Chapter 8
An Integrated Solid Waste Management (ISWM) Plan Using Google Earth and Linear Programming: A Case Study of Kharagpur City, West Bengal

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1 Introduction

Solid Waste Management (SWM) is an obligatory function of the urban local bodies (ULBs) such as a municipality. Today, ULBs in developing countries like India are creating new infrastructure for better SWM and are trying to change old and unsustainable practices. A major issue in current SWM practices in developing nations is availability of timely data and financial resources. Remote Sensing (RS) and GIS can be used together to develop an integrated solid waste management plan since RS provides spatial and temporal data readily in the form of satellite images available on the Internet and GIS allows mapping with overlays of population distribution, for locating bins, vehicle routing and facility siting. A major advantage of using RS and GIS is that they can provide accurate, inexpensive, wide-ranging and rapid results which can be further combined with other tools like linear programming. This approach has been used for various applications in several cities around the world and was reviewed by Dutta and Goel (2017).

The objective of this study was to evaluate deficiencies in current solid waste management practices in Kharagpur city and propose an integrated solid waste management plan for a cleaner city using novel methods like remote sensing (RS) and Geographic Information Systems (GIS) along with linear programming for optimal vehicle routing.

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2 Description of Study Area – Kharagpur

Kharagpur is an important city in Paschim Medinipur district of West Bengal and was established as one of India's major rail junctions in 1898. Kharagpur is located at Latitude 22.330239 °N and Longitude 87.323653 °E covering an area of about 91 km^2. It has an average elevation of 29 m (95 ft.) above Mean Sea Level.

The Kharagpur urban area consists of the Kharagpur municipal area as well as railway settlements which are not included in the jurisdiction of Kharagpur municipality (Fig. 8.1). Kharagpur municipal area has a population of 289,129 (Census of India 2011) spread over 91 km^2 area and is divided into 35 wards (Kharagpur Municipality, 2016). Based on Census data and assuming exponential growth, the population of Kharagpur Municipality in 2016 was estimated to be 314,628.

The campus of Indian Institute of Technology (IIT) Kharagpur is designated as Ward No. 30 and is inside the municipal area. The Indian Air Force has two airbases close to Kharagpur: Kalaikunda and Salua.

2.1 Generation and Characterization of Waste

Major sources of MSW in the Kharagpur area are residential areas, commercial/ market areas, government offices, hotels/restaurants, fruit and vegetable markets, and institutions. Kharagpur Municipality is responsible for the collection, treatment, and disposal of solid waste according to Indian regulations. Based on the current estimated population of Kharagpur of 314,628 and assuming a per capita waste generation rate of 0.5 kg/capita-day, the total amount of solid waste generated in Kharagpur is estimated to be 158 metric tons (MT) d^{-1}.

MSW from Kharagpur was characterized and recyclables such as plastic, paper, metals and textiles constituted 19.6% of the total MSW generated in Kharagpur (Kumar and Goel 2009). The remaining fraction (80.4%) was mixed residue, i.e., organic material mixed with soil, sand, mud and other inert materials. Mixed residue had an organic carbon content of 8.92 ($\pm$5.92) %, volatile solid content of 19.63 ($\pm$9.53) % and fixed solids content of 80.35 ($\pm$ 9.54) %. These results show the high inert content of the mixed waste which is mostly non-toxic and benign in nature. The moisture content of the waste was 42.05 ($\pm$10.05) %.

2.2 Collection and Storage of MSW

Waste from residential and commercial establishments is generally disposed of by residents in nearby community bins. The existing bins are stationary enclosures (also called vats) made up of plain concrete (Fig. 8.2). The sizes of the bins at every location are not the same, and vary depending on site and roadside conditions.

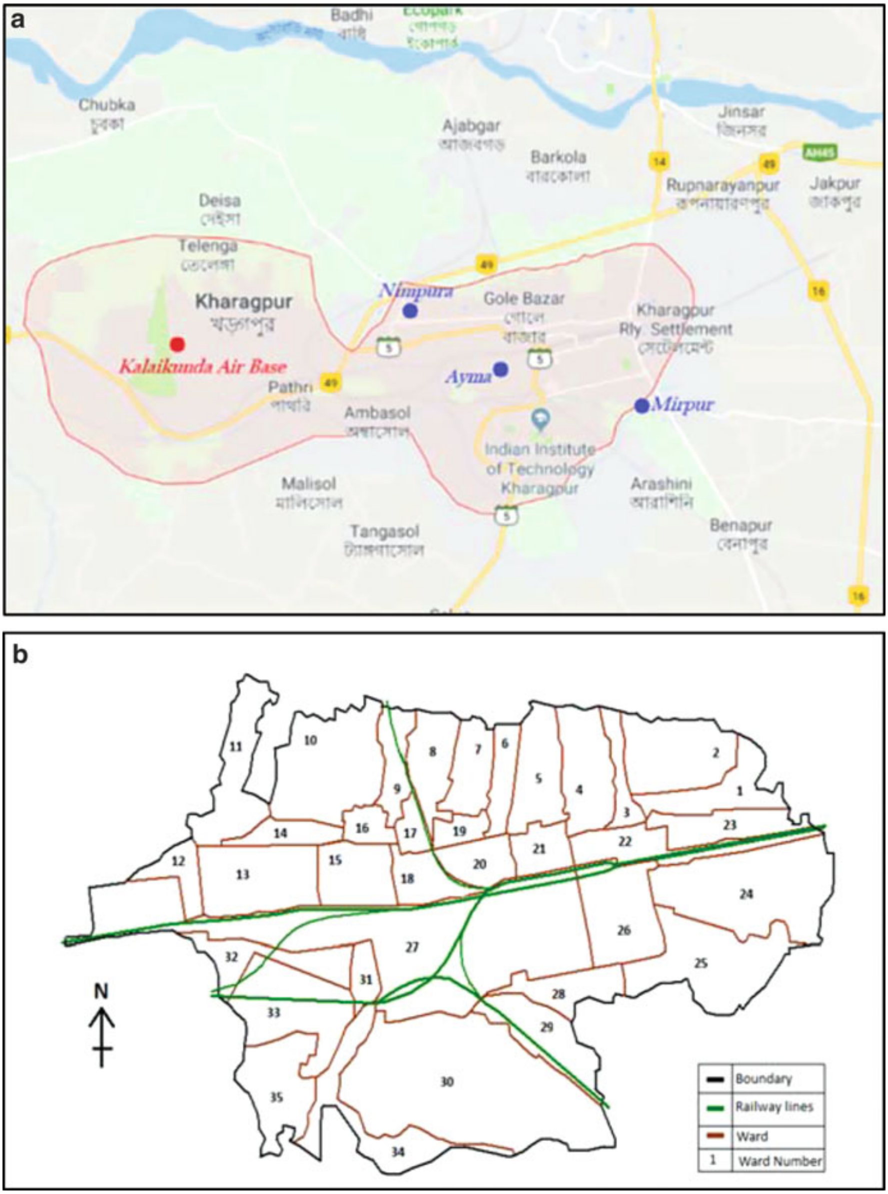

Fig. 8.1 (**a**) Map of Kharagpur with dump sites and air force base locations and (**b**) Ward-wise map of Kharagpur

