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Landfill demand and allocation for municipal solid waste disposal in Dhaka city—an assessment in a GIS environment

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Abstract

Site selection of new landfills for municipal solid waste (MSW) disposal is a great concern of urban governments around the world as old landfill sites are being filled-up and demand for new sites is increasing. Finding a suitable MSW disposal site of adequate size meeting all the regulations is a costly endeavor. With the advent of geographic information systems (GIS) and its decision support tools, preliminary screening and prospective site selection can be done effectively with high degree of accuracy. In this paper landfill demand for disposal of MSW of Dhaka, the capital of Bangladesh is assessed by projecting population and waste generation for the period 2007-2025. A spreadsheet modeling is done for the assessment of area requirement for landfill demand using waste generation rate and population growth rate. Several waste management scenarios is considered in assessing of waste generation and landfill demand. For finding suitable landfill sites, a multi-criteria evaluation (MCE) on various raster map layers is done in GIS environment. Various map layers of Dhaka city (1734 km^2) is prepared using standard exclusionary criteria. Map layers are then overlaid and combined using weighted linear combination (WLC) method. In the suitability analysis for weighting of factors a pair-wise comparison method provided by the analytic hierarchy process (AHP) is used which is built-in the GIS environment. Suitable areas further masked out for being small size or discontinuity of land parcel. Finally suitable land parcel is ranked with size in descending order as larger sizes are more suitable than smaller sizes for landfill development. The paper presents three scenarios for available suitable lands by changing relative importance factors.

Keywords: landfill siting, multi-criteria evaluation, analytic hierarchy process, geographic information systems, solid waste management, Dhaka.

1. Introduction

Municipal solid waste (MSW) has become a serious problem in many developing countries, especially in the urban areas of large and rapid growing cities. Dhaka, the capital city of Bangladesh is facing serious problem with urban solid waste management. Presently an estimated 7,000 tons of MSW is generated daily in the Dhaka City of which only 1200–1500 tons is disposed in the landfills and the rest left unattended or locally dumped. MSW is only being disposed and dumped for filling low-lying lands. The MSW is presently being disposed off mainly in *Matuail*, a low-lying land about three kilometer distance from the city corporation area and a number of minor sites which are operated in uncontrolled manner and without any proper earth cover and compaction. The uncollected wastes are dumped in open spaces, streets which clog drainage system creating serious environmental degradation and health risks. Dhaka City Corporation (DCC) is the MSW management authority in the corporation area (360 km^2) and outside DCC area local authorities conducts waste management activities. In order to maintain a sustained waste disposal in landfills new waste sites have to be designated as the old capacities are being filled-up.

Landfill is the final functional element of a solid waste management system. It has taken the bottom of the hierarchy of all options for waste disposal. Along with other waste disposal option such as, recycling, combustion (incineration) and composting, landfill is the most preferred option, because of its easy operation, low cost, less technological involvement and comfort of implementation.

The first step of potential site identification for MSW disposal is to determine the capacity of the required site i.e. demands. Various methods can be used for estimation of landfill capacity. It depends on the availability of quality waste related data of a region. The more the detail historical data of waste generation is available the more accurate will be the estimation. In absence of comprehensive waste related data, population and waste generation rate can be used for determination of future landfill capacity.

The site selection study for a municipal landfill can be a costly affair (Joyce, 1990). Regulations and public opposition can make siting municipal solid waste landfills difficult (Siddiqui et al. 1996). The successful siting of a sanitary landfill requires overcoming significant environmental and political obstacles. It depends on convincing decision-makers and the public that a sanitary landfill is needed and the site is the most suitable of the options available (or at least among the best) (Lane and McDonald, 1983).

Another aspect of solid waste landfills development is its limited end-use and long term detrimental environmental effect. After closing most solid waste landfills become unsuitable for most development works or agricultural use. Even a well operated sanitary landfill requires close monitoring and maintaining for many decades after the closure. However, despite the fact that solid waste landfills pose serious threat to environment, the final destination of urban solid wastes in most of the countries in the world is dominated by land filling (Williams, 1998). A sanitary landfill site selection involves evaluation of various criteria using national or local land-use guidelines, environmental regulations, location restrictions, and so on. Social, environmental and technical criteria should be considered for potential landfill site selection.

