



# Location–allocation of bins in urban solid waste management: a case study of Bilaspur city, India

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## Abstract

For an efficient management of solid waste across the cities, proper allocation of waste bins has become a subject of paramount importance. At present, most of the cities of developing countries are facing the problem of lack of waste bins in appropriate places. This deficiency in the number of waste bins results in littering habit and increases the number of waste collection points for the local authorities. Large numbers of collection points increase the collection cost and carbon emission in the environment. In this paper, a mixed integer linear programming model has been formulated to determine the total number of bins required in any site considering different factors like multiple types of sources, waste bins and wastes types along with safety and rag-picking. An efficient method has been proposed for the allocation of bins such that the bins are able to provide service to the entire targeted site. The developed model is tested using the data obtained from an Indian city to demonstrate its applicability. The result manifests the effectiveness of the model in terms of reduction in collection points (15%), idling cost (25%) and carbon emission (35%).

**Keywords** Solid waste · Bin allocation · MILP · GIS · Rag-picking · Multiple wastes · Multiple bins

## 1 Introduction

The dramatic increase in urbanization is leading to a high amount of urban solid waste generation (Abdoli et al. 2016), which has a great socio-economic and environmental impact (De and Debnath 2016). The worldwide urbanization was 30% in 1950 and 54% in 2014 and projected to be 66% by 2050 (United Nations 2014). This rise in urbanization varies from country to country. For instance, in India, the population living in urban cities in 1901 was 11.4%, in 2001 28.53% and in 2011 31.16% (Rathore and Sarmah 2018). It is forecasted that by 2050, 50% of the population will live in urban areas (Census of India 2011).

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Due to this increasing urbanization, it is projected that in 2021 urban India will generate 276,342 tonne per day (TPD) of municipal solid waste (MSW), 450,132 TPD in 2031 and 1.2 million TPD in 2050 in comparison with 143,449 TPD of MSW in 2014 (Planning Commission of India 2014; CPHEEO 2016a, b).

As per the Central Pollution Control Board (CPCB) India (2017), in 2014–2015, only 80% (117,644 TPD) of the total generated waste got collected, out of which only 22% (32,871 TPD) was processed or treated. The collected but untreated waste is sent to landfills, which is leading to degradation of the environment and poor quality of life (Abd El-Salam and Abu-Zuid 2015; Ali et al. 2014). Insufficient segregation at source, lack of collection facilities, inefficient transportation, improper treatment and unscientific disposal of waste are the major factors for this situation (Ghatak 2016). Meanwhile, the uncollected MSW remains in the community and creates a nuisance (bad odour, flies, stray animals, diseases, etc.).

Municipal solid waste management (MSWM) consists of forecasting, generation, storage and collection, transportation, treatment and waste disposal (Hazra and Goel 2009). Of all these multidisciplinary activities, waste collection and transportation account for 50–70% of the total cost of the system (Tavares et al. 2009; Rada et al. 2013). The collection of waste also accounts for the emission of carbon which is harmful to the environment. Nguyen and Wilson (2010) estimated the fuel consumption of the waste collection vehicle during kerbside collection of waste and found that more than 30% of the total fuel is consumed due to idling. The vehicle remains in idling condition most of the time due to the loading of MSW from collection points. The numbers of collection points in any urban centre are determined by the waste bins provided by the municipality. If the number of waste bins is less than the requirement, it encourages the littering habit and thus increases the number of collection points which are open dumps point (Arribas et al. 2009). The collection of MSW from this open dump points is more time-consuming compared to waste bins containing sorted waste. This situation of dumping of solid waste in open area within the community is very prevalent in developing countries, including India (Gupta et al. 2015). In developing countries, municipal authorities are often unable to provide waste collection bins in appropriate places, required for ‘proper management of MSW’ (Kumar and Pandit 2013; Boskovic and Jovicic 2015).

Apart from the collection system, an efficient MSWM system also depends on the separation of MSW at the source (Sukholthaman and Sharp 2016), because the collection of unsegregated waste is unfruitful and hazardous to the environment (Gandhe and Kumar 2016). The waste generated by sources (households, commercial and institutional establishments, parks and gardens, construction and demolition, urban agriculture, and safety and healthcare facilities) contains compostable organic matter (fruit and vegetable peels, food waste, etc.), recyclables (paper, plastic, glass, metals, etc.), toxic substances (paints, pesticides, used batteries, medicines), and soiled waste (blood-stained cotton, sanitary napkins, disposable syringes) (Kaushal et al. 2012; Upadhyay et al. 2012). In India, the waste is composed of organic fraction (40–60%), ash and fine earth (30–40%), paper (3–6%) and plastic, glass, and metals (each less than 1%) (Annepu 2012; Gupta et al. 2015). Therefore, it is very important to separate the MSW at sources so that they sent to respective processing plants for recycling or for converting into useful products (Datta and Kumar 2016).

The problem of lack of waste collection bins and unsegregated solid waste motivated us for this study. This paper proposes a bin location model for selecting the best potential points for different types of bins in an economical manner. Sensitivity analysis is done to investigate the behaviour of the objective function for different values of key parameters. These types of problems have been undertaken by facility location models and are found to be very useful in the management of MSW. Proposed model for the allocation of waste

bins helps in reducing the cost and pollution level while improving efficiency. To the best of our knowledge, until now, no study has taken a safety, rag-picking, type of waste and different types of bins all together in one model for choosing the best location of waste bins. This study adds value to the existing literature of mathematical models for the selection of sites for waste bins and also provides direction to researchers and municipal officials towards designing of economical collection systems with source separation.

## 1.1 Why waste collection bins are required?

Waste collection bins are intermediate facilities between sources and transfer stations (if the collection system is having transfer stations) or landfill or processing facilities. Installation of collection bins reduces the open dumping of waste within the urban centres (MoEF 2010; Khan and Samadder 2016). This results in a reduction in collection points and nuisance like a bad odour, stray animals, disease, etc., associated with open dumping. Decrease in collection points leads to decrease in idling time of waste collection vehicle, thus reducing the fuel consumption. Introduction of multiple types of collection bins for different types of waste encourages the recycling and reduces the amount of waste entering into a landfill (Bohm et al. 2010).

## 2 Literature review

There are only a few studies that have been conducted to address the collection bin location–allocation problem. Although the collection of solid waste accounts for a major portion of the budget, this issue has not been much explored by researchers (Purkayastha et al. 2015). Keeping in view of our research work, the review of the literature is divided into two sections: (1) literature related to mathematical modelling and (2) literature related to the application of GIS. Both research streams are discussed briefly in the following subsections.

### 2.1 Literature related to mathematical modelling

Over the past few years, several researchers have used mathematical programming techniques (MPTs), such as integer programming (IP), linear programming, nonlinear programming, dynamic programming (DP) and multi-objective and goal programming to determine the optimum cost for MSW management systems. All studies show that MPTs are useful tools for MSW management problems. Badran and El-Haggag (2006) proposed a cost minimization mixed integer linear programming (MILP) model of MSWM in Port Said (Egypt) for identifying the best locations for collection stations among the given possible locations. Their objective function is consisting of two cost components fixed and operation. Fixed cost includes transportation, fixed and variable cost of the facility, while the operation cost includes bin cost, staff uniforms and administrations. Ghiani et al. (2012) suggested an integer programming model for minimizing the total number of collection site by selecting the best site for bins. They had considered two constraints in their model: (1) capacity and linear space constraint to ensure that the total waste generated should get collected, and there should be enough linear space at site for placing the bin and (2) service constraint which forces the model to select the collection site such that it is able to serve all the targeted sources. Hemmelmayr et al. (2014) proposed a bin allocation MILP model to determine the

optimal number of different types of waste bins required for different types of waste generated by residential sources in a site. They had taken the availability of space and existing collection bins of a site as a constraint while developing the model. Mehr and Mcgarvey (2017) proposed a cost minimization mixed integer model by which they identify the collection points along with the frequency of service. In objective function, they had considered the collection cost of dumpsters and compactors along with compactors depreciation cost.

Apart from only locating the waste collection bins, many researchers had gone for multi-objective models. Erkut and Tjandra (2008) proposed a mixed integer multiple objective linear programming models for MSWM facilities of Central Macedonia region in North Greece. In their objectives, they tried to minimize the greenhouse gas emission, the amount of waste disposed of to landfills and the total cost associated with facility allocation. Coutinho-rodrigues et al. (2012) proposed a multi-objective linear programming model to locate the waste containers. Their objective was to minimize the total investment cost and the average distance between the source and waste container. Coutinho-Rodrigues et al. (2012) introduced a mixed integer, bi-objective programming approach to determine the locations and capacities of the collection bins. Their objectives were the minimization of the total investment cost (fixed and variable bin cost) and dissatisfaction level.