Collection of waste is done by the Kharagpur municipality after every 3–4 days. Two compactor trucks and five tractor-trolleys are used to collect the waste generated in the city. Sometimes large amounts of waste are piled by the road-side and are collected using a JCB backhoe loader and loaded into a tractor-trolley. For collection

Fig. 8.2 Stationary waste containers used in Kharagpur

of waste, two compactor trucks with 5–7 labourers are deployed and each truck makes four trips a day (each trip takes approximately 2 h including loading-transportation-unloading). Generally, loading and unloading alone take more than 1 h. There are a total of 112 community vats used for waste storage at source and are made up of plain concrete. Generally, each ward has three community vats but in Wards 20, 21 and 27, more than three community vats/ward are provided. Gole Bazaar which is the biggest market area in the city lies in Wards 20 and 21 where huge amounts of market waste are generated.

2.3 Treatment and Disposal of MSW

Nimpura, Ayma and Mirpur are the three dumping sites in Kharagpur. Municipal waste is regularly dumped on open land by Kharagpur municipality. There is no MSW treatment facility or sanitary landfill in Kharagpur; all three sites mentioned above are just open dumping grounds. Soil from the Mirpur site has a considerable amount of clay and both Nimpura and Ayma have laterite morum soil.

All three sites mentioned above are within a 15 km radius of the Kalaikunda Airbase of Indian Air Force and as per Indian regulations, i.e., SWM Rules 2016, the location of any disposal site should be at least 20 km away from the runway.

3 Problems with Present MSWM Practices in Kharagpur

3.1 Source Segregation and Waste Treatment

Ideally, waste should be segregated at source into three fractions:

(i) biodegradable waste like food and yard waste,
(ii) recyclables like paper, plastics, metals and glass, and
(iii) mixed waste or non-biodegradable waste.

However, very few areas in Kharagpur have source segregation of waste and the collection trucks are not designed for the collection of segregated waste which requires more than one compartment. Generally, all waste collected by the Municipality is unsegregated and is crudely dumped on open ground without any treatment. The absence of source segregation makes the treatment of waste very difficult and expensive.

3.2 Underestimation of Per Capita Waste Generation Rates

Kharagpur Municipality had estimated the average per capita generation rate to be 350 g/capita-day in 2007 (Kharagpur Municipality). They continue to use this estimate for designing their collection systems resulting in underestimation of collection equipment (containers and vehicles) requirements and inadequate collection (around half of the waste generated in Kharagpur is left uncollected daily). Uncollected waste results in health and odour problems, choking of storm water drains, and overflowing dustbins.

3.3 Collection

There are two major issues with waste collection in Kharagpur:

Bin location and design: Door-to-door collection is not provided in Kharagpur as is the case in many other cities like Kolkata, Ahmedabad, Mysuru, Guwahati and Surat. Waste from residential and commercial establishments are disposed by residents in nearby community bins. Current locations of the bins are not uniform, some are too far from houses and shops, and residents are often unwilling to walk a long distance in search of a bin. Further, waste is collected once every 3–4 days but bins are not designed for holding waste for this period of time. Due to all these reasons, illegal dumping of waste in the local area is common (Fig. 8.3). Stray animals are attracted to the scattered waste resulting in safety issues for residents. They also prevent municipal workers from attending to the bins and create traffic problems.

The existing bins are stationary enclosures made of plain concrete. These concrete walls break easily and currently, many of the community bins are in broken condition.

Vehicles: Kharagpur Municipality does not have enough vehicles to collect all the waste generated in the city. The present vehicles used for collection are garbage compactor trucks, mini-trucks, and tractor-trolleys. Compactor trucks are adequate for waste collection but simple cargo trucks and tractor-trolleys are not fit

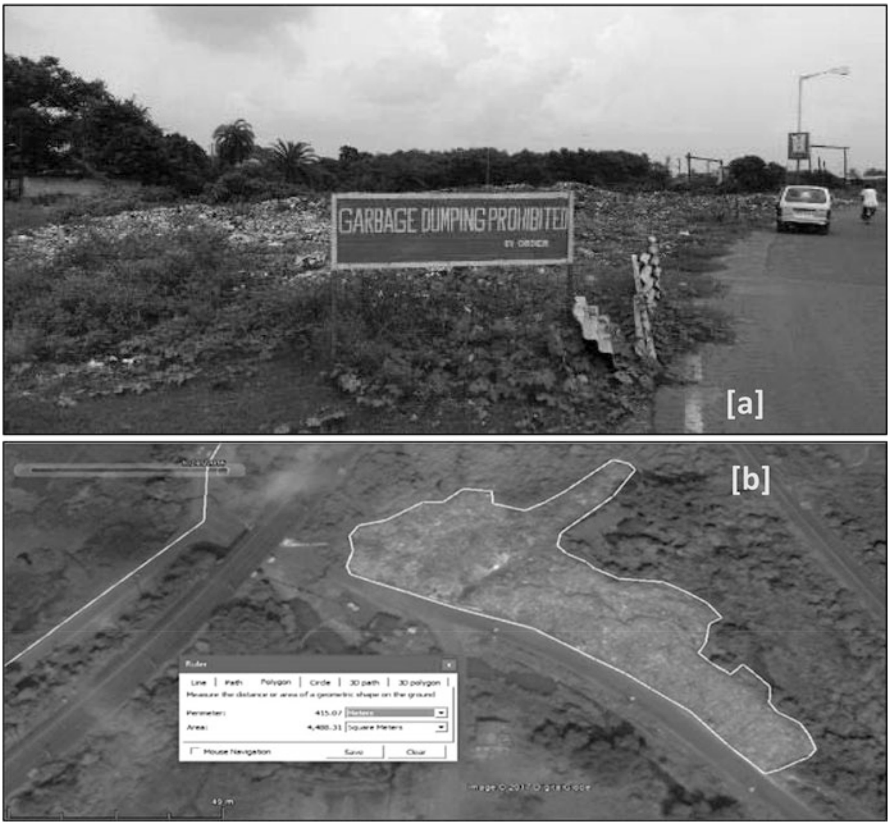

Fig. 8.3 Illegal dumping ground near IIT Kgp flyover (**a**. Dumping site, **b**. Google Earth image of the site)

for collection since they scatter waste and drip leachate (liquid coming out of biodegradable waste) while transporting waste, more so during the monsoon season. Also, most of the vehicles in current use are more than 5–10 years old and many are in deplorable condition.

