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Location/allocation of waste bins using GIS in Kolkata Municipal Corporation area

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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 urbanisation. Kolkata city, with an area of 187.33 sq. km and a population of about 10 million (including a floating population of about 6 million), generates about 3500 MT (Metric Tonnes) of solid waste per day. Daily disposal rate of solid waste at Dhapa exceeds 3000 MT/day while at Garden Reach the disposal is 100-150 MT/day. 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 paper examines GIS application in assisting locational analysis of waste bins in Kolkata and optimise the overall solid waste collection process.

I. INTRODUCTION

With rapid industrialisation and urbanisation, increasing population, limited urban space, solid waste management has become an issue of major concern — more so in developing countries which have access to limited fund, resources and technical manpower. Kolkata (latitude 22° 33´ North and longitude 88° 30´ East) has an area of about 187.33 sq. km and a population of about 10 million (including floating population). KMC is responsible for solid waste management within the city. KMC area comprises of 15 boroughs and 141 electoral wards (till 2015); each borough consisting of a cluster of wards. KMC area currently generates a total of about 3500 MT of solid waste per day. 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 (Chattopadhyay *et al*., 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.

Total collection points in the city is around 650 with 365 mild-steel MS skips/containers, 20 direct loading, and 265 open vat points (Chattopadhyay et al., 2009). KMC proposes to convert open vats to closed container systems gradually. Skips/Containers are of two sizes – Normal (4.5 m3) and Big (7 m3). Figure 1 illustrates container/skip (big), an open vat and a semi-enclosed vat.

The conservancy workers commence their work at 5-30 AM and continue till 12-00 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.

Fig. 1 Figure showing container (big), one open vat and a semi-enclosed vat.

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 per day. 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 *et al.*, 2009).

II. LITERATURE REVIEW

The present study was carried out with the objective of identifying optimised location and appropriate number of storage bins. While reviewing the existing system, the authors felt that the solid waste 'mismanagement' is more to be blamed than the work negligence on part of KMC. Data related to SWM (like waste generation, population, conservancy staff and vehicles data) should be available on a single platform so that proper logistic management and spatial planning can be executed. Researchers around the world are successfully applying GIS to assist engineers in locating suitable landfill site, locating waste bins, creating databases and their management, linking spatial data with non-spatial attributes like demography, socio-economic data and routing/scheduling of collection vehicles. Ghose et al. (2006) had proposed three types of waste bins compatible with the three different types of vehicles available with Asansol Municipal Corporation, West Bengal, 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. Vijay et al. (2008) tried to optimise bin locations considering the distance between the bins and proximity to the households. Sheikh Moiz Ahmed (2006) had considered the land-use of the study area marking the location of schools, hospitals, cinema halls and religious buildings, natural streams. Illeperuma and Samarakoon (2010) 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 100m service area polygons (using Network Analyst of ArcGIS) and ensuring the entire study area is covered by the service polygons.

Finally bin sizes were determined considering the waste volume generated from each service area. Kyessi and Mwakalinga (2009) have determined bin locations considering optimised route of the collection vehicles for Dar-es-Salam city, Tanzania.

Unfortunately, for KMC area, the vehicle and bin/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 authors in this paper had taken three contiguous KMC wards – 65, 66, 67 as their study area to showcase the effectiveness of GIS in bin location.

III. MATERIALS AND METHODS

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 ameliorate 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. 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. Attribute fields of 'Streets_Corr' layer were developed (Table 1). Figure 2 depicts the different layers developed in the ArcMap file for the study area.

Table 1. Table showing 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.

Service areas for existing open vats/ containers: Central Public Health & Environmental Engineering Organisation (CPHEEO) Manual (2000) suggests that in thickly populated areas, 250-350 metres of running road length along with adjoining houses may be given to each sweeper, whereas in less congested areas 400-600 metres of road length with adjoining houses may be given to each sweeper. In low density areas, 650-750 running metres of road length and houses can be allotted. CPHEEO, 2000 also stipulates that vat/containers/depots should be at a distance not exceeding 250 metres from the place of work of sweepers and the distance between two bins should not exceed 500 m. The 35 existing bin locations within the study area were loaded in Network Analyst extension as 'Facilities'. It is assumed that each sweeper will be assigned one road of 500 metres length along with adjoining houses and that houses located along both sides of the road upto a width of 250 metres 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 metres and Trim Polygon length as 250 metres. Network Analyst does not simply make a circular buffer of 500 m around each bin; rather it follows a road length of 500 m.