Multi-Criteria evaluation (MCE) technique can effectively be used for suitability analysis in GIS environment. MCE procedure includes: criteria establishment, standardization of factors, establishment of factor weights and finally weighted linear combination. With the advent of GIS and personal computers capability, land suitability analysis can be explicitly carried out because of its enormous capacity to store, handle and retrieve of huge volume of various spatial data. We now have the opportunity for a more explicitly reasoned process of land-use evaluation by using GIS (Eastman J.R., 1995). Clark Labs researched for several years in an exploration of decision making procedures for land allocation problems and finally added-in a special module named MCE in IDRISI (a GIS software for analyzing raster data). For criterion weighting in the MCE process the analytical hierarchy process (AHP) is the most preferred method and widely used in the decision making process. AHP uses a pair-wise comparison method developed by Saaty (1977). AHP process is successfully tagged in the MCE module of IDRISI (GIS).

The specific objectives of this study are therefore to (1) make an assessment of future demand of land for waste disposal in landfills in Dhaka city, (2) illustrate land suitability analysis method in GIS, and (3) identify qualitatively suitable locations for the landfills.

2. The study area

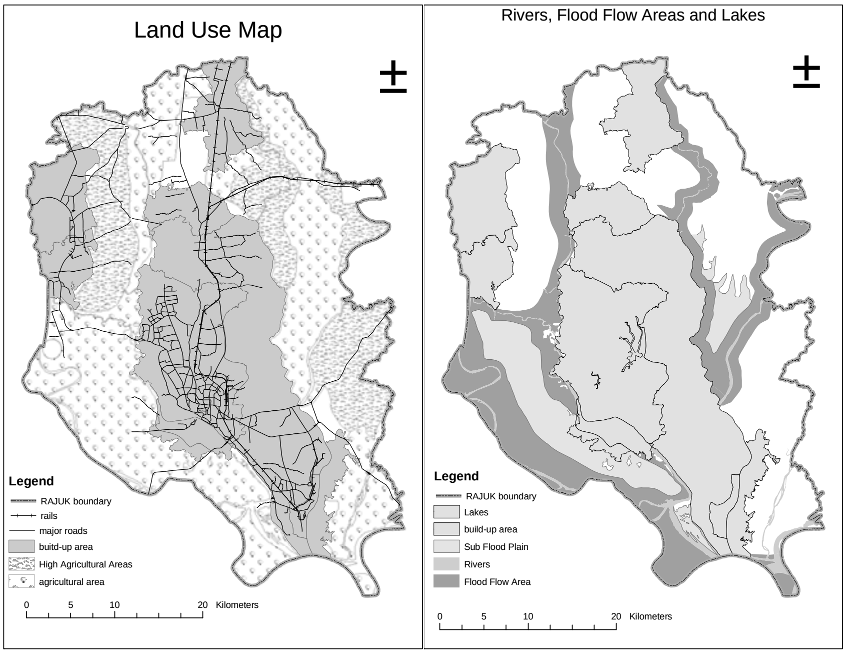

Fig. 1. Dhaka Metropolitan area under RAJUK jurisdiction

The study area for this study has been chosen as the area under the jurisdiction of *Rajdhani Unnayan Kortipakka (RAJUK)* (the capital development authority) which is around 1,734 km^2 (in GIS map). RAJUK is a government organization under the Ministry of Housing and Public Works which is mainly responsible for policy, planning and implementation of development activities within the metropolitan area of Dhaka City. The study area is comprises with areas from three districts (Dhaka, Narayanganj, and Gazipur) with the major area located in Dhaka district. The geographical location of the study area is between 23°30′–25°05′ N latitude and 90°15–90°35′ E longitude. Study area with land use map is shown in Figure 1.

3. Methodology and modeling

3.1 General considerations of landfill Siting

One of the most difficult tasks faced by most communities in implementing an integrated solid waste management program is the siting of new landfills. Tchobanoglous et al. (1993) demonstrated factors that must be considered in evaluating potential sites for the long-term disposal of solid waste include (1) haul distance, (2) location restriction, (3) available land area, (4) site access, (5) soil conditions and topology, (6) climatological conditions, (7) surface water hydrology, (8) geologic and hydro-geologic conditions, (9) local environmental condition, and (10) potential ultimate uses for the completed site. Final selection of a disposal site usually is based on the results of detailed site survey, engineering design and cost studies, and an environmental impact assessment.

The location criteria of Subpart B of the US EPA’s (US EPA, 1993) RCRA Act cover (1) airport safety, (2) floodplains, (3) wetlands, (4) fault areas, (5) seismic impact zones, and (6) unstable areas. Floodplain, fault area, seismic impact zone, and unstable area restrictions address conditions that may have adverse effects on landfill performance that could lead to releases to the environment or disruptions of natural functions (e.g., floodplain flow restrictions). Airport safety, floodplain, and wetlands criteria are intended to restrict MSW landfill units in areas where sensitive natural environments and/or the public may be adversely affected. In addition, a landfill unit must comply with all other applicable Federal and State regulations. Location restriction criterion varies and it depends on environmental and climatic condition of a region. Many municipalities have set their own location restriction parameters to met local environmental condition. Table 1 provides typical criteria with restriction parameters for landfill siting.