3.4 Lack of Financial and Human Resources

Currently, Kharagpur municipality does not have sufficient financial and human resources to collect all the waste generated in the city. Numbers and capacities of collection vehicles and sanitary workers for waste collection are highly inadequate. The recommended benchmark for sanitary workers is 2.8 workers/1000 population (Gupta et al. 1998). An estimated 300 persons were employed as labourers in 2016 for solid waste management in Kharagpur. For the estimated population of 314,628 persons in 2016, this amounts to 0.95 workers/1000 people which is well below the benchmark. In general, municipal workers have high rates of absenteeism and low productivity, partly due to public attitude and habits. Due to lack of financial resources, the Municipality does not have enough safety equipment for workers resulting in injuries. Due to manual sweeping and use of open carts, workers are exposed to waste causing health problems among the workers (Annepu 2012). Common health problems include respiratory and skin diseases, and infections in lungs or bladder.

3.5 Dumping Sites

There is no sanitary landfill in Kharagpur and all three sites mentioned previously are open dumping grounds. Sites in Mirpur and Nimpura are located close to densely populated residential areas and are responsible for causing health and foul smell-related problems in the nearby areas. Nimpura site is located about 30 m away from a school and is very close to NH-6. Ayma is relatively better located compared to other dumpsites (nearest settlement is 500 m away from the site). According to Indian regulations, a landfill should be located at least 500 m away from any residential settlement and State/National Highway (SWM Rules 2016). Both Nimpura and Mirpur are in contravention of these rules.

All three dumpsites are located in the proximity of the Kalaikunda Airbase of the Indian Air Force and as per Indian regulations, the location of any disposal site should be at least 20 km away from the runway (SWM Rules 2016). The disposal site at Nimpura is less than 5 km away, whereas the site in Ayma is around 8 km away. The other site at Mirpur is around 13–15 km away from the runway. There are many birds flying over these dumping sites due to which many accidents have occurred due to scavenger bird hits during take-off and landing of aircrafts.

Soil from the Mirpur site has considerable amounts of fine clay which has low permeability. Hence, ground water in this area is less vulnerable to contamination due to percolation of leachate generated from the solid waste dumped at these sites. On the other hand, Nimpura as well as Ayma have laterite morum soil, which is highly permeable, thus increasing the chance of groundwater contamination due to percolation of leachate at these sites.

4 Design and Planning of SWM System for Kharagpur

An integrated MSWM plan was developed for Kharagpur using Remote Sensing and Geographical Information System (GIS). Linear programming and all available data is shown in a flowchart (Fig. 8.4).

- First, all available data relevant to the preparation of an ISWM were collected. This included preparing a digitized ward map of Kharagpur and obtaining ward-

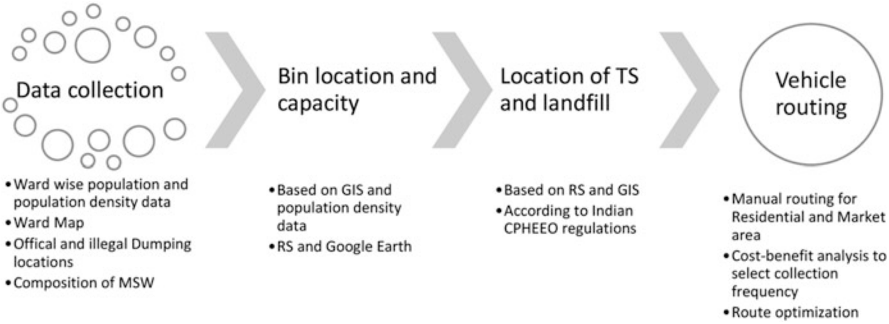

Fig. 8.4 Step-wise flowchart for developing an integrated ISWM plan for Kharagpur

wise population data. Locations of dumping sites and data regarding composition of MSW in Kharagpur were obtained from the literature. Known dumping sites were identified in satellite images and verified in a ground survey. Data regarding vehicles and labour employed were obtained from Kharagpur municipality officials.
- Second, bin location plans for residential and market area bins were developed for wards 20 and 21. Bin sizes for each area were calculated based on population density data.
- Third, siting of a transfer station and sanitary landfill was done using RS and GIS.
- Fourth, routing of garbage collection trucks in residential and market areas was optimized using linear programming and the results compared to manually drawn vehicle routes.

Google Earth Pro software and maps were used for developing the integrated solid waste management plan for Kharagpur.

4.1 Bin Location Plan and Bin Size Calculation

To solve problems related to overflowing waste bins, illegal dumping along roads and near houses and to improve the efficiency of the collection system in terms of time and fuel, adequate numbers of bins of proper size and location are required. Bin plans were developed for wards 20 and 21.

4.1.1 Methodology Used for Calculating Bin Size and Planning Bin Locations

Bin sizes and locations were determined using data from the literature and all assumptions are noted here:

- The bin size required depends on the density of MSW and the amount of waste generated alongwith a factor of safety. The density of the municipal solid waste generated in Kharagpur ranged from 250 to 500 kg/m^3 (Kharagpur Municipality, 2017). For an efficiently designed system, a per capita generation rate at the higher end and a low bulk density should be assumed (Goel 2008). So, for safety and greater efficiency even in extreme cases, 250 kg/m^3 was assumed as the density of MSW for design purposes.
- For source segregation, two bins are provided at each bin location. Both bins are placed close to each other and counted as a single bin location. One is "Mixed Waste" for storage of mixed waste and other is for "Recyclables" storage. This source segregation is applicable to both market and residential areas.
- The sizes of the 'Mixed waste' and 'Recyclables' bins in the residential areas are based on the composition of the waste generated in Kharagpur (Kumar and Goel 2009). MSW in Kharagpur has about 20% recyclables, so the size of the Recyclables bin should be 20% of the volume of the total waste brought to the bin location by the residents. The remaining 80% of the total waste, i.e., mixed residue, has to be deposited in the 'Mixed waste' bin. Therefore, the size of the mixed waste bin container should be 80% of the total waste. By using a factor of safety, additional space can be provided in the bins, and problems of overfilled bins and scattering of waste can be minimized.
- No data were available regarding the composition of waste generated in the market area in Kharagpur. Based on an on-going survey of MSW in Kolkata and Guwahati, two bins of equal capacity, i.e., 50% of the total weight of waste, were provided for the market areas.
- Based on Indian government guidelines, a bin has to be provided every 100 m (± 25) along the road (Swachh Bharat Mission 2016).
- For design purposes, the per capita waste generation rate was assumed to be 500 g/capita-day.
- Based on Census of India, 2011, the number of people per household was 5 and was used in these calculations.
- A factor of safety (FOS) of 2 was provided to avoid overloading of bins.
- Daily collection of solid waste was provided due to the high moisture content of MSW, considerable amounts of biodegradable materials in the waste and extremely hot and humid climate.
- Bins in DIG and Sub-divisional offices are assumed to be the same size as market area bins due to similar composition of the waste and are collected along with the market waste. Bin sizes provided for them are 0.5 m^3 and 1 m^3 for DIG office and Sub-divisional office, respectively.

