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ORIGINAL ARTICLE

Nature and extent of unauthorized waste dump sites in and around Bangalore city

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Abstract Bangalore city generates around 3600 tons/day of solid waste and a major constituent is organic (>70 %). The quantum of wastes generated is far greater than the capacity of the permitted waste treatment and disposal sites. As these sites are quite far-off, many of the trucks dump at unauthorized locations to reduce their transportation costs or meet their daily targets. To understand overall patterns, sources and reasons for dumping, an attempt is made to find the locations, composition and to assess the area of garbage spread at unauthorized dumps in and around the city. The field survey was conducted during August 2010 to April 2012 wherein the accuracy of three techniques (visual estimates, step measurement and Google Earth) was assessed to rapidly estimate area of garbage spread. The total number of unauthorized dumps located outside the core area was 393 and inside core area was 303. The results indicated that the visual estimates to determine the location and area of garbage spread were better in identifying locations of unauthorized dumps in a very short while and can be deployed to assess performance of various mega-cities in transition to good solid-waste management.

Keywords Unauthorized dump site · Waste · Method · Locations · Area

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Introduction

Unauthorized dumping of urban wastes refers to the open disposal of waste at private or public places other than the designated waste processing sites [1, 2]. This is now rampant in many rapidly urbanizing cities of developing countries, such as India where the required environmental laws are being implemented slowly and the waste processing infrastructure is being created even more slowly [3–5]. In this gradual transition, there is a need to understand the pattern, and choice of sites and likely reasons for unauthorized urban solid wastes (USW) dumping so that necessary control measures could be suitably effected. To minimize and control such environmentally unacceptable practices of unauthorized dumping, it requires that an inventory of unauthorized USW dump locations be made. Earlier studies showed that aerial photography interpretations, aerial photographs converted into digital format or temporal remote sensing data were used for identification or for monitoring of waste dump sites [6–13]. The major limitations of using aerial photographs or remote sensing data acquired through space-borne sensors are the difficulty to distinguish between general waste materials and the accompanying materials with similar spectral characteristics, identification of waste dump site near hilly or low-lying area and the high costs involved in obtaining digital data of such waste sites. In addition, finding the location of such dump sites based on questionnaires and other local information (newspaper) are limited in scope and scale [14, 15]. Conventional methods of carrying out a physical survey of unauthorized dump sites by trained persons would generally take long periods over which much of the dumped material and its spread would change significantly. It is believed that this would be the case with Bangalore USW generated 3600 tons/day, which has >70 % easily

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degradable organic material [4, 16]. These approaches have limited potential to detect a large majority of unauthorized dump sites as well as it limits the number of dump sites discovered when study periods are relatively short and dump sites keep shifting frequently. Locating a majority of such 'randomly' created dump sites accurately within a short period is, therefore, a challenging task.

The task of rapid estimation is often made easier because a large majority of the dump sites occurs only where there are motorable roads which the garbage laden trucks can drive on to carry out their unauthorized dumping. Such dumping is generally done using smaller roads which branch off the eight main arterial roads that emerge from the city of Bangalore [17, 18]. This pattern of occurrence and the need for being illegal provide researchers an advantage that such large motorable roads are often visible from aerial photographs and can be used easily to reach and locate these dump sites using handheld GPS (global positioning system) units. Further, a visual or physical measurement of the size or spread area may quickly be carried out at each location [19–26]. The size and depth of unauthorized dumps vary and such variations in the spread area of dump sites complicate the exercise of area estimation. It was felt that these limitations could be overcome by carrying out the rapid survey with a large team as well as by employing motorcycle-borne surveyors with provision for a limited level of random verification to assess the extent and types of errors. The approach of rapid large-scale survey has limited reliability and validity due to the limitations of visual assessments [22] and, therefore, random verifications are required to quantify variations and extent of errors. As the developing world urbanizes rapidly, rapid surveys of unauthorized dumping practices will be required [27].

