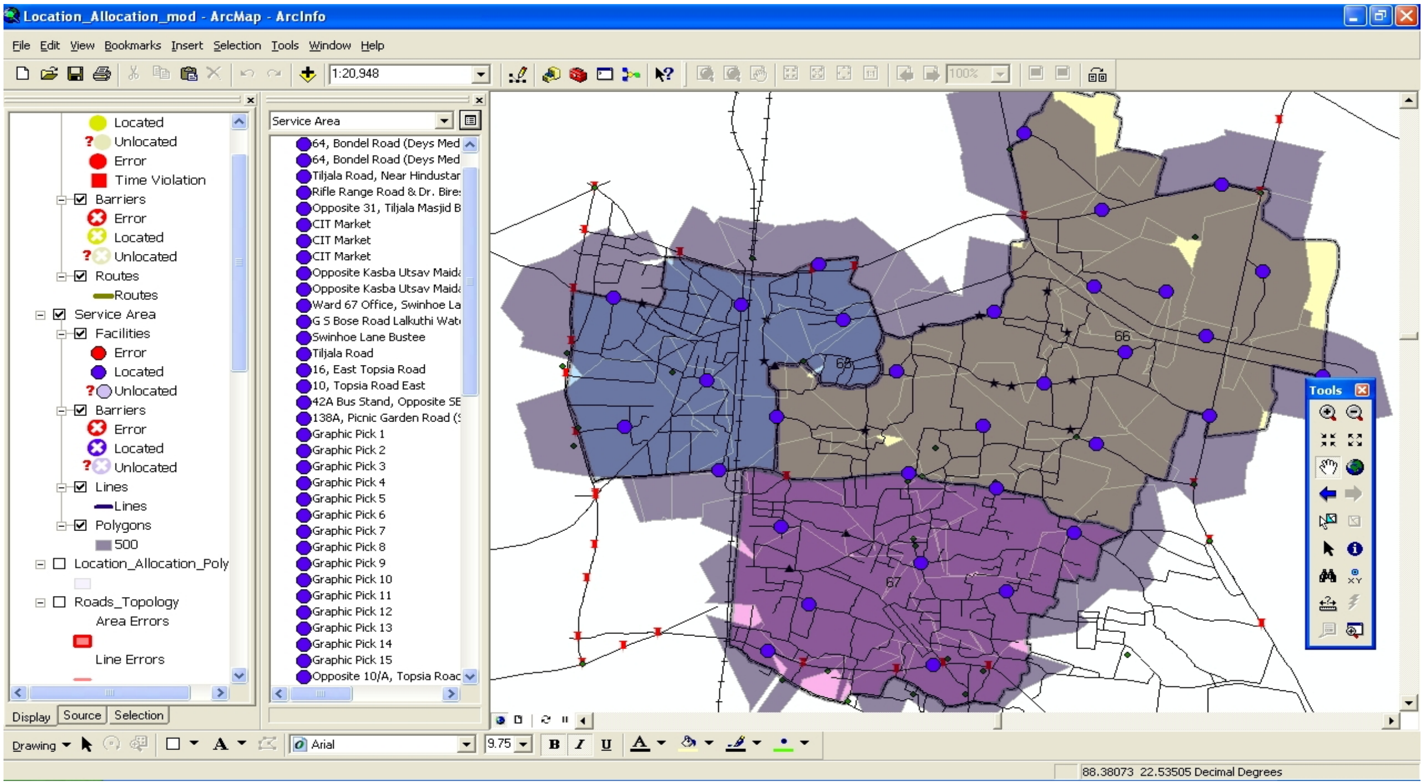

Figure 4. The optimised open vat/container location facilities and each service areas.

Table 5. Bin locations before and after optimisation.