4.1.2 Bin Location Plan

Bin location plans for ward 20 are shown in Fig. 8.5. Each node/pin represents a bin location and consists of two bins: one for 'Mixed waste' and another for 'Recyclable' waste. Green coloured nodes are for bins located in residential areas. Red and

Fig. 8.5 Bin plan for Ward 20

brown nodes with green labels are for bins in apartments. Yellow nodes represent bins in market areas. Special bins are provided with red colour node and a red label for specific locations like temples, government offices, and schools that are different from market and residential areas. Bins for temples and schools are of the same size as bins in residential areas of that ward.

4.1.3 Calculation of Size of Bins in Residential Areas

In residential areas, sizes of the bins were designed on the basis of the number of residents living within a 100 m radius of the bin location. To calculate the number of people living within 100 m radius of a bin, population and population density data for each ward was used along with GIS. Google Earth software was used to calculate the ward area and empty area in the ward (like playgrounds, open lands, and children parks). An example of a bin size calculation for a residential bin is shown below; a factor of safety of 2 was assumed in all calculations.

Bin size calculation for Ward 20 *(represented by green pin on bin plan)*
Population of Ward 20 = 8543
Area of ward = 879,368 m^2
Empty area = 152,000 m^2
Populated area = 727,368 m^2
Area of circle with 100 m radius = 31,400 m^2/bin

(continued)

Population per 100 m radius circle = (8543/727,368) × 31,400 = 370 persons/bin (approximately)
Total waste generated = 370 × 0.5 kg/person-day = 185 kg/day
Total volume of waste, assuming bulk density of waste is 250 kg/m^3 = 185 (kg/d)/250 (kg/m^3) = 0.74 m^3/d
Size of mixed waste bin = 0.74 × 0.8 × 2 (FOS*) =1.184 → 1.25 m^3 **
Size of recyclables bin = 0.74 × 0.2 × 2 (FOS*) = 0.296 → 0.5 m^3 **
*FOS is a factor of safety for the bin
**The final size of bin will be the larger available bin size

Therefore for Ward 20, the bin size is 1.25 m^3 for mixed waste and 0.5 m^3 for non-biodegradable waste bin. For Ward 21, the sizes required are 1.6 m^3 for mixed waste and 0.5 m^3 for non-biodegradable waste, respectively. Bins greater than 100 L capacity are too large and too heavy compared to common household bins. So, mechanical lifting is essential for emptying large bins into the garbage collection truck. Large bins can be substituted by two or more smaller bins.

There are some apartment buildings in Ward 20. Apartment bins have different sizes compared to other bins in the ward. There are a total of 20 apartment buildings having six floors and 20 buildings having three floors. Bin sizes for mixed waste in 3-storey and 6-storey apartment buildings were estimated using the same method and found to be 0.6 m^3 and 1.0 m^3 while sizes for recyclables bins were the minimum available size of 0.25 m^3 in both types of buildings.

4.1.4 Calculation of Size of Bins in Market Area

The methodology for designing bins for the market area is different from a residential area because the amount and composition of waste generated in the market are different from waste generated in residential areas. About one-third of the total waste generated in the city is commercial waste, i.e., 52.4 MT/day. Gole Bazar is the main market of Kharagpur city and it contributes about half of the total market waste generated in the city. Gole Bazar is located along the boundary dividing wards 20 and 21. In the bin location plan, 42 bins are located in the market area. Sizes of the bins were calculated by dividing the total waste generated in Gole Bazar by the total number of bins in the market area (with FOS). The composition for source segregation is taken as 50% recyclables and 50% mixed waste.

Total commercial waste in Kharagpur = 52.4 MT
Gole Bazar is the biggest market in Kharagpur and contributes 50% of the total commercial waste in the city
Waste generated in Gole Bazar = 26.2 MT/day

(continued)

There are 42 bin locations in Gole Bazar,
Therefore, the weight of waste in each bin location $= 26.22 \times 10^3/42 = 624.29$ kg/day
Volume of waste in each bin location = (624.29 kg/day)/(250 kg/m^3) = 2.5 m^3
Size of mixed waste bin $= 2.5 \times 0.5 \times 2$ (FOS) = 2.5 m^3
Size of recyclables bin $= 2.5 \times 0.5 \times 2$ (FOS) = 2.5 m^3

4.2 Site for Transfer Station (TS) and Landfill

As per recent SWM Rules 2016, if disposal sites are more than 15 km away from the collection area, it is economical to set up transfer stations to save transportation time and fuel (MSWM Manual, CPHEEO 2016). The maximum distance within the collection area to the landfill is from Ward 12 which is around 23 km and a transfer station is likely to be cost-effective.

A site was identified for a transfer station using Google Earth Pro and confirmed by a site visit. The site selected is located near the centre of the city with an area of 1.0 hectare (Fig. 8.6). This will help in decreasing collection costs by reducing travelling time and distance from the service area to the landfill. Also there is extra space available to construct Material Recovery Facility (MRF) to segregate recyclable or there is enough space available to build a treatment facility like a bio-gas or a compost plant (Outlined in yellow colour in Fig. 8.6).

