Sustainable Landfill Site Selection for Construction and Demolition Waste Management Using GIS and AHP

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Abstract The generation of Construction and Demolition (C&D) waste, which forms 30% of total Solid Waste, adds to the non-biodegradable component of inert waste. Majorly produced by the construction industry, this waste has a recycle value for the same industry. By proper fragmentation, treatment and disposal/recycle, demolition debris has a huge scope for application in landfilling or building non-structural elements like pavement blocks. But the current practice of mixed waste collection and disposal does not explore this potential of C&D waste. The city of Greater Mumbai is facing a crisis due to the limited availability of appropriate waste-land within the city. The authorities have stalled any new construction projects due to lack of operational dump sites. With a view to have separate landfill sites for C&D waste, and to identify the sites that could be available for the next 20–25 years, spatial analysis has been carried out in this study using ArcGIS. The criteria used for mapping sites include the buffer distance from water bodies, wells, forests, residences, heritage sites, airport, and roadways and site area. Site selection results have been processed further using Analytical Hierarchy Process (AHP) to identify and prioritize the limited number of sites that could be developed for future demands. This study would help town planning departments to identify land for waste processing and collection centers in other congested cities of India which are major contributors to Solid Waste.

Keywords Sustainability · Circular economy · Landfilling · Analytical hierarchy process

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1 Introduction

The megacity of Mumbai with a population of 13 million produces approx. 9000 MT/D of Solid Waste (SW) which is predicted to increase five-fold to 45,000 MT/D in 2041 corresponding to population growth [11]. The landfill sites currently in operation at Mulund and Deonar are packed to their full capacity. Kanjurmarg bio-reactor landfill site can process only 3000 MT/D of SW [10]. Supreme court has stalled any new construction activity in Greater Mumbai city due to the inability of local authority, i.e., MCGM to deal with and safely dispose the Solid Waste and Construction and Demolition debris. The imposed ban will continue until new Construction waste disposal sites are operational. Since construction activities are a direct generator of Construction and Demolition (C&D) waste, proper waste disposal operations including on-site processing and recycling, collection, transportation of remnants, treatment and landfilling need to be systematically planned. In order to emphasize on separate handling of Construction waste, C&D Waste Management Rules, 2016, have been formulated by Ministry of Environment, Forest and Climate Change (MOEF&CC). The ability to recycle and reuse such material requires technologically advanced methods. There is a wide scope for utilizing the recycled material in non-structural concrete, paver blocks, lower layers of road pavements, colony and rural roads, etc., which needs to be explored to form a circular economy of materials used in the construction industry. This study was undertaken to fulfil the following objectives-

- To identify suitable disposal sites for Greater Mumbai region taking into account the constraints set by MOEF&CC in Construction and Demolition Waste Management rules, 2016.
- To obtain ranking of the suitable sites for a sustainable Waste Management plan

Out of the total Solid Waste handled by Municipal Corporation of Greater Mumbai (MCGM), 30% is C&D waste which amounts to 2700 tons per day [12]. According to the C&D Waste Management Rules, 2016 [9], ‘Every waste resulting from construction, re-modelling, repair and demolition of any civil structure of an individual or organization or authority’ comes under the category of C&D waste. Brick bats, concrete, excavated earth, boulders, topsoil, metal and plastics, cellulosic materials, timber, lumber, roofing and sheeting scraps, crop residues, rubble, broken concrete, plaster, conduit pipes, wire, insulation, etc., are considered to be C&D waste as per National Building Code, Vol. 2, 2016 (Fig. 1). There is huge economic potential in bridging the construction materials demand–supply gap by recycling and reusing C&D waste as per Central Road Research Institute and Central Research Board [8].