## 2.2 Literature related to GIS application

Geographical information system (GIS) is also very effective and widely accepted method for bin allocation problem. The GIS allows visualization of the image of the site and provides the flexibility of adding the information as per requirement (Vuji et al. 2010). Ghose (2006) optimized the MSW collection system using GIS by planning the allocation of bins at Asansol, India. GIS is also used for collecting the data about the sites which can be used while solving the models. Zamorano et al. (2009) used GIS technology to collect information about city routes, population density and space availability. Then, they proposed an algorithm for the allocation of different types of waste bins to optimize the waste collection service in Churriana de la Vega (Granada, Spain). Arribas et al. (2009) proposed a methodology which was a combination of integer programming and GIS. Their objective was to minimize the operational and transport costs along with time. Chalkias and Lasaridi (2009) developed a model using GIS for reallocation of waste bins to enhance the efficiency of waste collection in the Municipality of Nikea, Athens, Greece. GIS also helps in testing the various scenarios by available data. Gallardo et al. (2014) proposed two ways of actions on the basis of data availability: direct way when the detailed data are available and indirect way when there is a lack of data. They combine the GIS with planning methodology to represent the final results in thematic maps. Boskovic and Jovicic (2015) developed a methodology to determine the optimal number of waste bins and optimize locations of collection points. Their method was based on GIS and conducted in the city of Kragujevac. They found 24% reduction in the number of collection points and 33.5% in the number of waste bins. Khan and Samadder (2016) studied the problem of waste bin allocation for city Dhanbad, India. They also used the GIS technology to locate the required number of bins based on population density, service area of bin and availability of space.

From the above-mentioned literature, it can be observed that most of the researchers have preferred MILP models to address the bin location problem and GIS tools to create the data for the model. It is also observed that no such MILP model is developed for Indian urban centre considering source separation, multiple types of sources, availability of space, and safety and rag-picking factor for MSWM.

### 3 Methodology

The methodology proposed here gives a logical framework to help the municipalities to develop an MSWM system, which focuses on the allocation of waste collection bins in an economical manner. The proposed methodology also emphasizes on the interconnection of mathematical models and geographical information system (GIS) in optimizing the cost by identifying the optimal number of bins required and choosing the best location for them within the urban area. GIS analysis is an integral part of this methodology and has been used for creating a data repository for allocation of bins. GIS is also used for the representation of wards, sources, collection points and selected potential points on real-time maps. This methodology comprises of two basic elements (Fig. 1): (1) a mathematical model to identify the required number of bins within an urban area (mathematical modelling) and (2) creation of data inventory for allocation of bins (GIS analysis). In the subsequent section, a detailed discussion is provided.

#### 3.1 Mathematical modelling

This subsection provides the mathematical model formulated to determine the number of bins required in an urban area at a minimum cost. It is very difficult to develop a mathematical model considering all the situations and factors of real scenarios. Therefore, some assumptions have been taken while developing the model.

##### 3.1.1 Assumptions

1. There is no restriction on the placement of waste collection bins at any location in a given area.
2. Waste collection sites are easily accessible by lightweight waste collection vehicle.

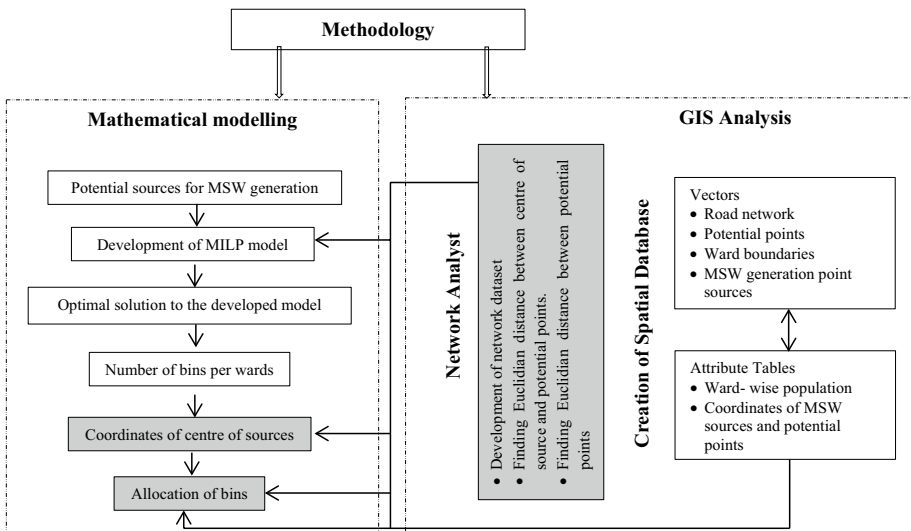


Fig. 1 Framework of methodology

3. All the MSW generated by selected sources in a site is completely collected by the local authority.

The notations used in the model are presented in Table 1, and it is followed by the description of the model.

$$\text{Minimize} = \sum_{i=1}^n \sum_{j=1}^m \sum_{k=1}^K (c_j + c_{wj}) * x_{ijk} \tag{1}$$

Subject to

$$\begin{aligned} \sum_{j=1}^m Q_i * x_{ijk} \geq & \left\{ P_i * q_k * (1 - Z_k) + \sum_{a=1}^A X' * H_{ika} * (1 - Z_{ika}) \right. \\ & + \sum_{b=1}^B B' * M_{ikb} * (1 - Z_{ikb}) + \sum_{g=1}^R Y' * G_{ikg} * (1 - Z_{ikg}) \\ & \left. + \sum_{s=1}^S L' * C_{iks} * (1 - Z_{iks}) \right\} * T * (1 + f) \quad \forall i = 1, \dots, n; \quad k = 1, \dots, K \end{aligned} \tag{2}$$

$$\sum_{j=1}^m \sum_{k=1}^K x_{ijk} * U_j \leq \sum_{r=1}^F O_{ir} \quad \forall i = 1, \dots, n. \tag{3}$$

$$x_{ijk} \geq 0 \text{ and integer} \quad \forall i = 1, \dots, n; \quad j = 1, \dots, m; \quad k = 1, \dots, K. \tag{4}$$

$$\text{Actual number of bins required} = x_{ijk} - p_{ijk} \tag{5}$$

In the proposed model, the objective function (Eq. 1) is linear and determines the number of bins ( $x_{ijk}$ ) at minimum cost. The constraints taken in the model are also linear in nature. The first constraint (Eq. 2) is a capacity constraint. It ensures that the combined capacity of all the bins ( $j = 1, \dots, m$ ) should be greater than the quantity of waste ( $k = 1, \dots, K$ ) generated in a site ( $i = 1, \dots, n$ ) in the time period  $T$ . The MSW generation sources considered in the constraint are hospitals ( $H_{ika}$ ); farmers market ( $M_{ikb}$ ); gardens or parks ( $G_{ikg}$ ); and commercial places (school, college, administrative area, offices, shopping complexes and malls) ( $C_{iks}$ ). The generation of MSW varies daily and from source to source. Thus, it becomes difficult to know the exact amount of waste generated every day. Therefore, a safety factor ( $f$ ) is considered for the collection bins to avoid the overfilling of bins. A special case of rag-picking or selling of MSW by sources has also been considered ( $Z_k, Z_{ika}, Z_{ikb}, Z_{ikg}$  and  $Z_{iks}$ ). This case is applicable in those urban centres, where people tend to not give away all the waste generated by them. For instance, in India, many people usually store and sell their recyclable waste to kabadiwalas (itinerary buyer) (Planning Commission of India 2014). Along with this, there are rag-pickers that collect waste from the roadside, households and some other sources and sell them to recyclers. Likewise, nowadays, there are many non-governmental organizations (NGOs) that collect waste foods from different areas and distribute it to needy ones (Steuer et al. 2017).

Second constraint (Eq. 3) is a space availability constraint. It restricts the number of bins in a site as per the space availability ( $O_{ir}$ ) and the space required for placing of all bins in a site. Third constraint (Eq. 4) is a non-negativity and integer constraint, which ensures

**Table 1** The notations and descriptions of indices, parameters and variables used in the proposed model

Symbol	Description	Type
<b>Indices</b>		
$i$	Site number	
$j$	Type of bins	
$k$	Type of waste	
$r$	Potential points in site	
$a$	Hospital at site	
$b$	Farmers market at site	
$g$	Gardens and parks at site	
$s$	Commercial place at site	
<b>Parameters</b>		
$n$	Number of sites	Integer
$m$	Number of type of bins	Integer
$K$	Number of type of waste	Integer
$A$	Number of hospitals at site $i$	Integer
$B$	Number of farmers markets at site $i$	Integer
$R$	Number of gardens or parks at site $i$	Integer
$S$	Number of commercial areas or complexes at site $i$	Integer
$F$	Number of potential points at site $i$	Integer
$Z_k$	Average rag-picking factor of waste type $k$ for residents	Real
$Z_{ika}$	Rag-picking factor of waste type $k$ for hospital $a$ of site $i$	Real
$Z_{ikb}$	Rag-picking factor of waste type $k$ for market $b$ of site $i$	Real
$Z_{ikg}$	Rag-picking factor of waste type $k$ for garden $g$ of site $i$	Real
$Z_{iks}$	Rag-picking factor of waste type $k$ for commercial place $s$ of site $i$	Real
$T$	Number of days between two consecutive trips for collection	Integer
$f$	Safety factor to avoid overfilling	Real
$\alpha_k$	Threshold quantity of waste generation of type $k$ for considering the source	Real
<b>Site data parameters</b>		
$P_i$	Population in site $i$	Integer
$q_k$	Average per capita waste generation (kg per day) of type $k$ by residents	Real
$H_{ik}$	Average quantity of waste (of type $k$ ) generated per day at hospital of site $i$	Real
$G_{ik}$	Average quantity of waste (of type $k$ ) generated per day at parks and gardens of site $i$	Real
$C_{ik}$	Average quantity of waste (of type $k$ ) generated per day at commercial places in site $i$	Real
$M_{ik}$	Average quantity of waste (of type $k$ ) produce per day at vegetable markets in site $i$	Real
$O_{ir}$	Space available for bin allocation within the site $i$	Real
$F_i$	Number of potential locations within the site $i$ , $r = 1 \dots F$	Integer
$P_i, P_{ij}, P_{ijk}$	Numbers of bins present in site $i$ of type $j$ for waste type $k$	Integer
<b>Bin data parameters</b>		
$U_j$	Space required by a type $j$ bin	Real
$Q_j$	Capacity of type $j$ bin	Real
$c_{wj}$	Cost of waiting for unloading bin type $j$ at collection point	Real
$c_j$	Purchasing cost of type $j$ bin	Integer