The transfer station site is adjacent to a railway line allowing transfer of recyclables to other cities for treatment. The selected site is about 1 km away from State Highway (SH-5) and 8.6 km away from Kolkata-Mumbai highway (NH-49). Due to proximity from SH-5, heavy vehicles can be used for transportation of waste from

Fig. 8.6 Site for transfer station

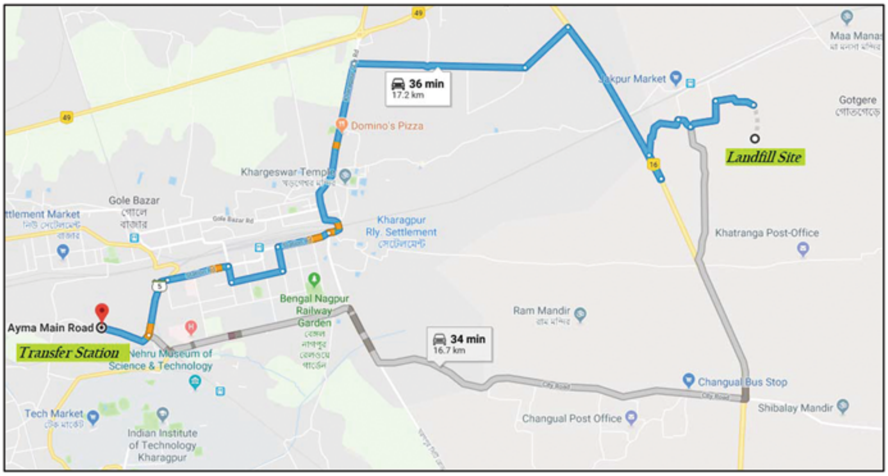

Fig. 8.7 Route from transfer station to landfill (17.2 km route length)

transfer station to landfills resulting in reduced transportation costs by reducing the number of trips (Fig. 8.7).

4.3 *Landfill Size Calculation and Site Selection*

The next step was to find a suitable location for the landfill. River Kansabati lies to the north of the city and on the west side of the city is the Kalaikunda Airbase of the Indian Air Force. Further, there are villages and vegetation on unused land to the south of the city. So, the only option left for a landfill site is to the west of the city as shown in Fig. 8.8.

The current site was selected according to CPHEEO guidelines of the Indian government and is at a considerable distance from the city to provide for future expansion (Fig. 8.8). Assumptions made for selecting the landfill site and calculating its size are:

- The landfill site is designed for filling of waste for 20 years.
- Only 15% of the total waste collected will be landfilled.
- The per capita waste generation rate is assumed to be constant over a period of a year. The literature shows that as economic conditions of the region or country improve, living standards of the people also increase resulting in higher per capita waste generation rates (Goel 2008). Therefore, it is assumed that per capita waste generation rate increases by 1.5 times every decade. So, in 20 years it will be three times the current per capita waste generation, i.e., in 2017, and is likely to increase to a maximum of 1.5 kg/capita-day.
- To calculate waste generated in each year, population data are needed. So, exponential growth rate method was used for population forecasting.

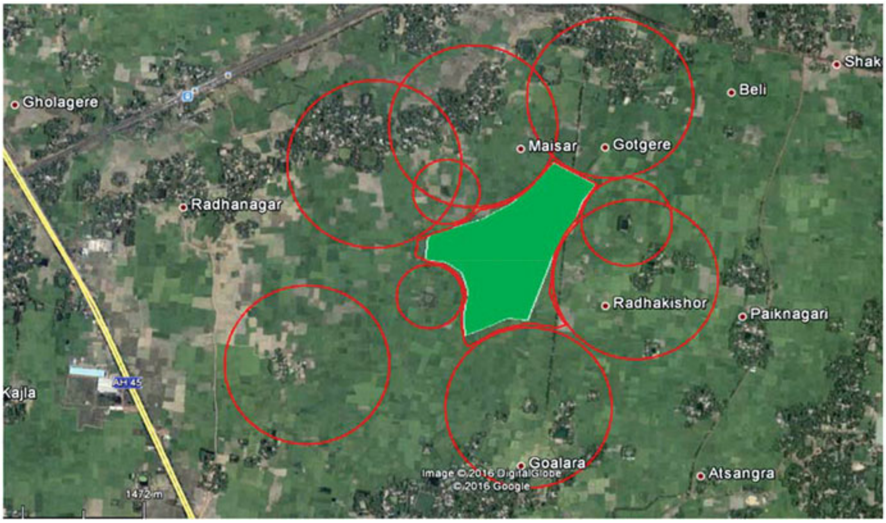

Fig. 8.8 Site for landfill based on regulations (larger circles are of radius 500 m and smaller circles are of radius 300 m showing site is minimum 500 m and 300 m away from residential areas and ponds, respectively)

- Due to shallow groundwater depth, height of the landfill is assumed to be 10 m of which 5 m is below and 5 m above the ground level.
- The landfill area used for design is 1.2 times the required area. In the extra 20% area, 10% extra is provided for buildings, roads, monitoring labs, leachate treatment plant and 10% extra area is provided as per CPHEEO guidelines.

The total waste generated in 20 years is estimated to be approximately 2.7 million metric tons of which 0.4 million metric tons of waste is to be landfilled (15% of total waste). Area required for the landfill is estimated to be 6.93 hectares. Landfill size calculation is shown below.

Total waste coming to landfill in 20 years = 404,358.42 MT (Table 8.7)
Compaction density = 700 kg/m^3
Volume of waste coming to the landfill = 577,654.88 m^3
Height of the landfill = 10 metres (2 m extra for landfill cover)
Area required = 577,654.88/10 = 57,765.488 m^2
20% extra area provided = 10% extra (CPHEEO) + 10% extra (building, treatment, others)
Net area required for landfill = $1.2 \times 57{,}765.49 = 69{,}320$ m^2 (approx.)

4.4 Vehicle Routing

In developing countries like India, waste collection and transportation comprise approximately 80–90% of the overall SWM budgets while collection efficiencies remain less than half. In contrast, collection efficiencies are greater than 90% in high-income countries and collection costs are less than 10% of the total SWM budgets (Hoornweg and Bhada-Tata 2012). Therefore, optimization of the collection routes and bin locations is a critical need in developing countries.

Vehicle routing can be done manually or with tools such as remote sensing, GIS and linear programming for any area. Best possible vehicle routes were drawn manually for the market area and compared with routes obtained using linear programing. Further, these routes can be monitored using global positioning systems (GPS) for automated control and data collection (Wilson et al. 2007).

4.4.1 Assumptions and Basic Requirements for Vehicle Routing

- If the system is *semi-automated collection*, then it typically requires a crew of two: a driver and a collector.
- Route starts from garage (at municipality office) and after collection goes to transfer station. All following routes on the same day begin from the transfer station and return to it. At the end of the work day, the collection vehicle returns to the garage from transfer station.
- Average velocity of truck on road is 25 km/h while it is 15 km/h during collection.
- Trucks provided are of sizes 19 m^3 and 11 m^3 (available in the market).
- Truck compartment ratio of 70:30 was assumed for residential areas assuming mixed waste as 70% of total volume and recyclables as 30% of total volume.
- Trucks used for collecting commercial waste were assumed to have two compartments: one for mixed waste (50% of volume) and second is for recyclables (50% of volume).
- Density of compacted waste in the truck is 590 kg/m^3.
- Collection time at a location: 1.5 min.
- Unloading time for truck at transfer station was 10 min (with factor of safety; otherwise 7.5 min maximum).
- 25% extra time was provided for off-route time to account for traffic problems, bad weather conditions, vehicle problems and personal requirements.