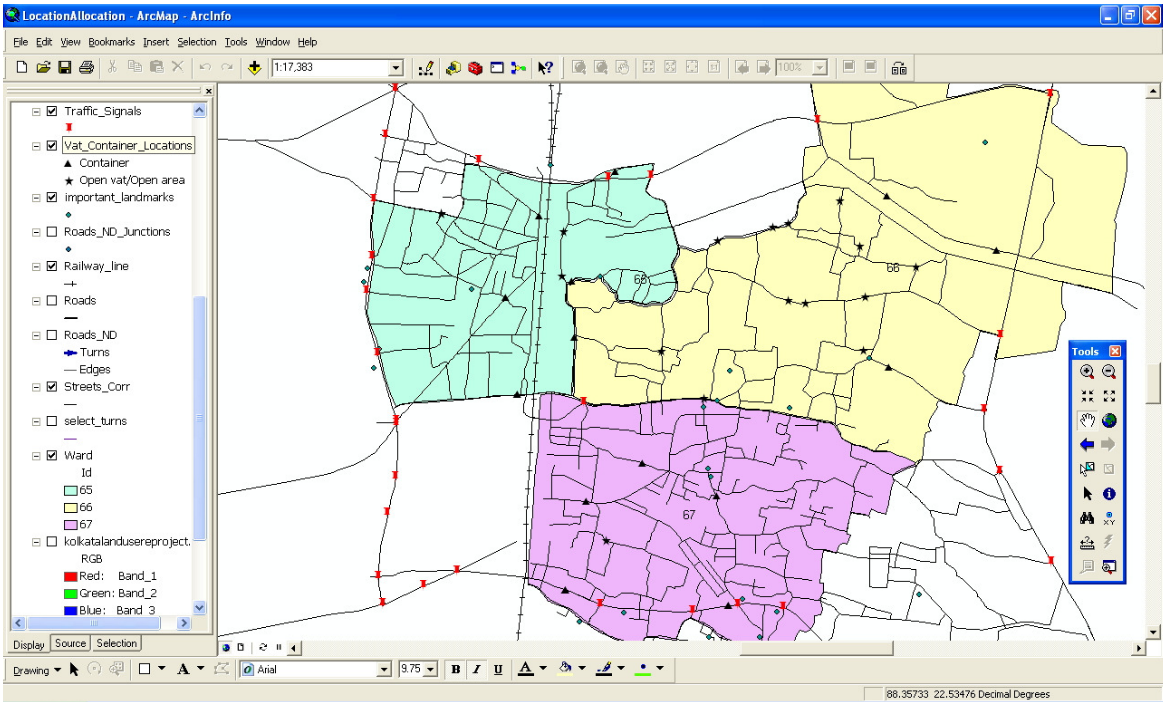

Fig. 2 ArcMap file (Location_Allocation.mxd) showing different layers and the study area.