**Table 1** (continued)

Symbol	Description	Type
Decision variables		
$x_i, x_{ij}, x_{ijk}$	Number of bins of type $j$ for waste type $k$	Integer
$X'$	Binary number which takes value 1 if hospital is selected; otherwise 0	Integer
$B'$	Binary number which takes value 1 if farmers market is selected; otherwise 0	Integer
$Y'$	Binary number which takes value 1 if park or garden is selected; otherwise 0	Integer
$L'$	Binary number which takes value 1 if commercial place is selected; otherwise 0	Integer

that the number of bins is positive and an integer value. Equation (5) represents the actual number of bins required on the site, which is a difference of the number of bins calculated and the number of bins already present in the site. Since the generation of waste varies from source to source, it is very difficult to consider each and every source. Therefore, in Eq. (2), binary decision variables ( $X', B', Y'$  and  $L'$ ) were taken into account. The sources which generate waste more than or equal to a threshold quantity ( $\alpha$ ) in a time period  $T$  will be selected as a source. The binary decision variables are defined as:

$$X' = \begin{cases} 1, & \text{if } H_{ika}(1 - Z_{ika}) \geq \alpha \\ 0, & \text{otherwise} \end{cases} \tag{6}$$

Here, the binary decision variable  $X'$  will take the value 1 if a hospital source is able to equalize or cross the threshold value of waste generation (considering rag-picking factor) in time period  $T$ , otherwise, it becomes 0. Similarly,

$$B' = \begin{cases} 1, & \text{if } M_{ikb}(1 - Z_{ikb}) \geq \alpha \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

$$Y' = \begin{cases} 1, & \text{if } G_{ikg}(1 - Z_{ikg}) \geq \alpha \\ 0, & \text{otherwise} \end{cases} \tag{8}$$

$$L' = \begin{cases} 1, & \text{if } C_{iks}(1 - Z_{iks}) \geq \alpha \\ 0, & \text{otherwise} \end{cases} \tag{9}$$

After calculating the number of bins, the best potential points have to be selected, where bins can be placed. In subsection below, steps for the selection of best potential points are presented.

### 3.2 Allocation of bins

In this subsection, the procedure has been developed for the selection of best potential points and allocation of different types of bins for various types of waste. The bins should be allocated on the site, such that all the generated waste get collected without getting over-filled. Following are the steps of the developed procedure:



### Step 1 Identification of the coordinates

The number of household sources is very high as compared to other sources. It is very difficult to find the coordinates of each household individually. Therefore, a centre for the entire residential source, termed as a residential centre (RC), is determined. RC represents the point source of MSW generation for all the households of a site. The coordinates of RC depend on the population density across the site. It is like determining the centre of mass of a body.

### Step 2 Identification of the centre of source

A site consists of many sources, and it is very difficult to select the best potential point while considering all sources as a reference point. Therefore, a common centre is identified by considering all the sources in such a fashion that the location of the centre is closer to those sources which generate the most amount of MSW as compared to sources which generate a relatively lesser amount of MSW. A site can have multiple centres depending on the type of waste. The formula for the calculation of centre is as follows:

$$\text{Latitude}_{ik} = \frac{\text{Sum of MSW generated from sources of type } k \times \text{latitude of source}}{\text{Sum of MSW generated from source of type } k} \quad (10)$$

$$\text{Longitude}_{ik} = \frac{\text{Sum of MSW generated from sources of type } k \times \text{longitude of source}}{\text{Sum of MSW generated from source of type } k} \quad (11)$$

### Step 3 Allocation of bins

In this step, bins are allocated at potential points ( $r$ ) on the basis of the following conditions:

1. The potential point must have the shortest Euclidian distance from the centre of the source.
2. The potential point must have available space as per the size of the bin.
3. Same types of MSW collection bins should not be placed together. There must be a minimum distance of  $d_{ij}$  between the two MSW collection bins of the same type. This condition is introduced to ensure the proper distribution of bins across the site to provide the maximum service. The value of  $d_{ij}$  calculated as the radius of a service area, provided by waste bins of type  $j$ .

$$d_{ij} = \sqrt{\frac{\text{Area covered by sources} \times Q_j}{\text{Total MSW generated by sources} \times \pi}} \quad (12)$$

It is to be noted that if in any case there is a contradiction between the above-mentioned conditions, then the preference should be given to the availability of space.

## 4 Case study

To illustrate and validate the proposed model and methods, it is applied in the city of Bilaspur, India. From Bilaspur, 15 wards (site) were taken in this study. The analysis of one ward is shown and described, while the results of all the other wards are presented.