This research, therefore, focuses on determining the efficiency and accuracy of rapid identification and assessment of (a) dump site locations and its shift with time and (b) dump site waste spread area and its composition. In this study, firstly a technique is developed to rapidly identify unauthorized dump locations, second to assess the area of land sacrificed and to compare possible techniques of area measurement and third to estimate the extent and nature of USW reaching such locations. The limitations of this technique with regard to the accuracy and types of errors encountered have been estimated and described.

Methods

The study area

The city of Bangalore is situated between 12°39′00″ to 13°13′00″ N and 77°22′00″ to 77°52′00″ E covering an area of 741 km^2. The entire study area was divided into 250 grids of size 2.7 km × 2.7 km. Unauthorized dumping of USW occurs both inside as well as outside the city boundary. Field investigations of dump sites were studied separately in three segments, namely, (a) inside core area of the city, (b) the region between the core area and the city boundary (outer city) and in (c) peripheral area of the city up to a buffer distance of 10 km from city boundary (Fig. 1). This distance of 10 km was chosen based on the earlier studies carried out in Bangalore [16, 17]. The surveys were carried out during pre- and post-monsoon periods of August 2010 to April 2012.

Identification of dump site locations

The first part of survey was focused on maximizing the identification of unauthorized dump site locations. This method involved the participation of 45 trained student volunteers riding on motorcycles. These volunteers were provided Google Earth (GE) images marked with probable dump sites. Volunteers were provided an initial orientation and hands-on training before undertaking the survey. They were trained in the usage of GPS, identification of wastes and estimation of their composition and determining the size of dump sites visually by taking them to a known dump site and assessing and validating the technique learnt. As a part of this preparatory field exercise to known dump sites, each group was required to make assessments visually, measure using footsteps and later calibrate the same with measuring tapes. Groups that could make repeated assessments within ±15 % error were selected for inclusion in survey group while others were provided remaining tasks such as collation, standby, etc. This ensured that there was a good match of recorded data among volunteers and compared the observations they made and allowed corrections to be made to become able to assess the length and width of dumps visually with a reasonable level of accuracy while also ensuring personal safety. Visual survey techniques are commonly used for estimation of target organism abundances in ecological field studies conducted in terrestrial [28–30] and aquatic environments [31, 32]. This approach facilitated covering a large area in a short time. It could be carried out with a basic level of training and was less expensive. This ensured that nearly all the unauthorized dump sites were surveyed and their locations identified and verified with reasonable accuracy. The approach and method included two stages.

In first stage, the purpose of site observation was to find the locations of unauthorized waste dump sites by traversing on motorable roads and paths in the designated grid. Each of the student volunteer team (2 persons) was allocated 2 to 4 grids to be completed in 2 days of survey time. All the dump sites discovered were photographed and