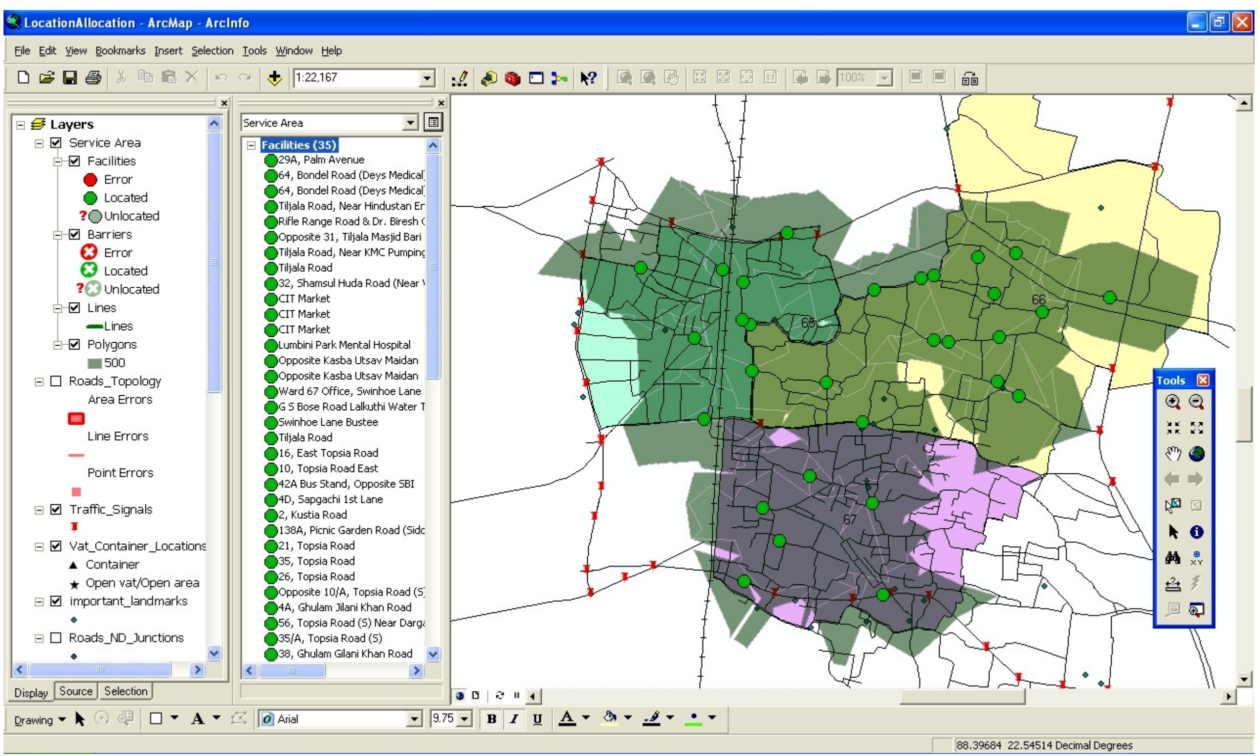

Fig. 3. Figure showing the Service Area (Command Area) of each container/vat location.

This is quite justifiable, since the conservancy workers along with handcarts will be traveling along the roads only. Figure 3 shows the Service Area (Command Area) of each existing container/vat location. It is seen that a large portion within the study area remains unserviced.

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. Service Area analysis by Network Analyst shows that the entire study area can be serviced by 36 open vats/container locations. 16 of these are new container locations, while some existing locations need to be closed. Figure 4 illustrates the modified open vat/container location facilities and the service areas of each.