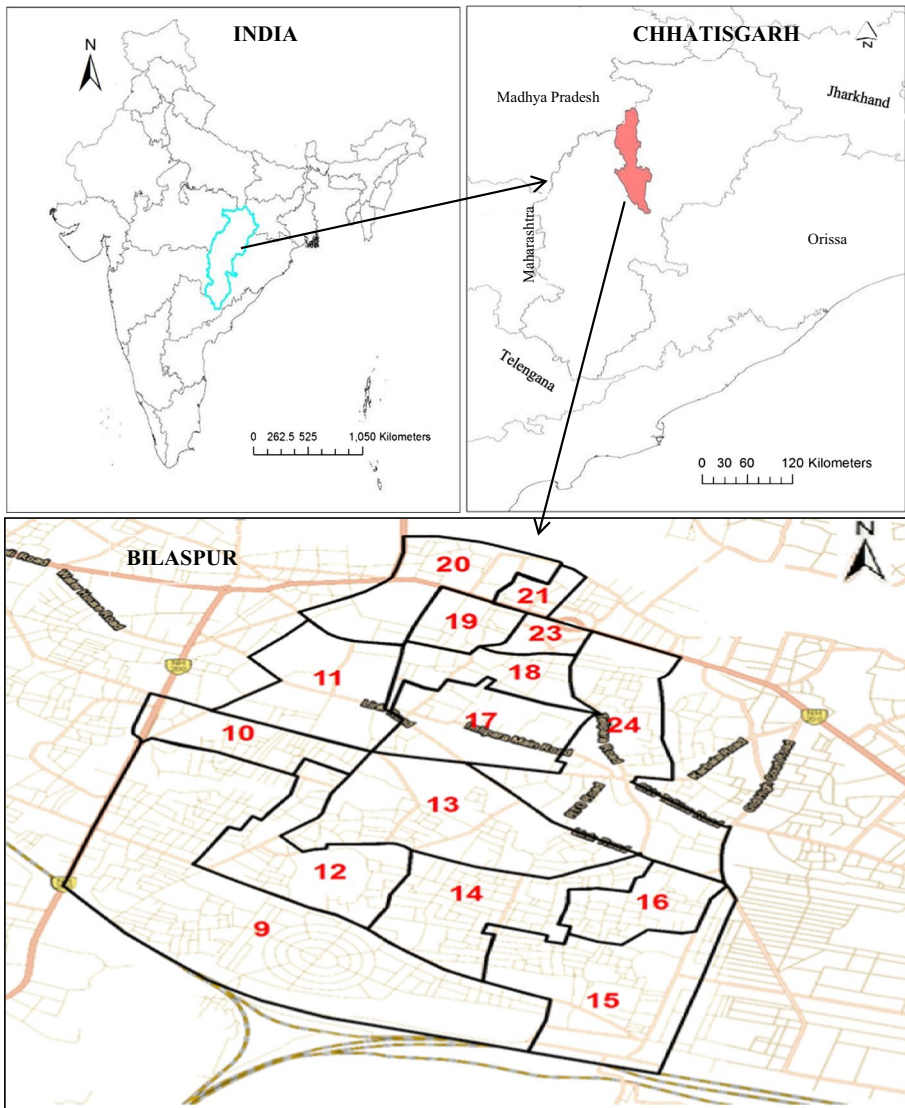


Fig. 2 Study area

#### 4.1 Study area and existing waste management system

As mentioned previously, the city of Bilaspur is chosen as a study area. Bilaspur (latitudes  $21^{\circ}37''$  to  $N23^{\circ}07''$  longitudes  $81^{\circ}12''$  to  $83^{\circ}40''E$ ) is one of the districts of the Chhattisgarh state, India, with the total population of around 355,745 residing in 55 wards. In this study, a total of 15 wards have considered (Fig. 2), which have 82,474 total populations residing in 16,743 households (Rathore and Sarmah 2019). The composition of MSW is organic or compostable (40%); recyclables (8%); plastics (8%); and inerts (textile, fine earth, rubber, etc.) (44%) approximately. Presently, Bilaspur Municipal Corporation (BMC) is solely responsible for the collection and disposal of MSW every week, and due to the lack of waste collection bins in the city, 60% of the population resorts to open dumping of waste. There is no practice of segregation of MSW at the source, and many wards do not even have waste bins to collect waste. Lack of collection bins is leading to too many collection points for municipality vehicles, which results in high idling cost and carbon emission (Table 2) (Arti et al. 2013). The existing collection system of MSW in Bilaspur is shown in Fig. 3. The current sources of generation of wastes and collection points in all the 15 wards are shown in Fig. 4a, b. The data were collected from BMC and survey.

Presently,  $1.7 \text{ m}^3$  (type I) and  $3 \text{ m}^3$  (type II) bins are used by BMC for MSW collection. During the collection of MSW, the vehicles remain idle for approximately 10 min at the time of loading of waste at each collection point. This idling of the vehicle increases the fuel consumption which results in high cost and carbon emission.

The time period for this study is taken as 5 years (2018–2023). As per the Census of India (2011), BMC was serving approximately 355,745 people in 2010–2011 and it has estimated that by the end of the year 2023 it will serve to 430,533 people (projection of population is done by arithmetical increase method). It is assumed that the present situation

**Table 2** Present situation of collection points in wards

Ward number	Population (2018)	Open dumping	Current no. of stop-pages		Total	Idling cost (INR)	Carbon emission (kg)
			Bin type I	Bin type II			
9	7736	29	2	0	31	4560	211
10	6021	20	1	0	21	3105	144
11	5023	19	0	0	19	2850	133
12	9544	35	4	1	40	5895	271
13	9062	28	0	0	28	4200	196
14	9110	30	2	1	33	4935	228
15	7324	29	0	0	29	4350	203
16	3541	16	0	0	16	2400	112
17	4665	20	1	0	21	3105	144
18	4672	17	2	0	19	2760	127
19	2282	7	1	0	8	1155	53
20	3024	21	1	1	23	3480	161
21	2553	9	0	0	9	1350	63
23	2391	7	2	0	9	1260	57
24	5526	30	1	0	31	4605	214
Total	82,474	317	17	3	337	50,010	2317

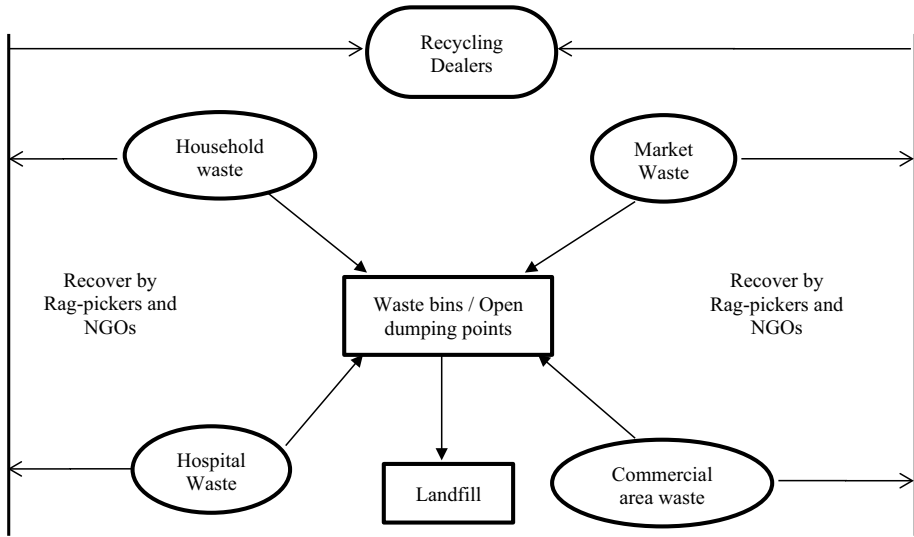


Fig. 3 Flowchart of existing waste collection system of Bilaspur city

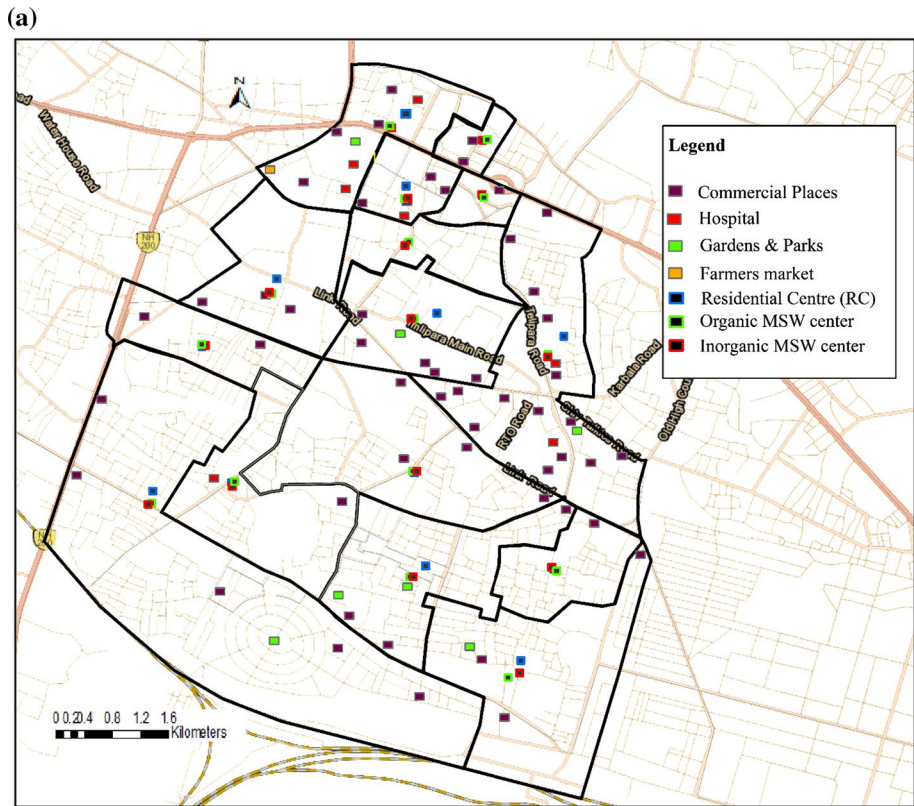


Fig. 4 a Presents selected sources of waste generation in 15 wards of Bilaspur city. b Present location of collection points in all 15 wards

(b)