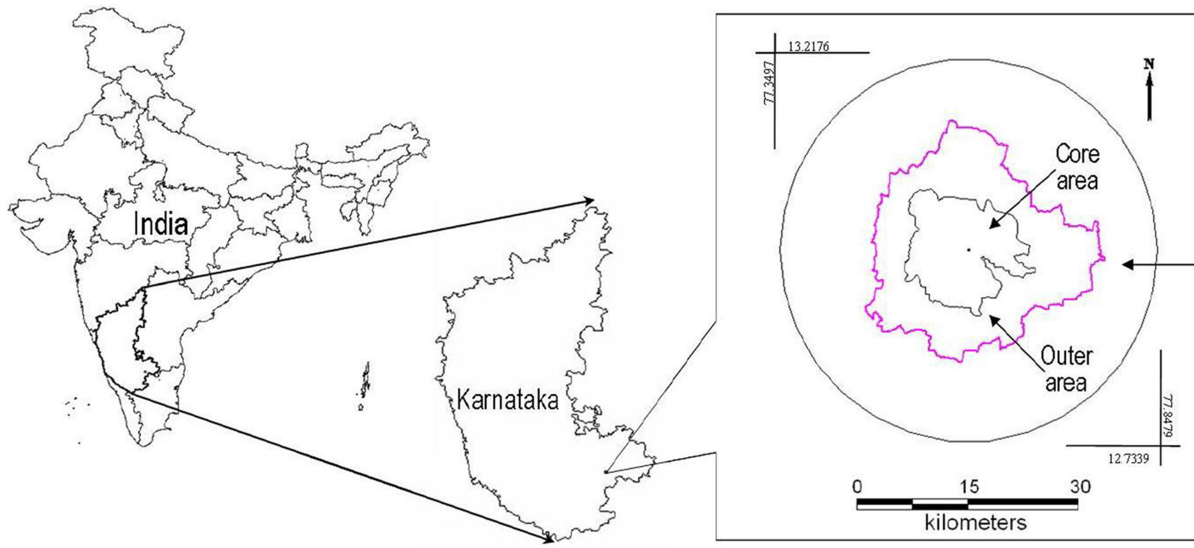

Fig. 1 Study area in and around Bangalore city

its location was determined using a calibrated GPS. Observations were recorded on hard copy of map (GE images of the respective grids). The USW spread area was determined by visually estimating the length and breadth of the dump while waste composition was determined based on visual inspection of 5–6 random regions of this dump. The training imparted allowed volunteers to identify the predominant type of waste within the dump. The most probable composition was then estimated by scanning about 5–6 randomly chosen 1 m^2 surface regions of the dump site to identify the predominant waste type. We have considered that most often the surface composition broadly represents the overall composition of wastes at the dump site because the waste is being brought from the same source over and over. This approach could identify the predominant waste type in dump sites. Rapid visual estimate was adopted (and necessitated) considering the local constraints including hostile attitude of the section of society dependent on waste for livelihood. The track points of volunteers were later verified using GE and compiled data were verified through field visit by an 'expert' to maintain accuracy of the assessment. A person who has measured more than 100 locations and who can achieve ±15 % accuracy of length and breadth is considered as an expert, and in this study 5 such experts were employed. Although it is very important to measure the height of dump to compute the volume of USW, with an uncertain nature of the terrain in Bangalore and the practice of dumping on the edge of a lake bed and abandoned granite quarry pits, it became impossible to determine the height/volume with accuracy without knowing the baseline height in each of these locations. As a start we examine only the area and expect to compute volume more accurately when baseline data begin to accumulate from a variety of sources and is validated for accuracy.

In second stage, identified locations and observations were verified in many ways. At the end of the survey of each grid, all GPS and physical data were downloaded and location or grid accuracy was validated by superimposing it on GE and estimates of composition were verified based on the photographs. These waste dumps were classified into six different categories based on the predominant form of wastes found during survey, namely—plastics, organic, construction debris, indeterminate (fresh wastes mixed up making segregation difficult), old (older dumps with traces of decomposed domestic USW and absence of most of the organic wastes) and others (non-USW wastes often from small industry, upholstery, etc.) based on waste type. After the survey of all the grids were completed (about 3–5 months) each of these participating groups submitted a report and made a presentation of their observations. Random field verification of the locations for both accuracy of location, size and general composition was carried out by experts. From a total of 696 dump locations identified by volunteers, an expert group randomly verified more than 40 % (269) of identified locations distributed across all the four quadrants of the city. The above total of 269 locations comprised 193 sites lying within the core city and 76 sites lying in the region outside the core city boundary. On the outskirts of the city at 33 selected locations the area of the dump site was physically measured using calibrated step measurement (SM) as used in step transect method [33] and these locations were also measured for their area using GE. Physical measurement of dump area was done through the measurement of dump length and width wherever these dumps were predominantly rectangle in shape or physically and socially accessible. Locations suffering continuous dumping over 2 to 3 years could be identified in GE (spatial resolution 0.5–30 m). Hence, comparison of expert-based area estimate versus volunteer estimates was, therefore, done predominantly with long-term older dump sites to ensure greater accuracy.

Monitoring of locations

A second survey was carried out after the completion of the first year survey by an expert team. A total of 452 locations visited by student volunteers during the first year were revisited. This was conducted to monitor whether the dumps identified in the previous year were continued. New dump locations in the peripheral area outside the city were also identified.

Data analysis

Regression analysis was carried out for all the USW dumps whose spread area was determined by SM with the dump spread area estimated by other methods such as, GE or Visual estimation (VE) to assess the probable relationships [19]. Mean and standard deviation were also estimated for different waste categories. In addition to this, a paired "*t*" test was conducted to determine grid-wise change in number of dump locations that had occurred in two consecutive years of field survey. All statistical analyses were performed with PAST software [34].