Table 1
Typical criterion parameters for landfill siting

Criterion	Parameter	Criterion	Parameter
Distance from water bodies	300– 500m	Distance from forest, park, etc.	50 – 500m
Distance from well	500–1000m	Soil permeability	$< 10^{-6}$cm/sec
Distance from urban area	500–2000m	Distance from roads	50 – 100m
Haul distance	30–45min	Slopes	< 15 – 20%

3.2 Evolution of landfill siting

Siting a sanitary landfill requires a substantial evaluation process in order to identify the best available disposal location, that is, a location which meets the requirements of government regulations and minimizes economic, environmental, health, and social cost (Siddiqui et al. 1996). Several landfill siting techniques have been outlined in the literature. When capabilities of computers and access to it were still limited, Lane and McDonald (1983), developed a composite map of suitability by integrating different criteria maps in the format of transparent printed maps. Advances in computer technology especially the development of geographical information systems (GIS) greatly improved this approach. GIS have capabilities for storage, retrieval and manipulation of spatial data, as well as for visualization of outputs, and provide the means for practical and efficient combination of a large amount of spatial information.

Siddiqui et al. (1996) developed a site selection method called ‘Spatial-AHP’ used selection criteria and area attributes recorded on GIS data maps to identify and rank potential landfill areas. The developed methodology to find the best locations for siting landfills was by integrating GIS, Multi-criteria Evaluation (MCE) and Analytical Hierarchy Process (AHP). Kao et al. (1997) developed a prototype network geographical information system with the goal of facilitating landfill siting. A multimedia network was provided for 24-hours local and remote access to the system from anywhere on the internet. The prototype system consisted of three major sub-systems: the network GIS (spatial functions for siting analysis), a siting rule guide (environmental, socio-cultural, and engineering-economic factors/rules), and a case study demonstration at Miaoli Prefecture in Taiwan. Leão et al. (2001) presents a method to establish relationship between the demand and supply of suitable land for waste disposal over time using GIS modeling techniques. Several other studies regarding development of Decision Support System (DSS) and landfill siting techniques have been discussed in the literature (Kontos et al. 2003, Ehler et al. 1995, Dugger 1997, Charnpratheep et al. 1997, Dorhofer and Siebert 1998 Yagoub and Buyong 1998, Herzog 1999, Lukasheh et al. 2001).

3.3 Site selection by GIS

3.3.1 Definitions[1]

A decision is a choice between alternatives. The alternatives may represent different courses of action, different hypotheses about the character of a feature, different sets of features, and so on.

A criterion is some basis for a decision than can be measured and evaluated. It the evidence upon which a decision is based. Criteria can be of two kinds: factors and constraints.

A Factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. It is therefore measured on a continuous scale. For example, a forestry company may determine that the steeper the slope, the more costly it is to transport the wood. As a result, better areas for logging would be those on shallow slopes—the shallower the better. Factors are also known as *decision variables* in the mathematical programming literature (Fiering, 1986) and *structural variables* in the linear goal programming literature (Ignizio, 1985).

A constraint serves to limit the alternatives under consideration. A good example of a constraint would be the exclusion from development of areas designated as wildlife reserves. In many cases constraints is expressed in the form of a Boolean (logical) maps: areas excluded from consideration being coded with a 0 and those open for consideration being coded with a 1. Constraints are used to limit the alternatives under consideration.

Decision Rule is the procedure by which criteria are combined to arrive at a particular evaluation, and by which evaluations are compared and acted upon, is known as a decision rule. A decision rule might be as simple as a threshold applied to a single criterion (such as, all regions with slopes less than 35 percent will be zoned as suitable for development) or it may be as complex as one involving the comparison of several multi-criteria evaluation.

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[1] Definitions are taken from Eastman et al. (1995).

Objective represents decision rules that are structured in the context of a specific purpose. The nature of that objective, and how it is viewed by the decision makers (i.e. their motives), will serve as a strong guiding force in the development of a specific decision rule.