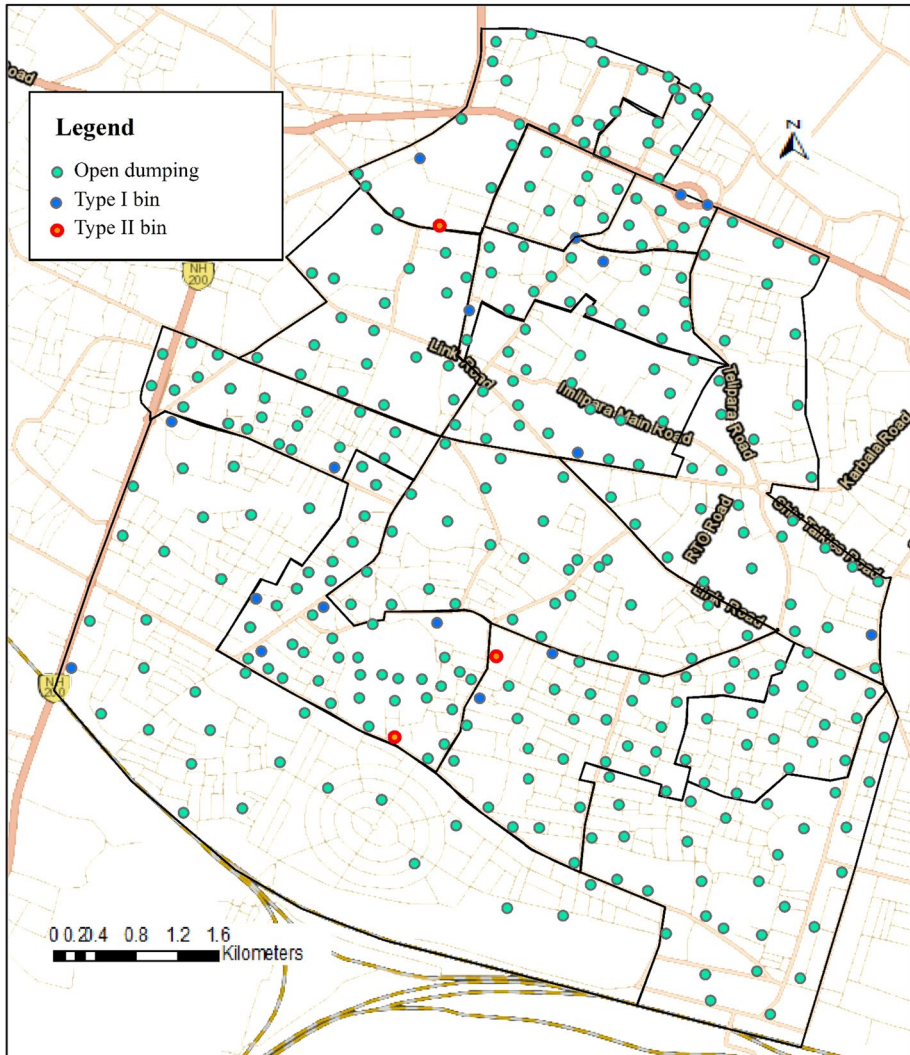
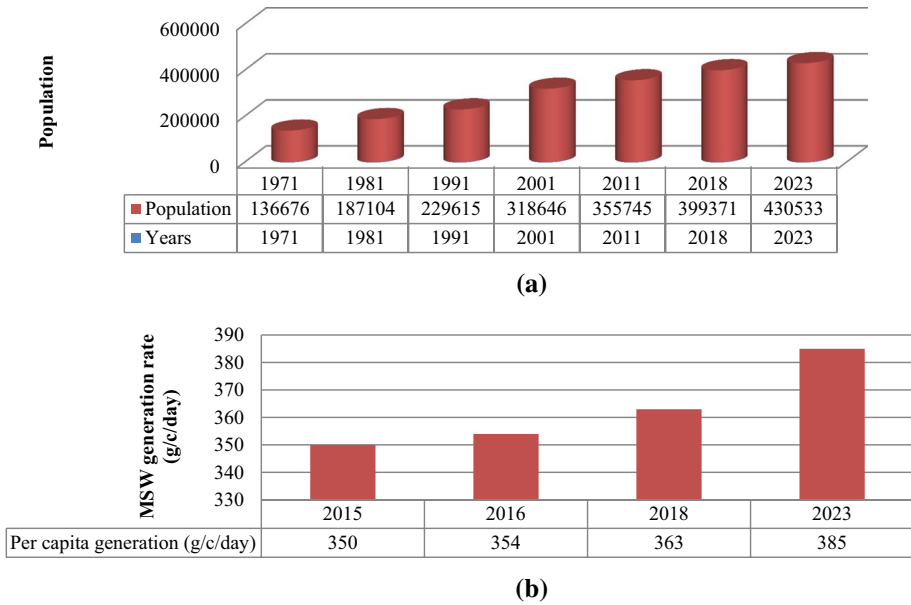


Fig. 4 (continued)

is fixed for 5 years and only population and per capita MSW generation is increasing. So that, the calculated number of bins should be able to serve for at least 5 years. The population projection is shown in Fig. 5a along with the projection of per capita waste generation (Fig. 5b) at the rate of 1.3% annually.

In the proposed system, we are considering two types of MSW: organic (compostable) and inorganic (recyclables, plastics, and inerts). A total of four types of bins are considered: two of 1.7 m<sup>3</sup> for organic and inorganic MSW, and two of 3 m<sup>3</sup> for organic and inorganic MSW. The value of  $\alpha$  is taken as the quantity of waste generated



**Fig. 5** a Presents population and b shows waste generation rate of Bilaspur by the end of the year 2023

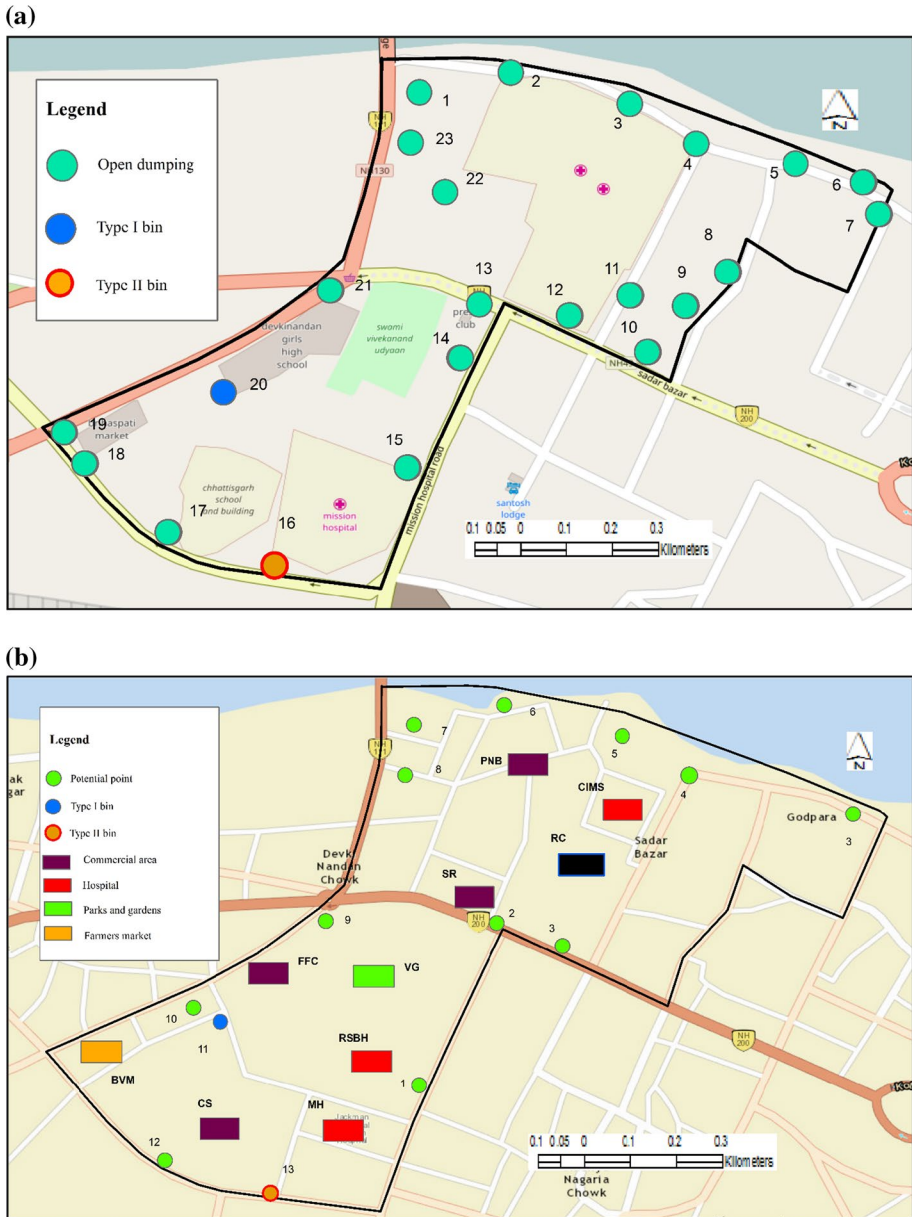
**Table 3** Forecasted generation of waste in Ward 20

Ward no. 20 (forecasted population = 4231)

Sources	Organic (kg/day)	Z <sub>o</sub> (%)	Inorganic (kg/day)	Z <sub>io</sub> (%)	Longitude (decimal degrees)	Latitude (decimal degrees)
Brihaspati Vegetable Market (BVM)	75	0	25	0	82.146	22.086
Chhattisgarh School (CS)	1.7	0	3	10	82.148	22.085
Mission Hospital (MH)	3	0	5	0	82.15	22.085
RSBH (H)	5	0	7	0	82.15	22.086
Vivekanand Garden	6	0	2	0	82.15	22.087
Fast Food Centre (C)	5	3	2	2	82.149	22.087
Santosh Restaurant (C)	3	0	1	0	82.151	22.087
Residential Centre (RC)	363	10	544	15	82.152	22.088
CIMS Hospital	115	30	143	0	82.153	22.088
Panjab National Bank (C)	0.7	0	2	0	82.152	22.089

by a household in a week so that MSW from every household should get collected i.e.,  $\alpha = \text{number of persons per household} \times q_k \times T$ .

As mentioned earlier, analysis of only one ward is presented here, but the results of all wards have been shown. From all the analysed wards, we have selected ward number



**Fig. 6** a Showing current collection points at Ward 20. b Showing sources and potential points of Ward 20

20 for presenting the analysis as it contains all the parameters which are required to test the model thoroughly. The ward number 20, named as Ram Nagar, has a population of 3024 at present. It is forecasted that Ram Nagar will have a population of around 4231 in the year 2023. At present, Ram Nagar has 3 numbers of hospitals (*H*), 1 farmers market (*M*), 1 park (*G*) and 5 commercial places (*C*) (Table 3). The present condition and locations of collection points of ward 20 are shown in Fig. 6a, and the locations of

sources along with the potential points are presented in Fig. 6b. Potential points are possible locations where bins can be placed.