Among all Multicriteria decision-making techniques, Ding et al. [3] state that AHP is effective in identification and ranking of suitable sites in a given region. Criteria selection based on regulations considering environmental, social and economic aspects has been implemented in landfill site selection. Karimi et al. [4] have applied a combination of AHP and GIS to select municipal landfill sites in Iran. The buffer distances and slope criteria maps were overlayed and standardized using fuzzy theory

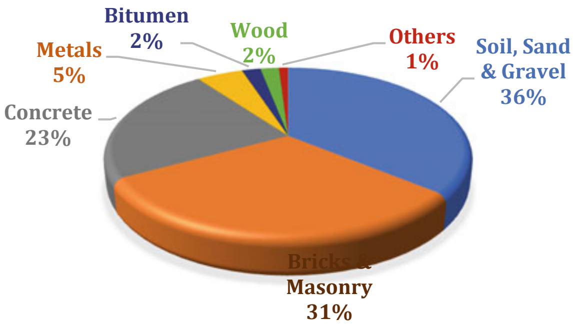

Fig. 1 Typical C&D waste composition in India. *Source* Toolkit on C & D waste management rules-2016 [12]

followed by AHP to obtain landfill suitability map. A GIS-based study for locating potential landfill sites has been carried out by Colvero et al. [1] for the Goias county in Brazil. The study by Chang et al. [5] used GIS tool to identify candidate sites for landfilling based on buffer distances decided by previous studies. Fuzzy Multi-criteria Decision Making (FMCDM) was applied followed by a sensitivity analysis by Monte Carlo technique, to find the pros and cons of developing potential sites in Harlingen, South Texas. Fuzzy preference ratings were given based on the opinion of two planning experts. Rajiv Gupta et al. [6] made use of GIS tools and Fuzzy Analytical Hierarchy Process (FAHP) to rank sites for the installation of solar plant in Rajasthan state, India.

The current study is similar in terms of the tools applied. The results obtained would be useful to prioritize suitable landfill sites for C&D waste disposal, treatment, and recycling facility development.

2 Materials and Methods

For fulfilling the objectives of this study, it was required to identify available Solid Waste disposal sites subject to the constraints for developing disposal sites as laid down by the MOEF&CC. These are the criteria for site selection for Storage and Processing or Recycling Facilities for Construction and Demolition Waste mentioned under Rule 7(1) of C&D Waste Management Rules, 2016 given in Table.1 as buffer distances.

Project Phase-1: The identification of sites was done using ArcGIS 10.2, which is a Geographic Information System (GIS) tool developed by ESRI. The features as images and co-ordinates data, which geographically represent the criteria with regard to the construction of landfills, were obtained from the below sources (Table 2):

The restriction values in Table 1 were then applied to these criteria to obtain vector feature maps. All maps were produced in WGS 1984 coordinates. Next, criteria feature maps were created using buffer tool and providing the distances in

Table 1 Restrictions on the construction of landfills in India

Sr. No.	Restricted areas	Distance of buffer zone
1	Flood plains as recorded for past 100 years, CRZ, wetlands, critical habitat and eco-fragile areas	Permitted 100 m beyond HTL (CRZ regulation 2011)
2	Airport or airbase (NOC required)	10 km
3	Habitation clusters, highways	200 m
4	Forest areas, parks	200 m
5	Ponds, water supply wells	200 m
6	Rivers	100 m
7	Ground water table less than 2 m below GL	Not permitted
8	Heritage sites	500 m
9	'No development' buffer zone within selected site	500 m

Source Construction and Demolition Waste Management Rules, 2016, MOEF&CC, Govt. of India

Table 2 Geographical features as per the criteria for site selection and the data sources

Sr. No.	Feature	Data type	Data Source
1	Lakes, rivers, Forests, habitation zones	Image	Website on Mumbai Data developed by Akshay Kore
2	Airport and airbase, highways	Image	Google Earth
3	Wells, spots with GW less than 2 m below GL	Coordinates	India- WRIS (Water Resource Information System)
4	High tide line	Image	Maharashtra Remote Sensing Application Centre Coastal Zone Studies 2006
5	Heritage sites	Coordinates	Google Earth

Table 1 as input. The erase tool was used to eliminate the area within the buffer from the remaining area. Lastly, an overlay map (Fig. 2a) of all the criteria feature maps applied together was created. The void areas obtained thus became the sites suitable for landfill development. Taking only the significant areas into consideration, a final map (Fig. 2b) showing all the suitable sites thus obtained was created. The area measurement tool was used to measure the areas of each individual polygon shapefile from the suitable sites map (Fig. 2b). Along with the distances measured from highways, Table 3 shows the areas of each site.