3.3.2 Multi-Criteria Evaluation (MCE)

The actual process of applying the decision rule is called evaluation. To meet specific objective, it is frequently the case that several criteria will need to be evaluated. Such procedures are called MCE. In the advent of GIS and its continuous development over the last decade including incorporation of decision making support (DSS) into it makes it an ideal tool for site selection or facility allocation problem. Landfill site selection by GIS is a multi-criteria evaluation (MCE) and generally has four steps: 1) criterion establishment, 2) standardization of factors, 3) establishment of factors weight, and 4) weighted linear combination. With a weighted linear combination, factors are combined by applying a weight to each followed by a summation of results to yield a suitability map, i.e.

$$S = \sum w_i x_i \tag{1}$$

where, S = suitability, w_i = weight of factor i, x_i = criterion score of factor i
The procedure can be modified by multiplying the suitability calculated from the factors by the product of the constraints, i.e.,

$$S_{i,j} = \left(\sum_{x=1}^{p} f_x w_x \prod_{y=1}^{q} r_y \right)_{i,j} \tag{2}$$

where $S_{i,j}$ = land suitability of cell i for the land use type j , f_x = attribute of factor x at cell i, w_x = weight of the factor x, p = number of factors f, r_y = attribute of constraint y at cell i, q = number of constraints r

All GIS software systems provide the basic tools for evaluating such a model. In addition, in IDRISI, a special module name MCE has been developed to facilitate this process. MCE landfill suitability analysis in Dhaka city is carried out using IDRISI.

3.3.3 Criterion weighting

The purpose of criterion weighting is to express the importance of each criterion relative to other criteria. A number of criterion-weighting procedures based on the judgments of decision makers have been proposed in the multi-criteria decision literature. The procedures include ranking, rating, pair-wise comparison, and trade-off analysis. They differ in terms of their accuracy, degree of easiness to use, and understanding on the part of the decision makers, and in the theoretical foundation. A weight can be defined as a value assigned to an evaluation criterion that indicates its importance relative to other criteria under consideration. The lager the weight, the more important is the criterion in the overall suitability. Assigning weights of importance to evaluation criteria accounts for (1) changes in the range of variation for each evaluation criterion, and (2) the different degrees of importance being attached to these ranges of variation. The weight value is independent on the range of the criterion values.

Although a variety of techniques exist for the development of weights, one of the most promising is pair-wise comparison developed by Saaty (1980) in context of a decision making process known as the Analytical Hierarchy Process (AHP). In MCE using a weighted linear combination, it is necessary that the weights sum to 1. In the AHP weight can be derived by taking the principal eigenvector of a square reciprocal matrix of pair-wise comparisons between the criteria. The comparisons concern the relative importance of the two criteria involved in determining suitability for the stated objective. Ratings are provided on nine-point continuous scale (Figure 2). For example, if proximity to roads is very strongly more important than proximity to urban areas in determining suitability for landfill siting, and 7 is taken on this scale. If the reverse is the case (urban is very strongly more important than stream) it will be 1/7.

1/9	1/7	1/5	1/3	1	3	5	7	9
extremely	very	strongly	moderately	equally	moderately	strongly	very	extremely
	less important					more important		

Fig. 2. Rating scale used for the pair-wise comparison of factors in MCE

3.3.4 Exclusionary criteria

In the DMDP report, various land use has been categorized. Major land use categories are: build-up area (urbanized), high agricultural area, agricultural area, flood flow area, sub-flood flow area, cantonment security zone, open space, urban fringe, and peripheral urban development area. There are areas for special development and some areas are designated for flood retention ponds. Most of the areas are restricted for solid waste disposal (landfill) use. Two categories of land-use: agricultural land and peripheral urban land have been considered for future landfill development. Table 2 presents the constraints criteria (area excluded from analysis with buffer distance) used for land suitability analysis along with parameter values and justification of the parameters.

Table 2
Exclusionary criteria with respective buffer distances

Criterion	Buffer Distance	Rationale
(1) Cantonment security zones	2000m	There are three cantonments in the study area. For the security and other confidential purpose 2000 meter buffer area is considered to be unsuitable for landfill site.
(2) Embankment (Existing & proposed)	1000m	A significant area of Dhaka city under the risk of being inundated by flood. To protect Dhaka city from inundation of flood water there exists some flood protection embankments. In addition some embankments are proposed to be built in the future. For the well protection of the existing and proposed embankments 1000 meter area around the embankments have been excluded from the land evaluation analysis.
(3) Flood flow areas	1000m	Designated flood flow areas are further buffered by 1000 meters to protect landfill site from waster seepage and for sound operation and maintenance of landfill site.