4.4.2 Calculation of Locations Served Per Trip

To design a collection system with 100% efficiency, the number of bins in each ward, the volume of waste collected in each bin and the truck capacity are required. So, number of locations/bins served are calculated below for each ward, market area and apartment buildings.

Truck size – 19 m^3

Volume available for mixed waste = 70% of total volume = 0.7 × 19 m^3 = **13.3 m^3** = 13.3 m^3 × 590 kgm^{-3} = **7847 kg**

Volume available for recyclables = 30% of total volume = 0.3 × 19 = **5.7 m^3** = 5.7 m^3 × 590 kgm^{-3} = **3363 kg**

For Ward 20

Mixed waste: Bin size = 1.25 m^3 (Volume); 1.25 m^3 × 250 kg m^{-3} = 312.5 kg (weight)

Locations served/trip = Maximum weight of waste/weight of bin = 7847 kg/ 312.5 kg = 25 locations

Recyclables: Bin size = 0.5 m^3 (Volume); 0.5 m^3 × 250 kg m^{-3} = 125 kg (weight)

Locations served/trip = Maximum weight of waste/weight of bin = 3363 kg/ 125 kg = 26 locations

Maximum locations served in a trip are ***25 locations per trip***

Similarly, maximum locations served per trip are calculated for Ward 21, market area and apartment area

For Ward 21: *Maximum locations served per trip are* ***19 locations per trip***

For market: *Maximum locations served per trip are* ***nine locations per trip***

For 6-floor apartment buildings: *Maximum locations served per trip are* ***31 locations per trip***

For 3-floor apartment buildings: *Maximum locations served per trip are* ***52 locations per trip***

4.4.3 Manual Vehicle Routing

In general, vehicles are routed manually. However for large areas, manual methods can result in inefficient utilization of resources and higher collection costs (when compared to other methods). Using tools/software like Google Earth and specific guidelines, routing efficiency can be increased.

The following guidelines were used for developing collection routes manually (Worrell and Vesilind 2012):

- Routes should not overlap, should be compact, and should not be fragmented.
- The starting point should be as close to the truck garage or transfer station as possible.
- One-way streets that cannot be traversed in one line should be looped from the upper end of the street.
- Dead-end streets should be collected from the left side of the street since most vehicles in India are ‘right hand drive’.
- Anti-clockwise turns around blocks should be used whenever possible.
- Long, straight paths should be routed before looping anti-clockwise.

- Routes should be laid out so that the last container to be collected on the route is located nearest to the disposal site.
- Existing policies and regulations related to such items as the point of collection and frequency of collection must be identified.
- Existing systems, such as crew size and vehicle types, must be coordinated.
- Wastes generated at traffic-congested locations should be collected as early in the day as possible or even at night.

4.4.4 Routes for Residential and Apartment Area

Routes were developed using Google Earth software and time was calculated from route length and average velocity of the truck. Routes are drawn to collect waste generated in the residential area, apartment area and special bins like the police office, and schools. All routes start from the garage in the morning which is located in the municipality office complex and end at the garage. The first route starts from the garage and then it goes to the entry point in the service ward. After that, waste is collected from the service ward/area till the truck is completely filled. After it is completely filled, the truck goes to the transfer station to unload its contents. The next route will start from the transfer station (TS), return to the next collection point in the ward and start collecting from bins. After it is completely filled, it will again come back to the TS for unloading. At the end of the day, the truck will return to the garage from the TS.

A total of six routes were planned for waste collection in the residential and apartment area. The six routes have a total distance of 63.91 km and the time required for these routes is 603 min (including unloading and 25% extra time). Since the time taken for completing the routes is more than 8 h, two collection trucks will be required (routes distance and time are shown in Table 8.1). Calculation for the collection time required for NR_1 is shown below and the route is shown in Fig. 8.9.

Route 1: NR_1 (10 stops and 34 bins locations)
Garage to entry point: 4.8 ≈ 5 min [Distance: 2 km (with 25 km/h speed)]
Entry point to first bin: 2.4 ≈ 2.5 min [Distance: 1 km (with 25 km/h speed)]
Picking up time: 51 min [34 locations × 1.5 min]
Travelling time: 8.5 min [Route length: 2.13 km (with 15 km/h speed)]
From starting point to TS: 6.24 ≈ 6.5 min [Distance: 2.6 km (with speed 25 km/h)]
Time taken: 73.5 min + 18.38 min (25% extra) ≈ 92 min
Distance covered: 7.73 km (NR_1 shown in Fig. 8.9)

Using the same methodology, time was calculated for the remaining five routes and the results are summarized in Table 8.1.

Table 8.1 Time and distance of six routes covering household areas in wards

Routes	Routing time (including 25% extra time), min	Unloading time, min	Total time, min	Distance, km
NR_1	92	10	102	7.73
NR_2	102	10	112	9.04
NR_3	87	10	97	9.72
NR_4	82	10	92	10.77
NR_5	86	10	96	12.02
NR_6	94	10	104	14.63
Total	543	60	603	63.91

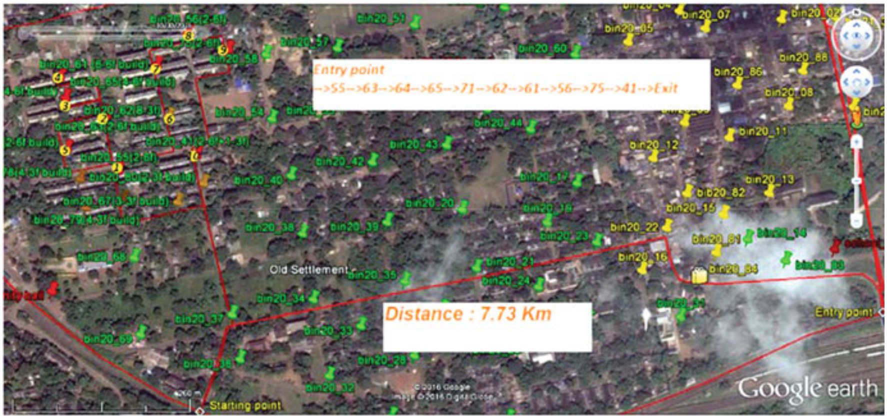

Fig. 8.9 Route NR_1

4.4.5 Routes for Commercial/Market Area

The market area is a very busy place so the quantity of waste produced is large and varies from day-to-day. Two possible options for collecting market waste are: collect all commercial bin waste once or twice a day. The method that is most economical in terms of efficiency and cost is the best choice. Methodology for planning vehicle routes for both options is the same as the methodology used for residential and apartment areas.