## 5 Results and discussion

The proposed mathematical model is written and solved in linear programming solver ILOG CPLEX 12.2 to determine the number of bins. Software ArcGIS is used to create the data set and allocate the waste collection bins while selecting the best potential points. The number of bins calculated for Ward 20 is as follows: 12 type I bins—8 for organic and 4 for inorganics; 3 type II bins for inorganic only. As 1 bin of each type is already present, which are currently neither organic nor inorganic, so it depends on the decision-maker to assign the bins as per the requirement during the bin allocation procedure. In our case, bins are assigned to collect inorganic waste. Therefore, the actual number of bins required is 8 organic and 3 inorganics of type I bin along with 2 inorganics of type II bin. The total cost incurred is INR 394,000. The coordinates identified for the centre of organic sources is 82.1511 decimal degrees in longitude and 22.0876 decimal degrees in latitude. Similarly, the coordinates identified for inorganic sources are 82.1519 and 22.0878 decimal degrees in longitude and latitude. The value of  $d_{ij}$  calculated as 150 m as for bin type I and 450 m for bin type II. The selected collection points are 1, 2, 4, 5, 7, 8, 10 and 13 for organic and 1, 3, 4, 6, 9, 11 and 13 for inorganic. The allocations of bins in ward 20 are presented in Fig. 7.

Following the same methodology described above, the number of bins required in all the other 15 wards was calculated and allocated. The numbers of bins identified for every ward are shown in Table 4, and allocations of bins are presented in Fig. 8.

From Tables 2 and 4, it can be observed that the calculated number of bins in each ward is less than the number of collection points of wards at present. Due to a decrease

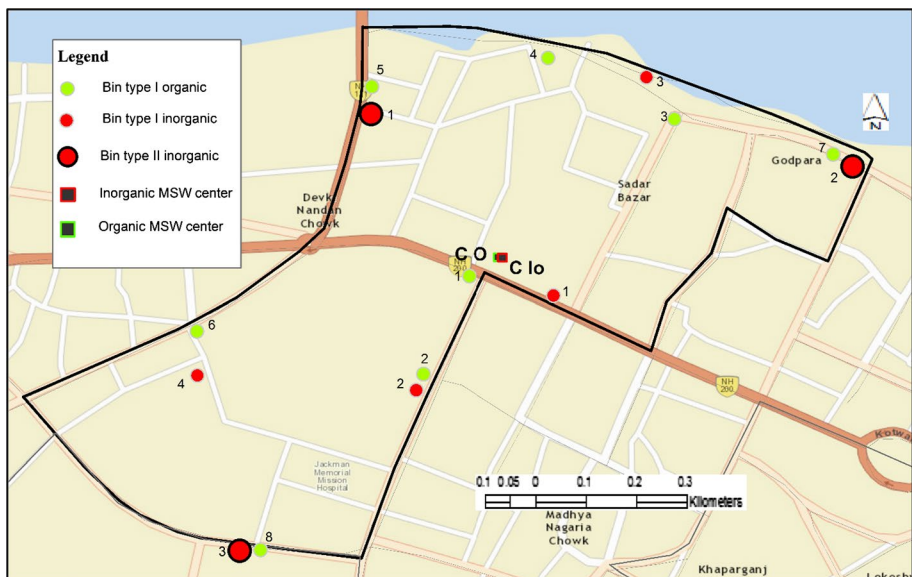


Fig. 7 Bin allocation in ward 20



**Table 4** Number of bins determined for all 15 wards

Wards	Bin type I		Bin type II		Total
	Organic	Inorganic	Organic	Inorganic	
9	10	12	2	3	27
10	5	8	3	3	19
11	7	6	1	3	17
12	13	21	2	0	36
13	14	10	1	2	27
14	14	6	1	8	29
15	11	11	1	3	26
16	1	8	3	0	12
17	7	6	1	3	17
18	8	5	0	3	16
19	1	0	2	3	6
20	8	3	0	2	13
21	1	4	2	1	8
23	1	2	2	2	7
24	11	9	0	3	23
Total	112	111	21	39	283

in the collection points, the number of stoppages of waste collection vehicles is also reduced, which results in less idling cost and emission of carbon. In Table 5, the reduced number of stoppages in each ward is shown along with the reduced cost of idling and emission per week. Comparison of the present condition and proposed scenario on the basis of idling cost and carbon emission in each ward is shown in Fig. 9a, b.

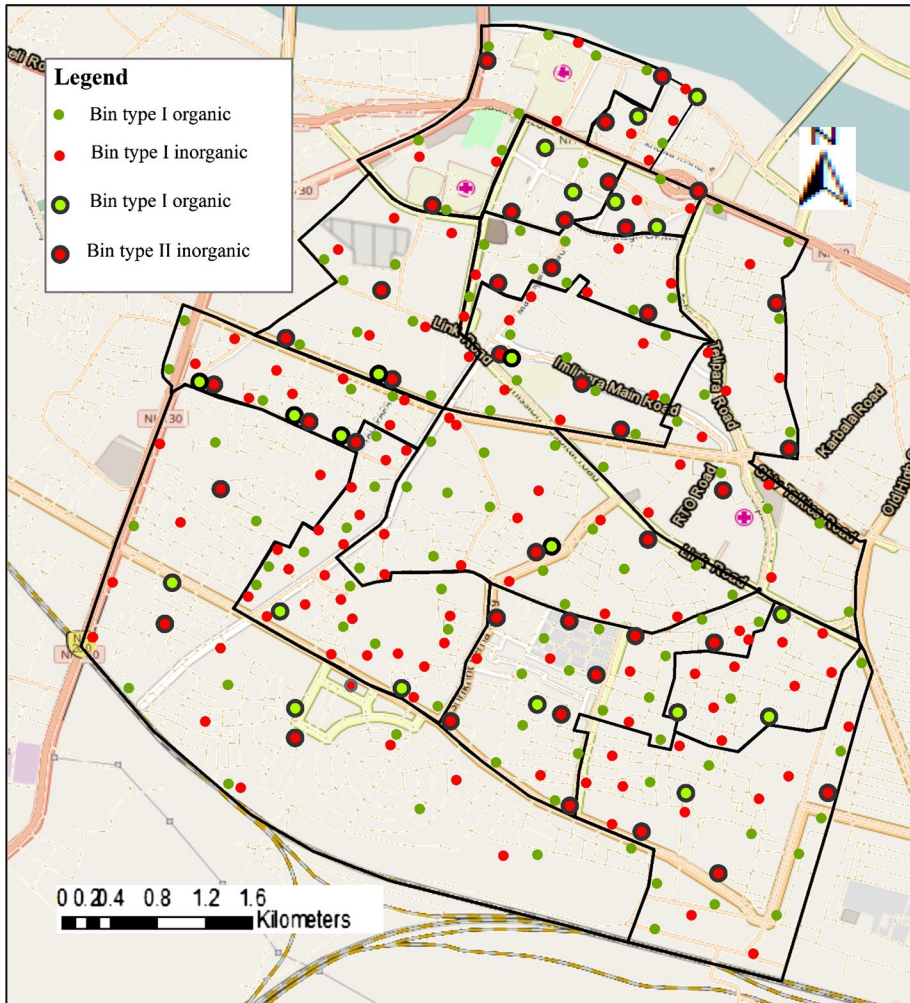
To check the behaviour of the objective function under different values of key parameters, sensitivity analysis is done. The analysis is presented below in the following subsections.

## 5.1 Sensitivity analysis

The per capita generation and frequency are the key parameters that affect the value of the objective function (total cost) (Eq. 1). To test the behaviour of the total cost against different values of the parameters, sensitivity analysis is done.

### 5.1.1 Analysis of per capita generation

The organic and inorganic per capita generation of MSW from households varies on a daily basis (NIUA 2015). To check the impact of this uncertainty on the total cost, a sensitivity analysis has done. The values of the parameter varied by  $\pm 15\%$  with respect to the present value and the total cost are obtained (Fig. 10). From Fig. 10, it can be observed that there is a linear relationship between per capita generation and total cost. Fifteen per cent increase or decrease in the value of the parameter increases or decreases the total cost value by around 15%. This means if the variation in per capita generation is minimized, then the variation in the total cost will also reduce. Less variation in total cost means more accurate determination of a number of bins. An accurate number of bins help to collect 100% MSW.



**Fig. 8** Allocation of bins across all 15 wards

### 5.1.2 Analysis of time period or frequency

As previously mentioned, the time period between two consecutive MSW collection by the municipality is 7 days. However, by that time organic MSW starts to decompose. Therefore, a sensitivity analysis is done to identify the optimal frequency based on the total cost. The proposed model is solved by varying the  $T$  from 1 to 7 days and the total cost per day is calculated (Fig. 11). It is found that the total cost per day is decreasing with the number of days and the rate of decrement is also decreasing. From Fig. 11, it can be seen that the reduction in cost in the first 3 periods (days) is very high, after that, from period 4 to 5 it is comparatively less, and after period 5, it is nearly constant. Thus, the optimal frequency of collection can be chosen as 5 days so that the total cost could be minimum and MSW can be collected before degrading.