Project Phase-2: The suitable sites were ranked based on their proximity from the features used as criteria and the area of site for selection. The Analytical Hierarchy Process (AHP), developed by Thomas Saaty [7], is a discrete multicriteria decision making process of relative ranking on absolute scales of criteria based on expert judgment. It converts the set of unrelated criteria into a system of priorities

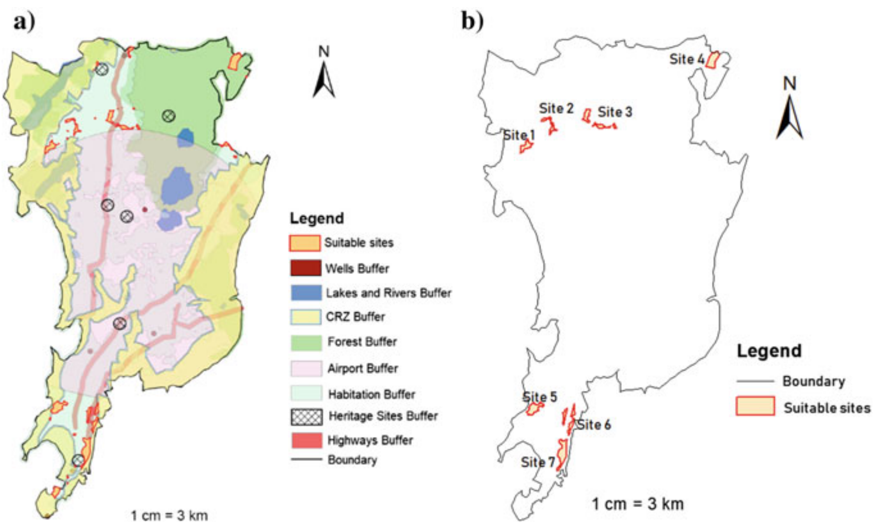

Fig. 2 **a** Overlay map combining all criteria feature vectors. **b** Map of 7 identified sites in Mumbai

Table 3 Geometrical area and distance from highways of each of the seven sites

Site No.	Area (in Ha)	Distance from road (km)
1	43	2.5
2	33	2.0
3	63	0.2
4	85	8.0
5	73	1.0
6	63	0.2
7	102	0.25

thus, reducing the problem to one-dimension. The AHP ranking of selected criteria was done on Expert Choice 11.1 software. With the objective of maximizing the appropriateness of site subject to criteria constraints, pairwise comparison was made in 2 steps: **Step 1.** Relative importance of criterion *i* in comparison with criterion *j* for each criteria pair (*i*, *j*). **Step 2.** Relative preference of alternative n in comparison with alternative m for each criterion k.

These comparisons were in the form of numerical values as per Saaty's scale designed for AHP. The inconsistency ratio (IC) was noted to be less than 0.1 throughout the expert decision-making process. It is a measure of how inconsistent the judgements have been relative to large samples of purely random judgements.

The ranking of criteria (1–9 grades) was done by concentrating on any two criteria at a time taken from 3 experts. For example, heritage sites were considered to be more important (moderate plus-4.0) than Residential zones as they attract tourists and are historical markers of the country. To avoid aesthetical impairment and to maintain

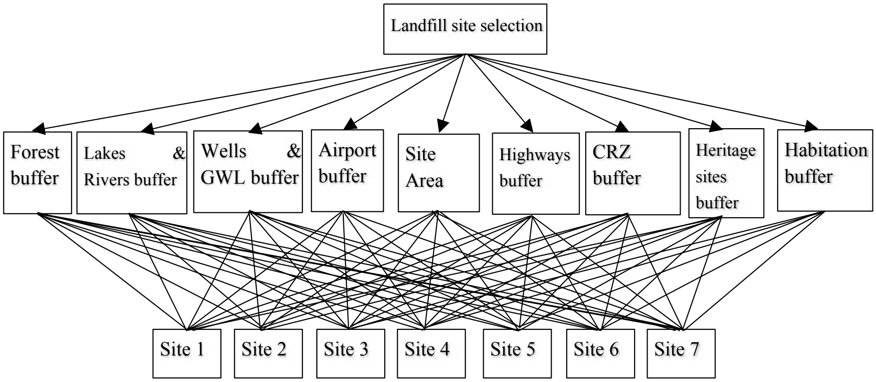

Fig. 3 Description of the hierarchy of the decision-making process

such places odor free, dump sites must be located far from them [5]. CRZ buffer and forest buffer were given equal importance as both serve as ecologically active zones. The normalized weights for the criteria were generated by the software based on the comparison matrix (Fig. 3).