Results and discussion

Spatial locations of dump site

A total of 162 grids were covered in the survey carried out during the first year and 696 unauthorized dumps were found to be located in 122 grids. These dumps were found in all the four quadrants of the city (namely, North East (NE), South East (SE), South West (SW) and North West (NW) despite significant differences in the level of development and access to the city centre (Table 1). The average intensity of dumps was 0.55, 0.69, 0.82 and 1.23 dumps/km^2 in NE, SE, SW and NW, respectively. There are seven grids situated in SW and NW of the city having more than 14 occurrences of dump location. Most of these sites are located at a distance of more than 1.5 km from the city's main road network (National Highways, State Highways and Major District Roads) which connect one end to other end of the city or passes from centre to periphery of the city (Table 2). Out of these abovementioned seven grids, four grids falling inside core city area are more urbanized with high proportion of built-up area compared to other three grids outside the core city boundary where the grid area is predominantly represented by open land.

Contrary to expectations, 303 dumps were found within core area of the city (Table 1). The average intensity of the spread of such dumps was 2 dumps/km^2. These dumps were distributed non-uniformly in the four quadrants of the city (Fig. 2a). The number of dump sites determined was 27 (NE), 10 (SE), 54 (SW) and 212 (NW). The number of dump sites was highest in NW although the NW quadrant is the closest quadrant to the only authorized waste processing site in Bangalore.

Bangalore city administrative jurisdiction was redefined in the year 2006 by merging 8 neighboring Urban Local Bodies (ULBs) and 111 villages of Bangalore urban districts. Many of these areas have not been urbanized and the character of land use and intensity of use in many parts of the outer area closely resemble the area in the periphery of Bangalore city even before their inclusion into the city. Therefore, these two zones have been taken up as one in this study to interpret the observed results and needs to be used for other cities too. The unauthorized dumps located outside core city area were 393, distributed in all four quadrants of the city (Table 1). The average intensity of the spread of the dumps per grid was 4 (1 dump/km^2). Most of the dumps are located near to the main road network which can bear the weight of waste loaded trucks and also close to vegetation covered areas, hilly regions, barren unused land or water body. The number of dump sites were 90, 143, 125 and 35 in NE, SE, SW and NW quadrants, respectively. SE and SW quadrants of Bangalore city do not have any centralized USW processing and disposal facilities nearby. Whereas, the NE and NW are closer to existing centralized waste transfer and waste disposal sites such as Mandur and Mavallipura, respectively (Fig. 2b). Therefore, the higher numbers of the dumps in the SE and SW quadrants of Bangalore may be attributed to the greater distance of transport to the processing site and resulting reluctance by

Table 1 Quadrant-wise spatial distribution of dump locations

City	Number of dump locations				Total
	North–East	South–East	South–West	North–West	
Core	27	10	54	212	303
Outer	14	43	91	11	159
Periphery	76	100	34	24	234

Table 2 Description of grids with many of dump site

Grid number	Number of dump locations	Grid details		
		Location	Road network	Type
121	161	NW and inside city	Near outer ring road	Urban area
142	23	NW and inside city	Near NH 7	Urban area
143	15	NW and inside city	Near NH 7	Urban area
227	14	SW and inside city	Near SH 681	Urban area
204	7	SW and inside city	Near NH	Urban area
226	17	SW and outside city	Near outer ring road	Urban area
246	19	SW and outside city	Near SH 209	Urban area and barren land
225	18	SW and outside city	Near outer ring road	Urban area and barren land

transporters or related system to carry it away to the logical place. Transporting a truck load of USW through the city to the permitted disposal site, Mavallipura, could take as much as 2 h while these sites are only 20–40 min away in the northern quadrants. The permitted processing facility closes at sunset. However, collection vehicle already loaded with waste when delayed beyond 4.30–5.30 pm end up parking a fully loaded truck overnight at the gates of the processing site. This potentially becomes one of the major reasons for waste transporter to resort to unauthorized dump sites in NW segment and forms an exception to the pattern of dumping followed in the other three quadrants.