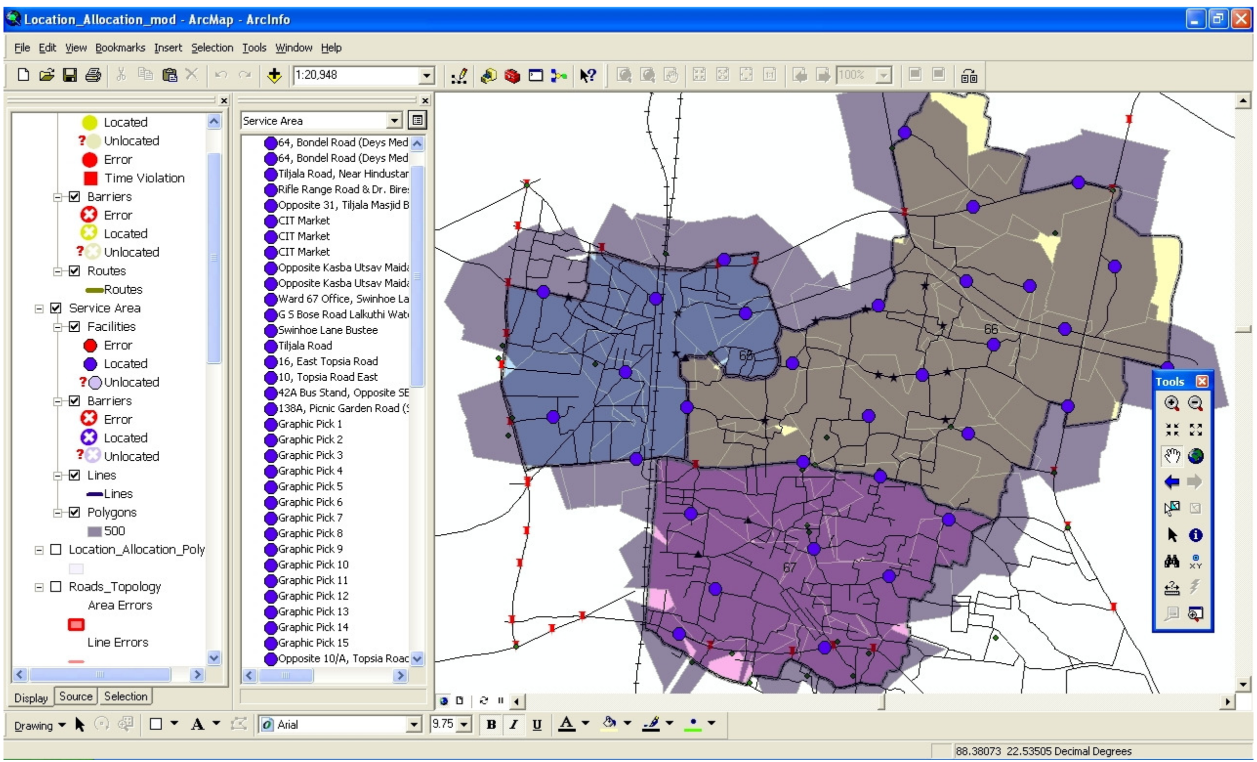

Fig. 4. Figure illustrating the optimized open vat/container location facilities and the service areas of each.

Table 2. 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/ day (Paul et al., 2014). Population of wards 65, 66, 67 are 80098, 70179, 54380 respectively (Census, 2001) and area of wards 65, 66, 67 are 1352051.92181 sq.m, 3398330.31364 sq.m and 1836720.48955 sq.m respectively. From these data, waste generated (in kg) per sq.m per day (was_sqm) has been calculated.

Name	Address of the vat/container location.
cum_waste	Cumulative waste (in tons/day) 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.

Source: Field survey (2012).

Figure 4 shows the service area polygon for each vat/container location that has to be serviced by a conservancy staff or a group of conservancy crews. The following attribute data (Table 2) were then attached to the Polygon layer to link spatial data with non-spatial attributes.

IV. RESULTS AND DISCUSSION

A perusal of Figure 3 reveals 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. Figure 4 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. This will increase collection efficiency, prevent over/under-utilisation of waste bins and help in optimum use of available manpower.

Table 3 depicts the results of locational analysis of waste bins — 16 new bin locations have been added while 15 locations (mostly vats/open areas) have been closed. 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 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.

In many KMC wards, markets areas, residential areas and office areas co-exist together. An example of this is Loc. No. 7, 8, 9 in Table 3. An additional huge amount of bio-degradable solid waste is generated everyday due to the presence of a market there. Thus, while determining the waste generated in service area polygon, simply multiplying the area with an uniform 'was_sqm' value may mislead us, unless 'ground truth data' is verified and past KMC records are perused.

Table 3: Bin locations before and after optimization.

LOC. NO.	NAME	AREA_SQM (old)	AREA_SQM (revised)	WAS_SQM^{c} kg sqm^{-1}d^{-1}	CUM_WASTE (tons d^{-1})	CORREC_CUM (tons 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.	Total 03 skips to be placed
8	CIT Market	Market Waste				2.00000	2MT capacity skip/container; 01 no.	
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) 5 MT	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
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

LOC. NO.	NAME	AREA_SQM (old)	AREA_SQM (revised)	WAS_SQM[c] kg $sqm^{-1}d^{-1}$	CUM_WASTE (tons d^{-1})	CORREC_CUM (tons d^{-1})	EXISTING CAPACITY	RECOMMENDATIONS ASSUMING DAILY COLLECTION OF WASTE
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

LOC. NO.	NAME	AREA_SQM (old)	AREA_SQM (revised)	WAS_SQM[c] kg $sqm^{-1}d^{-1}$	CUM_WASTE (tons d^{-1})	CORREC_CUM (tons d^{-1})	EXISTING CAPACITY	RECOMMENDATIONS ASSUMING DAILY COLLECTION OF WASTE
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) value

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