Criterion	Buffer Distance	Rationale
(4) Sub-flood flow areas	1000m	Sub-flood flow areas are also further buffered to 1000 meter to safe-guard landfill operation.
(5) Flood retention pond	500m	To preserve flood water and to protect neighbor urban area, 30 flood retention ponds are delineated in the DMDP project. These ponds will be used for fish cultivation and other purposes. To protect these flood retention ponds from possible contamination a 500 meter buffer area is excluded.
(6) High agricultural areas	500m	In the DMDP project high agricultural areas are designated for the purpose of agricultural food supply and these areas are restricted for other development. To avoid possible hazards from landfill 500 meter buffer area is excluded.
(7) Open space	1000m	Open space are designated as public recreational place. To avoid nuisance such as odor, noise, and air pollution 1000 meter buffer area is excluded.
(8) Special areas	500m	Special areas are designated to establish new industries and to relocate some vulnerable industries. A 500 meter buffer area is excluded from special areas.
(9) Recreation facility areas	1000m	To avoid odor, nuisance, etc.
(10) Roads	100m	Typical value for landfill siting
(11) Streams, Rivers, water bodies	500m	In order to protect water bodies of being contaminated from leachate. In order to maintain sound landfill operation
(12) Built-up urban areas	500m	In order to prevent health risk to neighbor community. Also, to avoid noise, odor, air pollution, etc.

3.3.5 Decision criteria

Three decision factors have been considered for suitability evaluation. They are: (1) road proximity, (2) stream proximity, and (3) urban proximity. Three scenarios have been analyzed for sensitivity of land suitability. Hierarchical ranking of three scenarios are: road > stream > urban, stream > road > urban and equal importance. The hierarchical structure of ranking criteria is shown in Figure 3.

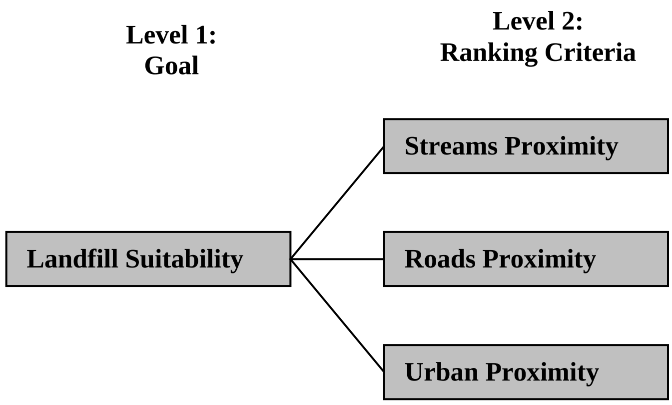


Fig. 3. Decision hierarchy for landfill area ranking in Dhaka City

3.3.6 Factor standardization

Criteria standardization measures degree of suitability of a criterion over the area under consideration. Fuzzy membership functions have been used for the standardization of factors. For road proximity (including railways) factor, 100 meters areas from road have been buffered as constraint (unsuitable) for landfill development. The buffer distance has been measured from the center of the roads and railways. Further 100 meter areas from the buffer area of roads and railways have been considered to unsuitable for landfill development. Land suitability at 200 meters from roads is 255 (highest) and it decreases linearly from 255 to 0 with the increase of distance from roads for the rest of the areas on a scale of 0 – 255. Thus areas nearest to roads but not closer than 200 meters from roads are most suitable and suitability decreases linearly with the further increase of distance from roads. Factor standardization for roads and rails is illustrated in Figure 4.

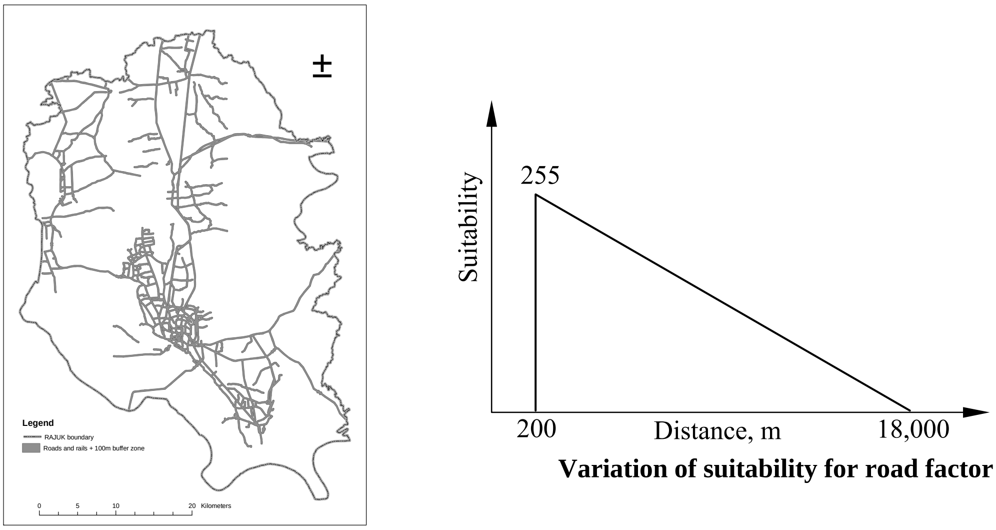


Fig. 4: Variation of land suitability (standardization) for road proximity factor