Composition of wastes in dump sites

Out of the possible six types of dominant wastes found at dump sites described under methods, 73.9 % of the total number of locations had construction debris and plastic wastes and to a smaller extent organic wastes. The predominant component of wastes recorded in unauthorized dump sites was construction debris followed by plastic and organic waste. Considering that a large part of the unauthorized dumps contain construction debris, it is imperative that alternative uses for them need to be evolved to recycle them back into the construction industry. This is important because India and more importantly Bangalore faces a significant shortage of construction materials mainly sand and aggregates and, therefore, recycling construction wastes back into the construction industry can make this industry a lot more sustainable [35]. Plastics and organic wastes occur next in the order of dominance among 25.3 and 23.3 % of total dump locations, respectively. Bangalore city houses a very large plastic recycling industry dominated by small units (1 tpd scale) and such a spread of plastic wastes, therefore, suggests that it would be more sustainable to locate these small units where plastic wastes dominate.

The dump sites located inside core area had organic wastes followed by construction debris and plastic (Fig. 3a), respectively, and outside core area's major contribution came from plastic and construction debris (Fig. 3b). From the dominant waste type found at the dump site and possible reasons for their occurrence it may be surmised that within the core area of Bangalore city, these dump sites occur due to inefficient and improper collection as maximum number of dump sites predominantly have organic wastes and the composition closely resembles fresh domestic wastes [16]. The presence of food and kitchen wastes, highly perishable wastes, shows that these dumps are ephemeral and are cleared within a weeks time. The organic fraction dominant unauthorized dump sites outside the city have a somewhat different character. The presence of organic wastes components at various stages of decomposition suggested that these dumps are not ephemeral in character. These are long-lasting dump sites in comparison to dumps situated inside the core area. After a certain point of time, either due to large size of dump site or due to the loss of cover and anonymity, they are abandoned.

Size-wise distribution of dump sites

Unlike developed countries, Indian waste (especially freshly collected wastes in Bangalore) has a large fraction of decomposable organic matter [16]. Most of organic matter decomposes while leaving behind predominantly the non-decomposable fraction that gradually spreads over the area and becomes unaesthetic. Table 3 shows the mean, range and standard deviation of physically measured area estimated at 33 locations for construction and non-construction waste categories. The greatest area was recorded for construction waste category. The land area occupied by these dump sites varies significantly in size. Table 4 presents the mean, range and standard deviation with three