Loc. No.	Name	AREA_ SQM (old)	AREA_ SQM (re-vised)	WAS_ SQ Mckg m^{-2} d^{-1}	CUM_WASTE (t d^{-1})	CORREC _CUM (t d^{-1})	Existing Capacity	Recommendations Assuming Daily Collection of Waste
1	29A, Palm Avenue	518885.594	518885.594	0.029	15	3.00000	2MT capacity skip/ container; 01 no.	02 skips to be placed
2	64, Bondel Road (Dey's Medical)	454316.625	454316.625	0.029	0.5X(13.175)= 6.5875	2.19000	2MT capacity skip/ container; 01 no.	Total 03 skips to be placed.
3	64, Bondel Road (Dey's Medical)	454316.531	454316.531	0.029	0.5X(13.175)= 6.5875	2.19000	2MT capacity skip/ container; 01 no.	
4	Tiljala Road, Near Hindustan Engineering Industries & VVF	477620.906	477620.906	0.029	13.85	3.00000	2MT capacity skip/ container; 01 no.	02 skips to be placed
5	Rifle Range Road & Dr. Biresh Guha Street Crossing	524310.188	524310.188	0.029	15.2	3.04000	2MT capacity skip/ container; 01 no.	02 skips to be placed
6	Graphic Pick 16 (88°22'41.215"E 22°32'11.886"N)		396588.281	0.029	11.5	3.00000	New container location proposed	02 skips to be placed
7	CIT Market	225375.703	225375.703	0.0145	3.28	2.00000	2MT capacity skip/ container; 01 no.	
8	CIT Market	Market Waste	Market Waste	Market Waste	Market Waste	2.00000	2MT capacity skip/ container; 01 no.	Total 03 skips to be placed
9	CIT Market					2.00000	2MT capacity skip/ container; 01 no.	
10	Opposite Kasba Utsav Maidan	438057.906	438057.906	0.0145	0.5 X(6.351)= 3.1755	1.59000	2MT capacity skip/ container; 01 no.	Total 02 skips to be placed
11	Opposite Kasba Utsav Maidan	502278.781	502278.781	0.0145	0.5X(7.28)= 3.64	1.82000	2MT capacity skip/ container; 01 no.	
12	Ward 67 Office, Swinhoe Lane	5062866.49	394726.375	0.0145	5.723	1.43000	2MT capacity skip/ container; 01 no.	01 skip to be placed
13	G S Bose Road Lalkuthi Water Tank	425223.219	425223.219	0.0145	6.616	4.00000	2MT capacity skip/ container; 01 no.	02 skips to be placed
14	Swinhoe Lane Bustee	567278.875	567278.875	0.0145	8.225	2.50000	Open Vat (protected) 5MT	Open Vat (protected) 5MT
15	Tiljala Road	368262.969	368262.969	0.029	10.68	3.56000	2MT capacity skip/ container; 01 no.	02 skips to be placed

Table 5. Bin locations before and after optimisation. (cont.)