For comparing the relative preference of a pair of sites with respect to a particular criterion, 1–9 grades were entered in the matrix. A check of inconsistency (<0.1) was made for each of the nine matrices. For example, based on the distance from CRZ, site 2 is moderately more important than site 1. Similarly, sites 5 and site 6 are equally important in terms of CRZ since they are equidistant from the buffer line.

3 Results and Discussion

The sites obtained are suitable since they meet all the criteria as per norms for waste disposal sites. As per opinion of experts, wells and ground water level are found to be the most important criteria affecting site selection, the least important being proximity to residential zone. This is same as the ranking taken by Karimi et al. [4] and Debishree et al. [2] for MSW. Upon synthesis based on the goal of site selection, the first three are most suitable sites and cover 260 ha, 0.59% of the total area of Mumbai city, similar to the result obtained by Ding et al. [3]. The evaluation of the results indicates that site 4 of 85 ha area ranked first in suitability (See Fig. 4) even though it is away from transportation network. Since the criteria for distance from highway had lower weight, validated as per study by Karimi et al., such a result was obtained.

Priority list of sites to be developed in future indicated that site 4 could be developed first followed by site 7, site 5, site 6, site 3, site 2, and site 1, in that order.

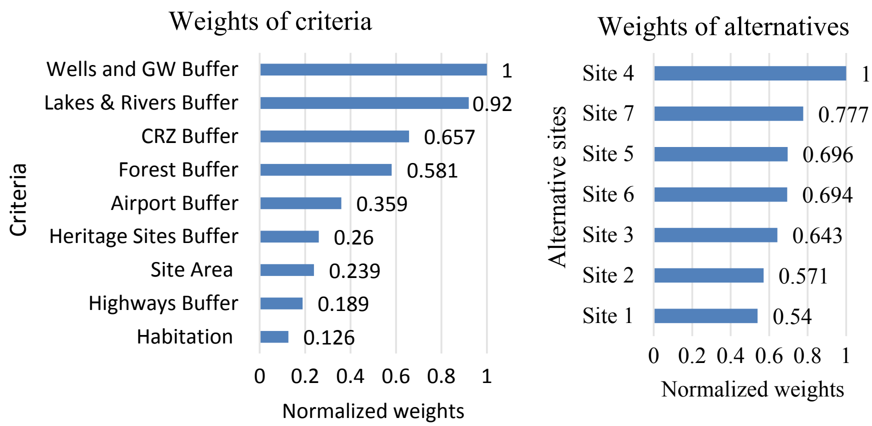

Fig. 4 Ranking and weightages obtained for seven alternative sites based on criteria weights

4 Conclusion

This study provides us with the sites which abide by the norms. The largest existing dump site in Mumbai is at Kanjurmarg of 141 ha area but only 66 ha is useable as the remnant portion does not comply with CRZ norms. The areas of first three sites are greater than 66 ha and hence are considered to serve the purpose of C&D waste disposal for next 20–25 years. The results obtained are useful as they provide sustainable sites and indicate the basis for their selection. Also, obtaining a priority list broadens the vision of town planners by giving a sustainable solution to the issue of waste disposal.

Road network connectivity must be ensured to avoid transportation issues. The ‘Not in my backyard’ syndrome comes into picture if public nuisance is created due to landfill site in a residential neighborhood. Though C&D waste is odorless inert material, its processing will produce noise. The site can be developed by keeping 500 m buffer within the boundary. Segregation of C&D waste from other MSW must be practiced if we are to make economical use of this material resource. With the help of technology in treatment, reuse and recycle of C&D waste, a major portion of the waste material will find its proper utility in the construction of less important structures, minor roads, filler material, and making paver blocks. Further reduction in waste production is possible if such technology is applied on-site itself.

This study has limitations that can be addressed in the future research. If any change occurs in the criteria weights, the decision taken is bound to change. Many factors affecting the landfill site selection are yet to be considered in this model. Site slope, soil conditions, land-use pattern, noise produced in recycling plant are few criteria which need consideration. Also, the criteria weights are calculated based on experts’ opinions.

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