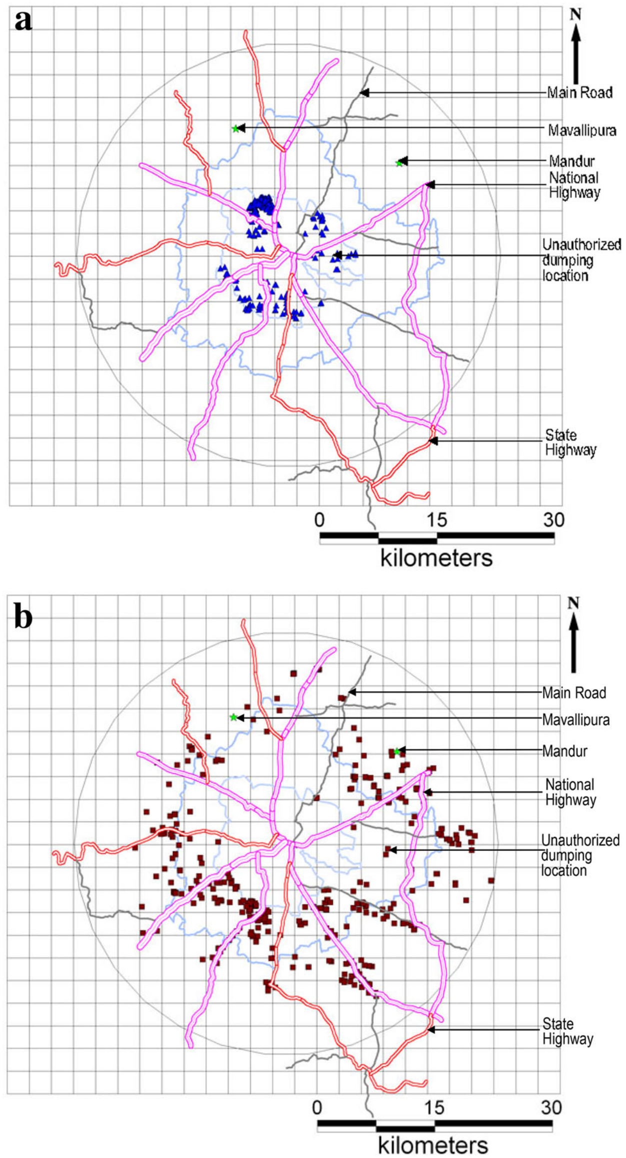

Fig. 2 **a** Spatial distribution of unauthorized dump sites found inside the core area. **b** Spatial distribution of unauthorized dump sites found outside the core area

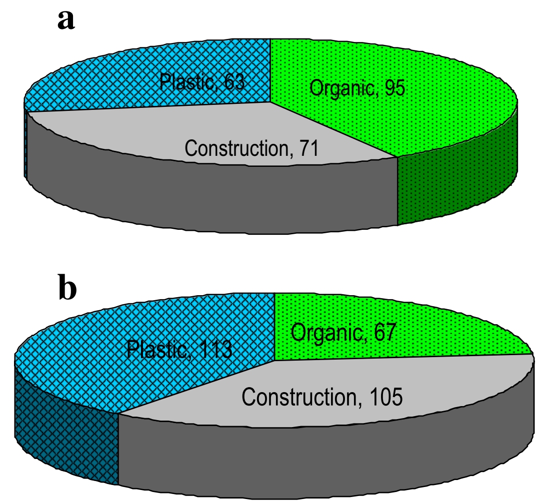

Fig. 3 **a** Predominant wastes of dump site locations found within the core area (expressed as number of locations found). **b** Predominant wastes of dump site locations found outside the core area (expressed as number of locations found)

size classes chosen for waste spread area namely, <200, 200–400 and >400 m^2. Waste dumps which are in class of >400 m^2 occupy greatest area. This suggests that there is pattern in the dumping at each of these locations and these locations also remain functional over a specific period of time. These dump sites are used at irregular hours and the act of unauthorized dumping cannot be easily detected and monitored. Therefore, regular survey or assessment of dump sites area can assist in making decisions on planning and improving the quality of solid-waste management by the city authorities.

A physical survey that involves measuring the length and breadth of all of such dumps is not possible because, as mentioned under methods, people residing nearby these 'unauthorized' dumps often vehemently oppose such surveys and volunteers can suffer harm. Second, as material dumped is loose, physical measurements can lead to injury and even death. Therefore, alternatives need to be developed. To overcome these survey difficulties, in this study the spread area of 33 dump sites was assessed by three methods of SM-, VE- and GE-based assessment. Using coefficient of variability (CV) as an index [19, 23], the VE method of area estimation was found to be the most accurate having a CV of 2 %. A higher CV value (5 %) has been found for GE method. The correlation coefficient in Table 5 for expert's estimate with VE is more than that with GE. Both these measures show weak correlation with the physically step measured area. In both types of area estimation, there is a decrease in correlation coefficient with an increase in the dump size except for 200–400 m^2 category of waste dump sites. This suggests that smaller dumpsites are estimated more accurately compared to the large dump sites. The correlation coefficient for VE is −0.538 and 0.300 for dump sites of <200 and >400 m^2, respectively. Similarly for GE method, the correlation coefficient is −0.386 for unauthorized dumps of size <200 m^2 whereas for unauthorized dumps of >400 m^2, it is −0.217. In general, there are both underestimation as well as overestimation in area for the different categories of waste; a similar phenomenon where agriculture-related observers have overestimated low herbage volume and underestimated cases with high herbage volumes [36]. From this study, it appears that a higher accuracy of assessment can be achieved in two ways. Firstly ensuring that volunteers are trained better and exposed to a larger