Land suitability for streams and urban proximity factors has been taken 0 for areas within the distance of 500 meters. Suitability increases linearly and reaches to highest suitability at 2,000 meter. Areas after 2,000 meters, all the areas have been considered to equally suitable (highest suitability value). For the stream proximity factor decision maker might think that areas within 500 meters must be protected and shall not be suitable for landfill development. However, for better protection of natural water bodies it would be reasonable if landfill site were located further away and it would be best if it could be located at distances further than 2,000 meters from water bodies. Likewise, landfills shall not be developed within 500 meters of neighbor community and it would be better if it could be located further away. Variation land suitability for streams (rivers) and urban proximity are shown in Figure 5 and Figure 6.

3.3.7 Weighting of factors

Pair-wise comparison method provided by analytic hierarchy process (AHP) is applied for computing relative importance weights of factors. Three scenarios weighting of factors have been considered for assessment of sensitivity of analysis. In the first scenario relative importance of three factors are considered as road > stream > urban. Second scenario is stream > road > urban. In the third scenario all the three factors are considered equally important (weight 0.333). Relative importance and respective weight computed by AHP (scenario 1) is shown in Table 3.

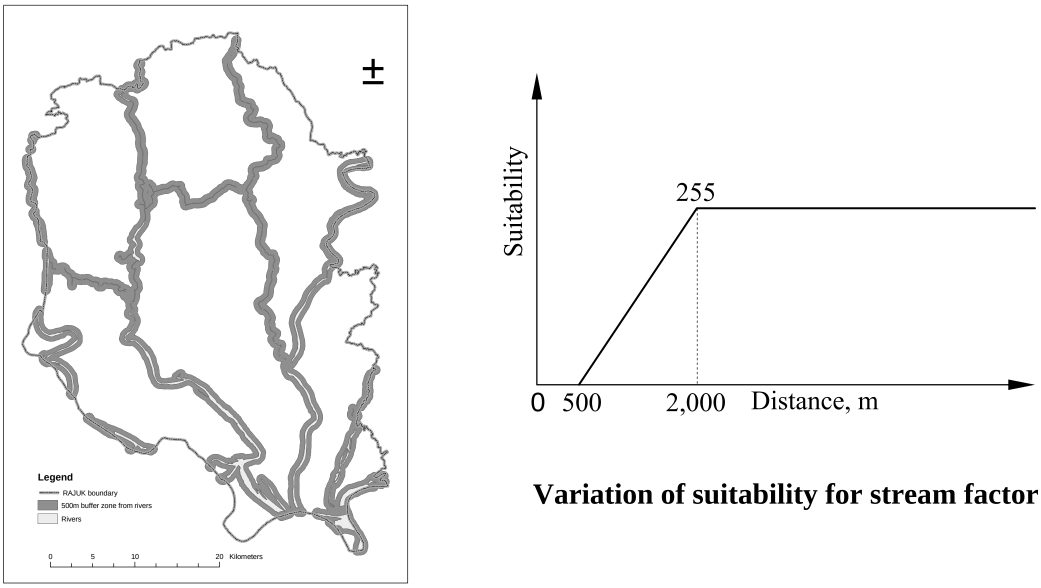


Fig. 5: Variation of land suitability (standardization) for stream proximity factor