Loc. No.	Name	AREA_ SQM (old)	AREA_ SQM (revised)	WAS_ SQ Mckg m^{-2} d^{-1}	CUM_ WASTE (t d^{-1})	COR-REC _CUM (t d^{-1})	Existing Capacity	Recommendations Assuming Daily Collection of Waste
16	16, East Topsia Road	384507.875	384507.875	0.01	3.84	0.96000	2MT capacity skip/container; 01 no.	01 skip to be placed
17	10, Topsia Road East	442426.750	442426.750	0.01	4.4	2.00000	2MT capacity skip/container; 01 no.	01 skip to be placed
18	42A Bus Stand, Opposite SBI	471021.12	494794.406	0.01	4.947	1.00000	2MT capacity skip/container; 01 no.	01 skip to be placed
19	138A, Picnic Garden Road (Siddhivinayak Timber Works)	445124.063	445124.063	0.01	4.451	1.48000	Open Vat (protected) 5 MT	Open Vat (protected) 5MT
20	Graphic Pick 1 (88° 22'1.34" E, 22° 32"16.16"N)		550446.188	0.029	15.96	3.99000	New container location proposed	02 skips to be placed
21	Graphic Pick 2 (88° 22' 2.977" E, 22° 31" 52.972"N)		459797.125	0.029	13.33	3.33000	New container location proposed	02 skips to be placed
22	Graphic Pick 3 (88° 22' 50.63" E, 22° 32" 2.551"N)		490245.313	0.01	4.902	2.45000	New container location proposed	02 skips to be placed
23	Graphic Pick 4 (88° 23' 21.374"E, 22° 31" 33.534"N)		471207.875	0.0145	6.832	1.70800	New container location proposed	01 skip to be placed
24	Graphic Pick 5 (88° 23' 9.439"E, 22° 31"23.169"N)		334845.063	0.0145	4.855	1.21375	New container location proposed	01 skip to be placed
25	Graphic Pick 6 (88° 23' 7.889"E, 22° 31"41.536"N)		488238.344	0.01	4.88	0.70000	New container location proposed	01 skip to be placed
26	Graphic Pick 7 (88° 23' 5.571"E, 22° 31"52.651"N)		390832.719	0.01	3.908	0.55000	New container location proposed	01 skip to be placed
27	Graphic Pick 8 (88° 23' 16.286"E, 22° 32" 0.317"N)		406123.406	0.01	4.06	2.00000	New container location proposed	01 skip to be placed
28	Graphic Pick 9 (88° 23' 45.293"E, 22° 31"54.168"N)		537114.688	0.01	5.371	1.07420	New container location proposed	01 skip to be placed
29	Graphic Pick 10 (88° 23' 26.9"E, 22° 32"31.002"N)		376195.563	0.01	3.76	0.94000	New container location proposed	01 skip to be placed
30	Graphic Pick 11 (88° 23' 47.729"E, 22° 32"35.53"N)		517265.344	0.01	5.17	1.72000	New container location proposed	01 skip to be placed
31	Graphic Pick 12 (88° 23' 13.292"E, 22° 32"45.199"N)		417136.000	0.01	4.17	2.00000	New container location proposed	01 skip to be placed
32	Graphic Pick 13 (88° 23' 37.642"E, 22° 32"16.334"N)		239101.516	0.01	2.39	2.00000	New container location proposed	01 skip to be placed
33	Graphic Pick 14 (88° 24' 4.846"E, 22° 32"1.5"N)		324454.406	0.01	3.244	1.08130	New container location proposed	01 skip to be placed
34	Graphic Pick 15 (88° 23' 54.752"E, 22° 32"20.15"N)		413249.969	0.01	4.13	1.37600	New container location proposed	01 skip to be placed
35	Opposite 10/A, Topsia Road (S)	488407.51	427214.500	0.01	4.27	2.13500	Open Vat 1.5 MT	02 skips to be placed
36	38, Ghulam Gilani Khan Road	159447.250	159447.250	0.01	1.59	0.75000	Open Area; narrow road	Open Vat
37	Lumbini Park Mental Hospital	542169.44					2MT capacity skip/container; 01 no.	To be closed
38	32, Shamsul Huda Road (Near Ward 65 Office)	471219.67					Open Vat	To be closed
39	32, Shamsul Huda Road	471219.67					Open Vat	To be closed
40	4D, Sapgachi 1st Lane	480973.15					Open Vat	To be closed
41	2, Kustia Road	481760.92					Open Vat	To be closed
42	21, Topsia Road	326114.65					Open Vat	To be closed
43	35, Topsia Road	314015.27					Open Vat	To be closed
44	26, Topsia Road	346079.99					Open Vat	To be closed
45	4A, Ghulam Jilani Khan Road	396476.56					Open Area	To be closed
46	56, Topsia Road (S) Near Dargah Iftakhariya	418017.34					Open Area	To be closed
47	35/A, Topsia Road (S)	357323.06					Open Area	To be closed
48	59, Gulam Jilani Khan Road	390971.64					Open Area	To be closed
49	Tiljala Road, Near KMC Pumping Station	377335.82					Open Vat	To be closed
50	Tiljala Road	484149.97					Open Vat	To be closed
51	Opposite 31, Tiljala Masjid Bari Lane	459554.01					2MT capacity skip/container; 01 no.	To be closed

[c] WAS_SQM is calculated based on AREA_SQM(revised) values.

accessibility, population density or rate of waste generation in the local service area. Similarly, in the recent years KMC has set up quite a few protected (enclosed by brickwork/ grille and asbestos-roofed) vats in wards 66 and 67. These newly-built protected vats are also recommended to be left untouched.

CONCLUSIONS

It is estimated that KMC currently spends around Rs. 400 crores (1 crore = 10 million, 1 U.S. $ = Rs.65 approx.) per year on SWM – of which a major portion is devoted to collection of MSW. Although, investment in solid waste management does not require a justification in terms of profit or loss, nevertheless, considering the mammoth size of investment, the authors find it appropriate to look into the different technologically feasible options to increase the collection efficiency of the solid waste system. The paper shows that GIS as a tool assists in optimising the location of bins thus helping to design an efficient and cost-effective solid waste management. Service area of a bin (vat or container) can be determined using Network Analyst extension of ArcGIS software. Further, the quantity of waste generated within the service area of each bin, number of handcart trips required to collect waste from the service area to the assigned bin, size of bins, haulage frequency, and conservancy staff needed to cater to each bin location can be estimated based on this method. This will inevitably lead to better planning, better manpower and infrastructure utilisation and cost reduction. KMC proposes to bring 100% of its households under door-to-door collection from the present 70%-80%; under such circumstances optimising of bin location becomes much more relevant.

Periodic reviewing, accessing and updating spatial and attribute data of the bins related to their storage capacity, collection frequency and transportation is required to be maintained to evaluate the status of SWM practices from to time. The GIS generated reports can also be utilised by the municipality to record the status of the bins (cleared/ uncleared), number of trips made in a day, attendance of sanitary workers, quantity of waste deposited at the transfer station, etc. on a real-time basis. This will allow greater transparency in operations and accountability at the time of public grievances.

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