Table 3 Mean, range and standard deviation of waste dump area (m^2) physically measured at site for different waste categories

Waste category	No. of samples	Mean ± SD	Range
Construction waste	17	2592.10 ± 7180.40	9–30,000
Non-construction waste*	16	658.10 ± 878.70	23–3500

* It includes plastic, organic, indeterminate and other categories of waste

SD standard deviation

Table 4 Mean, range and standard deviation of waste dump physically measured area (m^2) for different classes

Class categories (m^2) for physically measured area	No. of samples	Mean ± SD	Range
<200	11	86.8 ± 61	9–180
200–400	10	296.8 ± 52.4	223–397
>400	12	4222.8 ± 8216.7	486–30,000

SD standard deviation

Table 5 Linear regression between physically measured area and estimated area of waste dump (at *p* value >0.05)

Class categories (m^2) for actual area	No. of samples	Physical vs GE		Physical vs VE	
		Residual SD	*R*	Residual SD	*R*
<200	8	522.0	−0.386	159.0	−0.538
200–400	9	279.0	0.308	70.0	0.151
>400	9	3338.0	−0.217	14.0	0.300

SD standard deviation)

sample size prior to visiting actual dump sites. On the other hand, this approach could still be used; however, the area needs to be classified into at least three classes as done in this study with varied accuracies. Therefore, it is concluded that VE can be used reasonably well for smaller areas. Visual assessment of dump area is an efficient, rapid and non-risky method for determining the area of USW spread at these unauthorized dumps. However, continuous calibration of the observer's estimates is required to maintain the method accuracy.

Temporal change in dump sites

New dumpsites are being created constantly in this study area while older dumps are being abandoned after a certain period of usefulness. Dump sites inside core area of the city are ephemeral and their contribution to the overall waste spread area accounts for <20 %. Therefore, the second survey that examined the extent of earlier dump sites used in subsequent year was restricted to outside core area of the city. In the second year survey, a total of 452 locations were visited in the very same grids which were visited earlier by student volunteers of the first year. It includes 125 new dump locations and 327 old dump locations (Fig. 4). The site where 128 earlier dump site existed had now become locations for the construction of new buildings. The average intensity of dumpsites was 0.69, 1.1, 0.69 and 0.41 dumps/km^2 in NE, SE, SW and NW, respectively. Compared to the first survey, the frequency of dump site per grid in the second survey had reduced in SW and NW quadrants, whereas, there was only a small reduction of dump sites in NE and SE quadrants. A paired *t* test was performed to check grid-wise change in number of dump locations for the two consecutive years of field survey. This confirms that there is a significant change in grid-wise locations observed in two complete surveys conducted outside core city area at $p < 0.05$ ($\alpha = 0.05$, $n = 87$). Thus, there is a continuous temporal change in waste dump locations and we need to adopt methods that can locate dump locations in minimum time and possibly at the lowest cost.

The results of this study demonstrated that such a method was preferable to identify locations of unauthorized dumping as well as quantify the composition and extent of wastes spread through dump sites. However, there is a lower potential to accurately determine spread of the dump sites through visual methods. Thus, with this approach an assessment can be replicated and applied to other cities.

Fig. 4 Change in number of unauthorized dump site locations with time

Conclusions

An assessment of unauthorized waste dump sites was carried out for finding its locations and analyzing composition and spread area. It shows that method adapted and described can help to find locations of unauthorized dumping at a lower expense of time, money and effort within reasonable level of accuracy. Visual estimates can be used to measure dump area for smaller dump sites (<400 m^2). However, differences exists among volunteers' groups regarding how visual scale is perceived and reported. This showed weak correlation with actual measurement. To increase the level of accuracy of measurement, a greater level of training is required before starting of field survey. A total of 696 locations were identified by student volunteers and most of the locations had construction waste, plastic and organic waste in order of predominance. Waste dumps which are in class of >400 m^2 occupy greatest area. There is continuous temporal change in these dump site locations, so we need to adopt rapid methods of surveys to locate these dumps in short time durations. The amenability of the method to adapt to various locations makes it repeatable and applicable in other cities where unauthorized dumping is a common practice of waste management.

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