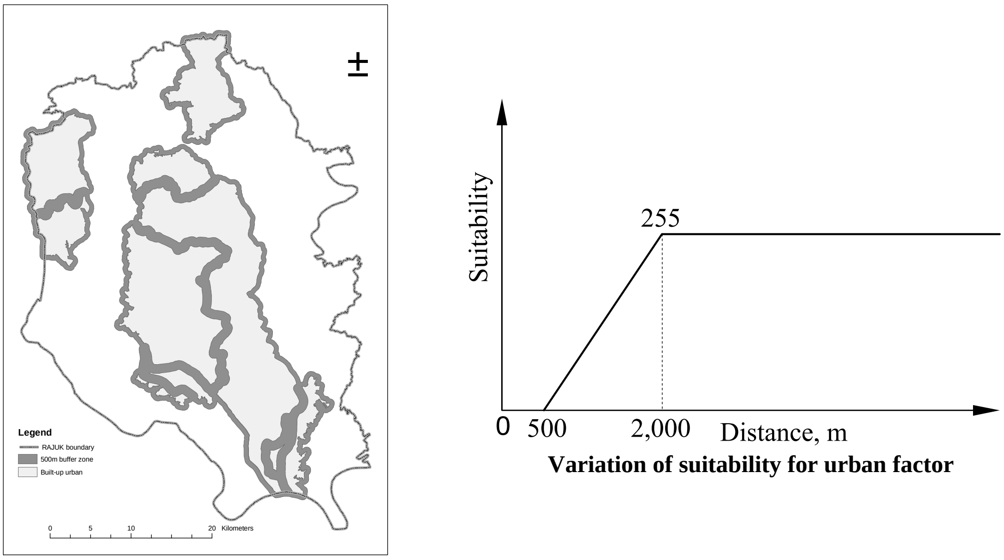


Fig. 6: Variation of land suitability (standardization) for urban proximity factor

Table 3
Factor weights computed by pair-wise comparison method in AHP

Decision factor	Pair-wise comparison			Relative importance
	Decision factor 1	Decision factor 2	Decision factor 3	
Scenario 1: road > stream > urban				
	Road	Stream	Urban	
Road	1	5	7	0.7306
Stream	1/5	1	3	0.1884
Urban	1/7	1/3	1	0.0810

Consistency ration (CR) = 0.06 << 0.1

4. Results and discussions

4.1 Assessment of solid waste quantity

Demand of land for MSW disposal in landfills depend on various factors. Typical factors include future population, trends of waste generation, waste management objectives, waste diversions, change of consumer's habit, urban growth, and so on. Accurate estimates of present and future waste generation and composition of waste are essential for integrated waste management. Waste quantity can be used to determine type, size, and design of waste disposal facilities. Accurate historical and current waste generation data is required for forecasting and assessing of total waste generation. Most common methods used for waste generation forecasting are: (a) generation factors or multipliers, (b) time series analysis, and (c) regression models. The conventional approach for developing waste generation assessments is to use waste generation factors or multipliers reported in solid waste studies and engineering reports. These factors express the relationship between the amount of waste produced and identifiable parameters that represent a measure of the waste-producing activity (Rhyner and Green, 1988).

Four types of waste streams i.e. domestic (49%), commercial (21%), industrial (24%), and hospital (6%) constitute the total solid wastes of Dhaka city. World Bank (1999a) forecasted per person waste generation rate for the period 1995-2025 for both developed and developing countries of Asia based on economic trends, population predictions, and waste generation trends. According to this study report (DCC-JICA, 2005), daily per person waste generation rate varies from 0.49 – 0.6 kg in Bangladesh. In a joint survey by Dhaka City Corporation (DCC) and Japan International Cooperation Agency (JICA) found the average daily per person waste generation rate from domestic source ranges between 0.21–0.59 kg for lowest income group and highest income group people respectively with a weighted average 0.34 kg. However, in this study and for the purpose of assessment of landfill demand an average daily per person waste generation rate of 0.5 kg is used throughout the period 2007-2025. To assess the landfill area requirement waste quantities is to be converted into compact volume. According to McBean and Fortin (1993), a well run landfill can achieve a compacted density up to 600 kg/m^3. However, wastes are a mixture of materials with different properties and characteristics. Some materials compact much more readily than others. Haith (1998) also presents landfill densities of some waste components. In this study, for calculation of waste volume a compact waste density 500 kg/m^3 is adopted.

Rapid and unplanned urbanization makes Dhaka one of the top ranked high-risk cities in the world. In 1975 it has a population only 2.2 million while in 2007 it reached 13.5 million which is more than 500 percent increase in 32 years. United Nations report *"World Urbanization Prospect: The 2007 Revision"* projected urban population of major cities of the world. According to this report population of Dhaka city will increase at an annual average rate of 2.72 percent and by 2025 it will reach to 22.0 million. This prediction and growth rate, as may be justified, is used for projection of population 2007-2009.

A spreadsheet computation is carried out for estimation of waste quantities using population and waste generation rate (0.5 kg). Computed waste quantities are then converted to equivalent landfill volume dividing waste quantities by the compacted specific weight (500 kg/m^3) of waste in landfills. Population, waste generation and corresponding waste volume are shown in Table 4.