For a collection frequency of once a day, a total of six routes were planned for waste collection in the market area (Fig. 8.10). The six routes have a total distance of 54.79 km (shown in Table 8.2) and time required for these routes is 365 min (including unloading and 25% extra time). The time taken for completing the routes is less than 8 h, so only one truck per day is required for collection.

For collection frequency of twice a day, a total of three routes were planned in the market area (Fig. 8.11). These three routes have a total distance of 60.96 km (after two-time collection) and time required for these routes is 468 min (shown in

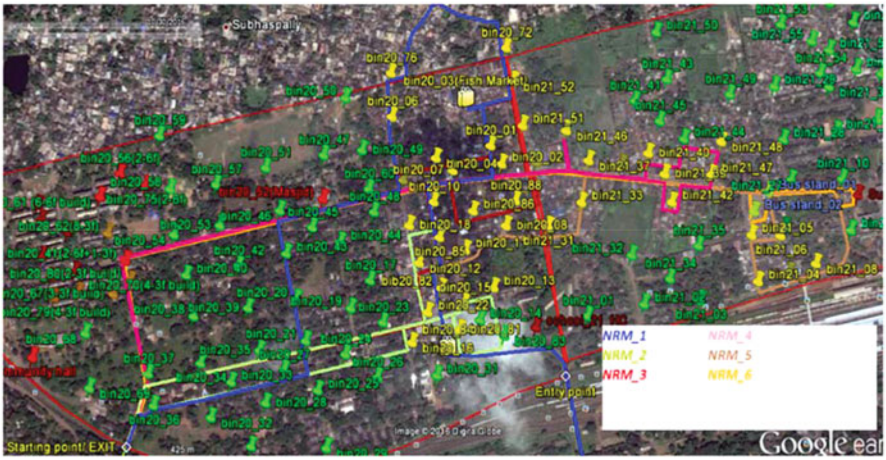

Fig. 8.10 Collection routes for market area (one time collection)

Table 8.2 Time and distance of six routes covering commercial area in wards (one time collection)

Routes	Routing time (including 25% extra time), min	Unloading time, min	Total time, min	Distance, km
RM_1	46	10	56	7.45
RM_2	46	10	56	7.73
RM_3	50	10	60	8.38
RM_4	53	10	63	9.15
RM_5	56	10	66	9.71
RM_6	54	10	64	12.37
Total	305	60	365	54.79

Table 8.3). The time taken for completing the routes is less than 8 h, so only one collection truck is required per day.

On comparing both cases, time taken and distance covered in collection is more with collection frequency of two times a day compared to one time a day. This implies that labour and fuel costs will be greater with two times a day collection rather than one time a day collection. Therefore, one time a day collection is more cost-effective and will provide 100% collection efficiency (Table 8.4).

4.4.6 Optimization of Routes in the Market Area Using Linear Programming (LP)

Another approach for route optimization is to use the same algorithm as the *travelling salesman problem (TSP)*. Travelling salesman problem is defined as "If a list of nodes and distances between each pair of nodes is given, what is the shortest

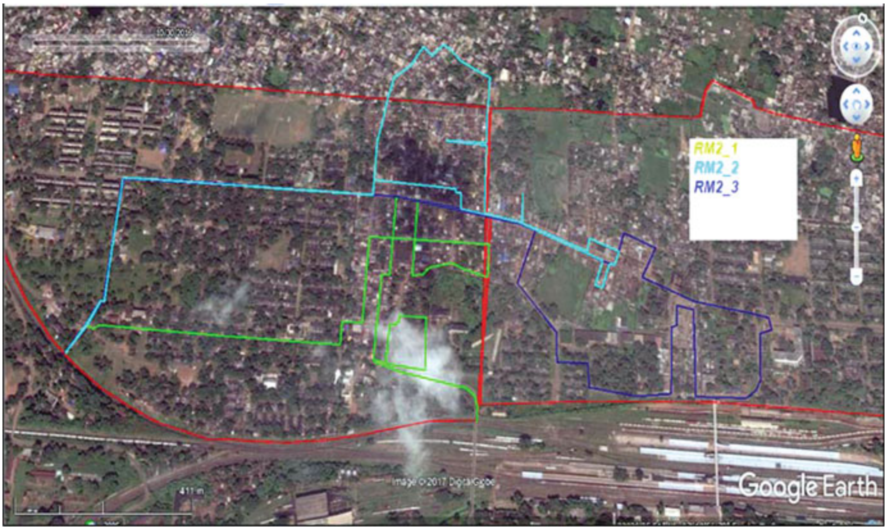

Fig. 8.11 Collection routes for market area (two times collection)

Table 8.3 Time and distance of six routes covering commercial area in wards (two times collection)

Routes	Routing time (in min) (Including 25% extra time)	Unloading time (in min)	Total time (in min)	Distance (in km)
RM2_1	61	10	71	7.5
RM2_2	72	10	82	9.82
RM2_3	71	10	81	13.16
Total	204	30	234	30.48

Table 8.4 Cost analysis of one and two times a day collection of waste in market area (for 20 years)

Factors	Case a	Case b
Bin Volume	2.5 m^3	1.25 m^3
Bin price	Rs 20,000	Rs 13,000
Price of all bins	42 × 20,000 = 8.4 lakhs	42 × 13,000 = 5.46 lakhs
Fuel (CNG) required in a year (truck mileage 4 km/L)	365 × 54.79 km/4 km/L = 4999.6 L	365 × 60.96 km/4 km/L = 5562.6 L
Fuel price (On 01-11-2017)	Rs 43.6 per L	Rs 43.6 per L
Cost due to fuel in a year	Rs. 4999.6 × 43.6 = 2.18 lakhs/year	Rs. 5562 × 43.6 = 2.43 lakhs/year
Cost for 5 years	(5 × 2.18) + 8.4 = 19.3 lakhs	(5 × 2.43) + 5.46 = 17.61 lakhs
Cost for 10 years	30.2 lakhs	29.76 lakhs
Cost for 20 years (Design life)	52 lakhs	54.06 lakhs