**Table 5** Reduction in cost and carbon emission per week

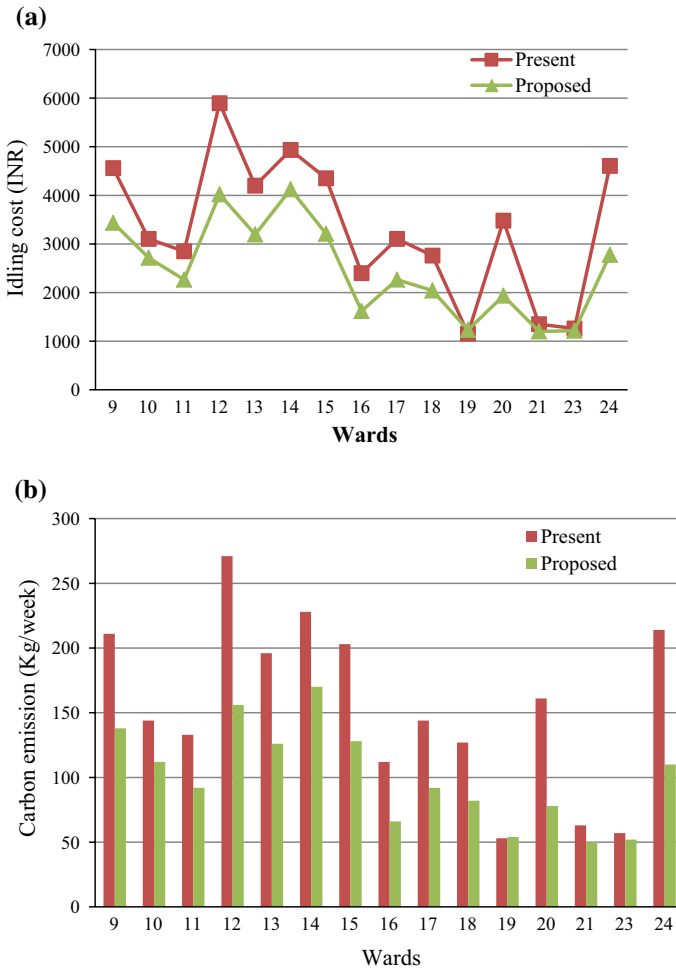
Ward number	Reduced number of stoppages	Reduction in idling cost (INR)	Reduction in emission (kg)
9	4	1125	73
10	2	390	32
11	2	585	41
12	4	1875	115
13	1	1005	70
14	4	810	58
15	3	1140	75
16	4	780	46
17	4	840	52
18	3	720	45
19	2	390	32
20	8	1545	83
21	1	150	13
23	2	45	5
24	8	1830	104
Total	52	12,765	811

## 6 Conclusion and future scope

We have considered the bin allocation problem of the waste collection system. The study presents a two-phase methodology for bin allocation: (1) determination of the number of different types of waste bins required in a site for various kinds of waste; (2) selection of the best potential points for allocation of bins. The proposed methodology integrates MILP and GIS tools to identify the number of waste collection bins and the best potential points. The proposed MILP model is solved in ILOG CPLEX 12.2 solver, and best potential points were identified using ArcGIS 10.

A real-world instance, the city of Bilaspur, India, is considered for testing the proposed approach. A total of 15 wards were analysed, and the results obtained show the effectiveness of the model in terms of reduction in the number of collection points by 15%. The decrease in the number of collection points leads to a reduction in idling cost by 25% and the reduction in carbon emission by 35% in per week. Annually, it gives a saving of INR 663,780 in idling cost and around 42 tonnes in carbon emission. Additionally, allocation of different types of bins for various kinds of wastes will help in the collection of the segregated wastes, which further sent for reprocessing facilities instead of landfills. Thus, the problem of large size landfills will also be solved.

Sensitivity analysis on per capita waste generation reveals the direct linear relation with the total cost. It shows that a high variation in MSW per capita generation gives a high variation in total cost. This will lead to the inaccurate calculation of the number of bins. Therefore, the variation in per capita generation should be minimum for determining the optimal number of bins at a minimum cost. Another sensitivity analysis is done on a time period parameter. It is observed that with an increase in the time period, the total cost per day is decreasing and the rate of decrement is also decreasing. From the analysis, it is identified that the time period of 5 days is optimal for the collection of MSW.



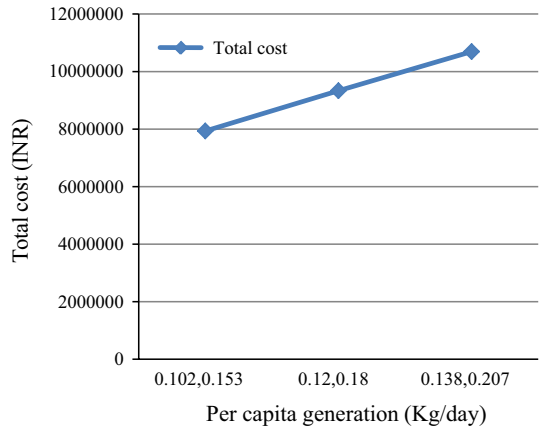
**Fig. 9** **a** Idling cost (INR) comparison between present and proposed. **b** Comparison of carbon emission between present and proposed

The proposed approach allows the decision-makers to increase the efficiency of their collection system while reducing the cost and carbon emission. The model ensures the collection of all the waste generated on the site while also considering the waste collected by rag-pickers, kabadiwalas and NGOs. The inclusion of safety factor makes sure that all the generated waste goes to the waste bins from which it can be collected by responsible authorities. The restriction on the availability of space helps the decision-makers to utilize the available land resource wisely and effectively.

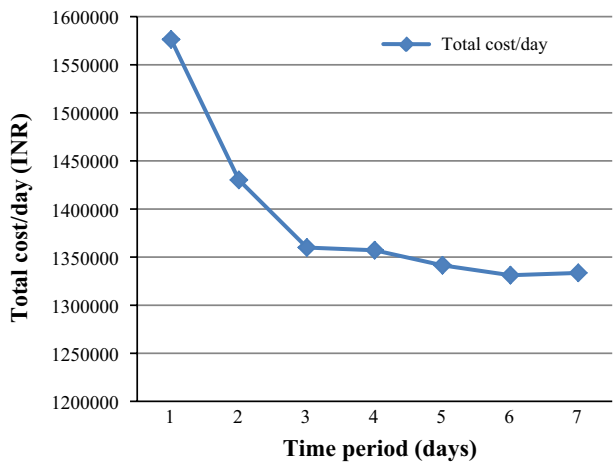
The proposed model is highly flexible as it can be used for different scenarios with a different type of waste having a different type of bins. It is applicable to special events like festivals when the generation of waste is very high as compared to normal scenarios.

The presented work can be extended further in numerous directions. Vehicle routing can be incorporated to further minimize the collection cost and carbon emission.

**Fig. 10** Variation in total cost due to per capita generation



**Fig. 11** Variation in total cost per day due to time period



Stochastic MSW generation can be considered to capture the daily variation in MSW. Other sources like industries, road sweeping etc., can also be incorporated while calculating the MSW generation. The model can be made more realistic by relaxing some of the assumption considered in this work.

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**Compliance with ethical standards**