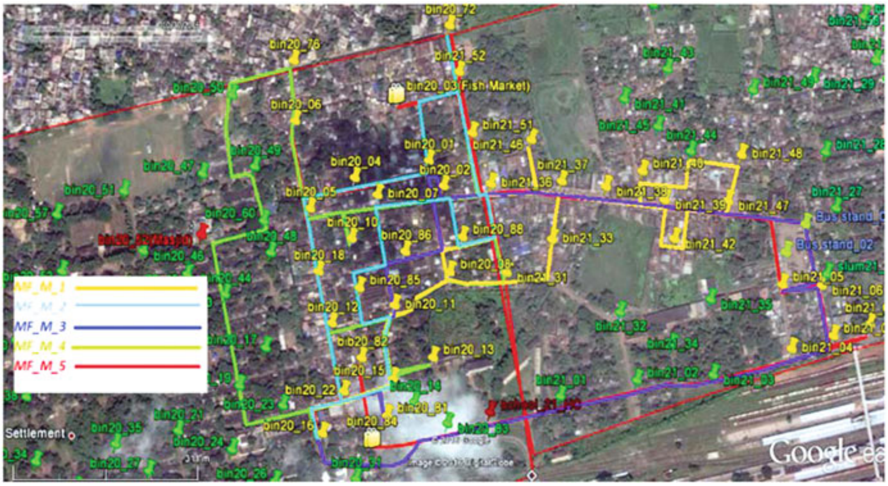

Fig. 8.12 Optimized collection routes based on linear programming for the market area

Table 8.5 Time and distance covered in five optimized routes in the commercial area

Routes	Routing time (including 25% extra time) (in min)	Unloading time (in min)	Total time (in min)	Distance (in km)
MF_M_1	47	10	57	8.17
MF_M_2	47	10	57	8.52
MF_M_3	50	10	60	9.11
MF_M_4	48	10	58	9.17
MF_M_5	60	10	70	12.69
Total	252	60	**302**	**47.66**

possible route that will visit each and every node exactly one time and at the end return to the origin". Assuming each bin is a node, TSP ensures collection from all bins while minimizing distance covered. Two constraints were applied for optimization, no value can be negative, and a maximum of nine nodes can be covered in a single route. The second constraint was applied because in the market area, a maximum of nine bins can be picked up in a single route due to truck capacity limitation. In TSP, the route begins and ends at bin 20_16 in Ward 20. Bin 20_16 is selected because it is closest to both garage and TS while entering in the market area for collection. Distance of bin 20_16 from TS and garage was calculated using Google Earth and included in route planning. The linear program code was written in Visual C++ and used to determine optimum routes.

After optimization, there are five collection routes for the market area (shown in Fig. 8.12). These five routes have a total distance of 47.66 km (shown in Table 8.5) and time required for these routes is 302 min (including unloading and 25% extra

Table 8.6 Comparison between manually developed collection routes and those based on linear programming (LP)

Parameter	Manually	After optimization	Reduction after optimization
Time	6 h 5 min	5 h 2 min	63 min
Distance	54.79 km	47.66 km	7.13 km

time). The time taken for completing the routes is less than 8 h, so for collection only one truck per day is required.

Optimized routes result in reducing total routing distance by 7.13 km and total vehicle routing time by approximately 1 h (63 min). After optimization, there are five routes instead of six resulting in significant savings in fuel, time and cost in the collection process. A comparison of the results obtained manually versus those obtained using LP is provided in Table 8.6.

5 Conclusions

An integrated solid waste management (ISWM) plan was developed for Kharagpur using RS, GIS and linear programming. Major conclusions of this study are:

1. A bin location and sizing plan was developed using Google Earth Pro and guidelines provi ded by the Government.
2. Sites for a transfer station and landfill were identified using Google Earth Pro and their areas calculated

Using Google Earth Pro, it was possible to route collection vehicles manually based on ground/local information or using a linear programming approach.

These methods were applied successfully at very low materials and labour costs since satellite images and Google Earth Pro are freely available from the Internet. These methods can be extended further for detailed project monitoring, cost estimation and cost-benefit analyses of alternatives for developing an ISWM plan for any other city or region.

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Appendix

Table 8.7 Calculation of the total amount of waste going for landfilling from 2016 to 2036

Year	Population	SW gen. rate (kg/capita-day)	Total waste generation/day (in kg)	Total waste going to landfill (in kg/day) (15% of total waste)	Landfill waste (kg/year)	Volume of waste for landfill (p = 700 kg/m^3)
2016	314,628	0.5	157,314	23,597.1	8,636,538.6	12,337.91229
2017	317,015	0.55	174,358.25	26,153.7375	9,546,114.188	13,637.30598
2018	320,000	0.6	192,000	28,800	10,512,000	15,017.14286
2019	323,013	0.65	209,958.45	31,493.7675	11,495,225.14	16,421.7502
2020	326,055	0.7	228,238.5	34,235.775	12,530,293.65	17,900.4195
2021	329,125	0.75	246,843.75	37,026.5625	13,514,695.31	19,306.70759
2022	332,224	0.8	265,779.2	39,866.88	14,551,411.2	20,787.73029
2023	335,352	0.85	285,049.2	42,757.38	15,606,443.7	22,294.91957
2024	338,510	0.9	304,659	45,698.85	16,725,779.1	23,893.97014
2025	341,697	0.95	324,612.15	48,691.8225	17,772,515.21	25,389.30745
2026	344,915	1	344,915	51,737.25	18,884,096.25	26,977.28036
2027	348,162	1.05	365,570.1	54,835.515	20,014,962.98	28,592.80425
2028	351,441	1.1	386,585.1	57,987.765	21,223,521.99	30,319.31713
2029	354,750	1.15	407,962.5	61,194.375	22,335,946.88	31,908.49554
2030	358,090	1.2	429,708	64,456.2	23,526,513	33,609.30429
2031	361,462	1.25	451,827.5	67,774.125	24,737,555.63	35,339.36518
2032	364,866	1.3	474,325.8	71,148.87	26,040,486.42	37,200.69489

(continued)

Table 8.7 (continued)

Year	Population	SW gen. rate (kg/capita-day)	Total waste generation/day (in kg)	Total waste going to landfill (in kg/day) (15% of total waste)	Landfill waste (kg/year)	Volume of waste for landfill (p = 700 kg/m^3)
2033	368,301	1.35	497,206.35	74,580.9525	27,222,047.66	38,888.63952
2034	371,769	1.4	520,476.6	78,071.49	28,496,093.85	40,708.7055
2035	375,270	1.45	544,141.5	81,621.225	29,791,747.13	42,559.63875
2036	378,803	1.5	568,204.5	85,230.675	31,194,427.05	44,563.46721
				Total waste	404,358,414.90	577,654.89

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