**Conflict of interest** The author declares that there is no conflict of interest.

## References

- Abd El-Salam, M. M., & Abu-Zuid, G. I. (2015). Impact of landfill leachate on the groundwater quality: A case study in Egypt. *Journal of Advanced Research*, 6(4), 579–586.
- Abdoli, M. A., Rezaei, M., & Hasanian, H. (2016). Integrated solid waste management in megacities. *Global Journal of Environmental Science Management*, 2(3), 289–298.
- Ali, S. M., Pervaiz, A., Afzal, B., Hamid, N., & Yasmin, A. (2014). Open dumping of municipal solid waste and its hazardous impacts on soil and vegetation diversity at waste dumping sites of Islamabad city. *Journal of King Saud University Science*, 26(1), 59–65.
- Annepu, R. K. (2012). *Sustainable solid waste management in India*. Department of Earth and Environmental Engineering at Columbia University, pp. 1–189. Retrieved from [http://www.seas.columbia.edu/earth/wttert/newwtert/Research/sofos/Sustainable\\_SWM\\_India\\_Final.pdf](http://www.seas.columbia.edu/earth/wttert/newwtert/Research/sofos/Sustainable_SWM_India_Final.pdf). Accessed 7 Apr 2016.
- Arribas, C. A., Blazquez, C. A., & Lamas, A. N. (2009). Urban solid waste collection system using mathematical modelling and tools of geographic information systems. *Waste Management and Research*, 00, 1–9.
- Arti, S., Ayushman, M., & Bhawana, M. (2013). Urban sprawl development and need assessment of landfills for waste disposal: A case study of Bilaspur Municipal Corporation of Chhattisgarh, INDIA. *Journal of Environmental Research And Development*, 7(4), 1718.
- Badran, M. F., & El-Haggag, S. M. (2006). Optimization of municipal solid waste management in Port Said, Egypt. *Waste Management*, 26, 534–545.
- Bohm, R., Folz, D., Kinnaman, T., & Podolsky, M. (2010). The costs of municipal waste and recycling programs. *Resources, Conservation and Recycling*, 54, 864–871.
- Boskovic, G., & Jovicic, N. (2015). Fast methodology to design the optimal collection point locations and number of waste bins: A case study. *Waste Management and Research*, 33(12), 1094–1102.
- Census of India. (2011). Provisional Population Totals e India Data Sheet. Office of the Registrar General Census Commissioner, Government of India. Indian Census Bureau. Source: <http://censusindia.gov.in/>. Accessed 5 Apr 2016.
- Central Pollution Control Board. (2017). Management of Municipal Solid Waste. Ministry of Environment and Forests, Delhi, India. Source: [http://cpcb.nic.in/uploads/hwmd/MSW\\_AnnualReviewReport\\_2015-16.pdf](http://cpcb.nic.in/uploads/hwmd/MSW_AnnualReviewReport_2015-16.pdf). Accessed 15 Sep 2017.
- Chalkias, C., & Lasaridi, K. (2009). A GIS based model for the optimisation of municipal solid waste collection: The case study of Nikea, Athens, Greece. *WSEAS Transactions on Environment and Development*, 5(10), 640–650.
- Commission, P. (2014). *Report of the task force on waste to energy (volume 1)*. Retrieved from [http://planningcommission.nic.in/reports/genrep/rep\\_wte1205.pdf](http://planningcommission.nic.in/reports/genrep/rep_wte1205.pdf). Accessed 7 Apr 2016.
- Coutinho-rodrigues, J., Tralhão, L., & Alçada-almeida, L. (2012). A multiobjective modeling approach to locate multi-compartment containers for urban-sorted waste. *Waste Management*, 30, 2418–2429.
- Datta, M., & Kumar, A. (2016). Waste dumps and contaminated sites in India—Status and framework for remediation and control. *Geo-Chicago 2016 GSP 273* (pp. 664–673).
- De, S., & Debnath, B. (2016). Prevalence of health hazards associated with solid waste disposal—A case study of Kolkata, India. *Procedia Environmental Sciences*, 35, 201–208.
- Erkut, E., & Tjandra, S. A. (2008). A multicriteria facility location model for municipal solid waste management in North Greece. *European Journal of Operational Research*, 187, 1402–1421.
- Gallardo, A., Carlos, M., Peris, M., & Colomer, F. J. (2014). Methodology to design a municipal solid waste generation and composition map: A case study. *Waste Management*, 34(11), 1920–1931.
- Gandhe, H. D., & Kumar, A. (2016). Efficient resource recovery options from municipal solid waste: Case study of Patna. *India. Current World Environment*, 11(1), 72–76.
- Ghatak, T. K. (2016). Municipal solid waste management in India: A few unaddressed issues. *Procedia Environmental Sciences*, 35, 169–175.
- Ghiani, G., Laganà, D., Manni, E., & Triki, C. (2012). Capacitated location of collection sites in an urban waste management system. *Waste Management*, 32(7), 1291–1296.
- Ghose, M. K. (2006). A GIS based transportation model for solid waste disposal—A case study on Asansol municipality. *Waste Management*, 26, 1287–1293.
- Gupta, N., Yadav, K. K., & Kumar, V. (2015). A review on current status of municipal solid waste management in India. *Journal of Environmental Sciences*, 37, 206–217.
- Hazra, T., & Goel, S. (2009). Solid waste management in Kolkata, India: Practices and challenges. *Waste Management*, 29(1), 470–478.
- Hemmelmayr, V. C., Doerner, K. F., Hartl, R. F., & Vigo, D. (2014). Models and algorithms for the integrated planning of bin allocation and vehicle routing in solid waste management. *Transportation Science*, 48(1), 103–120.

- Kaushal, R., Varghese, G., & Chabukdhara, M. (2012). Municipal solid waste management in india-current state and future challenges: A review. *International Journal of Engineering Science and Technology*, 4(04), 1473–1489.
- Khan, D., & Samadder, S. R. (2016). Allocation of solid waste collection bins and route optimisation using geographical information system: A case study of Dhanbad City. *India. Waste Management & Research*, 34(7), 666–676.
- Kumar, V., & Pandit, R. K. (2013). Problems of solid waste management in Indian cities. *International Journal of Scientific and Research Publications*, 3(3), 1–9.
- Mehr, M. N., & Mcgarvey, R. G. (2017). Planning solid waste collection with robust optimization: Location-allocation, receptacle type, and service frequency. *Advances in Operations Research*. <https://doi.org/10.1155/2017/2912483>. Accessed 16 Jan 2018.
- Ministry of Environment and Forests (MoEF). (2010). *Report of the committee to evolve road map on management of wastes in India* (pp. 1–54). Retrieved from <http://www.moef.nic.in/downloads/public-information/Roadmap-Mgmt-Waste.pdf>. Accessed 5 Aug 2016.
- Ministry of Urban Development. (2016a). *MUNICIPAL SOLID WASTE part I: An overview*. Central Public Health and Environmental Engineering Organisation (CPHEEO) (pp. 1–96). Retrieved from <http://moud.gov.in/pdf/57f1e55834489Book03.pdf>. Accessed 5 Nov 2017.
- Ministry of Urban Development. (2016b). *MUNICIPAL SOLID WASTE part II: The manual*. Central Public Health & Environmental Engineering Organisation (pp. 1–604). Retrieved from [http://cpheeo.nic.in/WriteReadData/Cpheeo\\_SolidWasteManagement2016/Manual.pdf](http://cpheeo.nic.in/WriteReadData/Cpheeo_SolidWasteManagement2016/Manual.pdf). Accessed 5 Nov 2017.
- National Institute of Urban Affairs. (2015). *Urban solid waste management in Indian cities* (pp. 1–44). Retrieved from [https://pearl.niua.org/sites/default/files/books/GP-IN3\\_SWM.pdf](https://pearl.niua.org/sites/default/files/books/GP-IN3_SWM.pdf). Accessed 17 Nov 2017.
- Nguyen, T. T. T., & Wilson, B. G. (2010). Fuel consumption estimation for kerbside municipal solid waste (MSW) collection activities. *Waste Management and Research*, 28, 289–297.
- Purkayastha, D., Majumder, M., & Chakrabarti, S. (2015). Collection and recycle bin location-allocation problem in solid waste management: A review. *Pollution*, 1(2), 175–191.
- Rada, E. C., Ragazzi, M., & Fedrizzi, P. (2013). Web-GIS oriented systems viability for municipal solid waste selective collection optimization in developed and transient economies. *Waste Management*, 33(4), 785–792.
- Rathore, P., & Sarmah, S. P. (2018). Allocation of bins in urban solid waste logistics system. In *Harmony search and nature inspired optimization algorithms* (pp. 485–495). Singapore: Springer.
- Rathore, P., & Sarmah, S. P. (2019). Modeling transfer station locations considering source separation of solid waste in urban centers: A case study of Bilaspur city, India. *Journal of Cleaner Production*, 211, 44–60.
- Steuer, B., Ramusch, R., Part, F., & Salhofer, S. (2017). Analysis of the value chain and network structure of informal waste recycling in Beijing, China. *Resources, Conservation and Recycling*, 117, 137–150.
- Sukholthaman, P., & Sharp, A. (2016). A system dynamics model to evaluate effects of source separation of municipal solid waste management: A case of Bangkok, Thailand. *Waste Management*, 52, 50–61.
- Tavares, G., Zsigraiova, Z., Semiao, V., & Carvalho, M. G. (2009). Optimisation of MSW collection routes for minimum fuel consumption using 3D GIS modelling. *Waste Management*, 29(3), 1176–1185.
- Upadhyay, V., Jethoo, A. S., & Poonia, M. P. (2012). Solid waste collection and segregation: A case study of MNIT campus, Jaipur. *International Journal of Engineering and Innovative Technology*, 1(3), 144–149.
- United Nations. (2014). *World Urbanization Prospects: The 2014 Revision*. Department of Economic and Social Affairs, United Nations Publications. Source: <http://esa.un.org/unpd/wup/highlights/wup2014-highlights.pdf>. Accessed 19 Sep 2017.
- Vuji, G., Jovi, N., Redži, N., Jovi, G., Batini, B., Stanisavljevi, N., et al. (2010). A fast method for the analysis of municipal solid waste in developing countries—Case study of Serbia. *Environmental Engineering and Management Journal*, 9(8), 1021–1029.
- Zamorano, M., Molero, E., Grindlay, A., Rodríguez, M. L., Hurtado, A., & Calvo, F. J. (2009). A planning scenario for the application of geographical information systems in municipal waste collection: A case of Churriana de la Vega (Granada, Spain). *Resources, Conservation and Recycling*, 54, 123–133.