Table 4
Population, waste generation and waste volume of Dhaka City (2007–2025)

Year	Projected Population (M)	Daily Waste Generation (tons)	Yearly Waste Generation (M tons)	Cumulative Waste (M tons)	Cumulative Landfill Waste Volume (Mm^3)
2007	13.50	6,750	2.5	2.5	4.93
2008	13.87	6,934	2.5	5.0	9.99
2009	14.24	7,122	2.6	7.6	15.19
2010	14.63	7,316	2.7	10.3	20.53
2011	15.03	7,515	2.7	13.0	26.01
2012	15.44	7,719	2.8	15.8	31.65
2013	15.86	7,929	2.9	18.7	37.44
2014	16.29	8,145	3.0	21.7	43.38
2015	16.73	8,367	3.1	24.7	49.49
2016	17.19	8,594	3.1	27.9	55.77
2017	17.66	8,828	3.2	31.1	62.21
2018	18.14	9,068	3.3	34.4	68.83
2019	18.63	9,315	3.4	37.8	75.63
2020	19.14	9,568	3.5	41.3	82.61
2021	19.66	9,828	3.6	44.9	89.79
2022	20.19	10,096	3.7	48.6	97.16
2023	20.74	10,370	3.8	52.4	104.73
2024	21.30	10,652	3.9	56.3	112.50
2025	21.88	10,942	4.0	60.2	120.49

4.2 Assessment of waste volume for different waste management scenario

Domestic MSW components of Dhaka city comprises: paper–7%, food waste–66%, wood & glass–7%, plastics–6%, and others–11% (DCC-JICA, 2005). Commercial waste has varied percentage components and depends on its sources. Different studies show that about 10% of total generated waste is picked and recycled by scavenger. As significant portion of waste dominated by organic waste, total waste can reasonably be reduced by composting of organic waste. At present about 2–5% of total waste get composted. This amount can easily be increased by establishing composting plants commercially. For the purpose of present study three waste reduction scenarios as shown in Table 5 is simulated keeping recycling as fixed and varying composting quantities and corresponding waste volumes for different period is shown in Figure 7.

Table 5
Three waste management scenario

Waste Scenario	Land filling	Recycling	Composting
Scenario A	85%	10%	5%
Scenario B	80%	10%	10%
Scenario C	75%	10%	15%

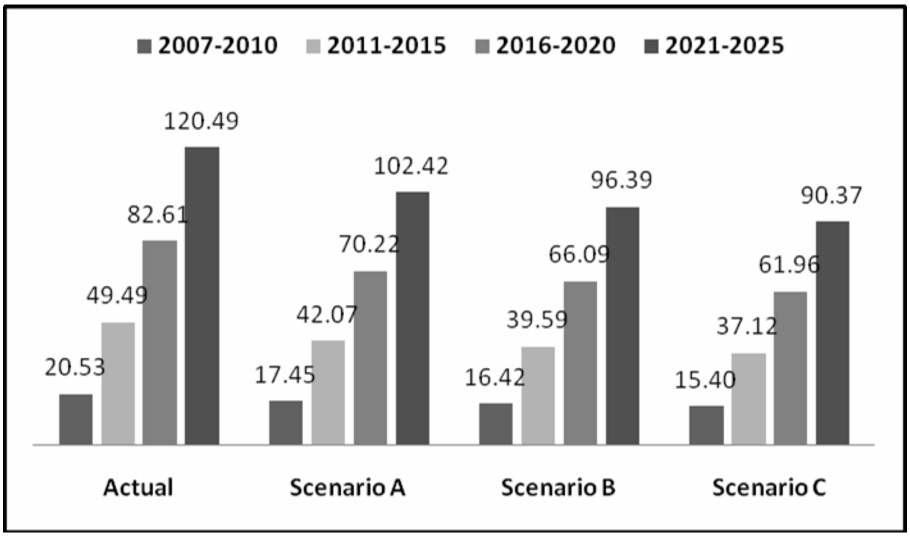


Fig. 7. Compacted waste volume (Mm^3) for different waste management scenario

4.3 *Assessment of landfill area*

Assessment of landfill area in the preliminary stage typically involves rough computations. Determination of actual capacity and useful life of a selected landfill requires real computations. Usually the computation is carried out by using contour map of the selected site, height of individual lift including the cover material, side slopes, compacted solid waste density in landfill and maximum elevation of the site. For preliminary assessment of landfill demand a regular shape with certain height and side slope including a buffer zone around the surface is justified and reasonable. World Bank (1999b) suggested an inverted truncated pyramid (sometimes called *tumulus*) shape landfill capacity for determination of landfill demand.

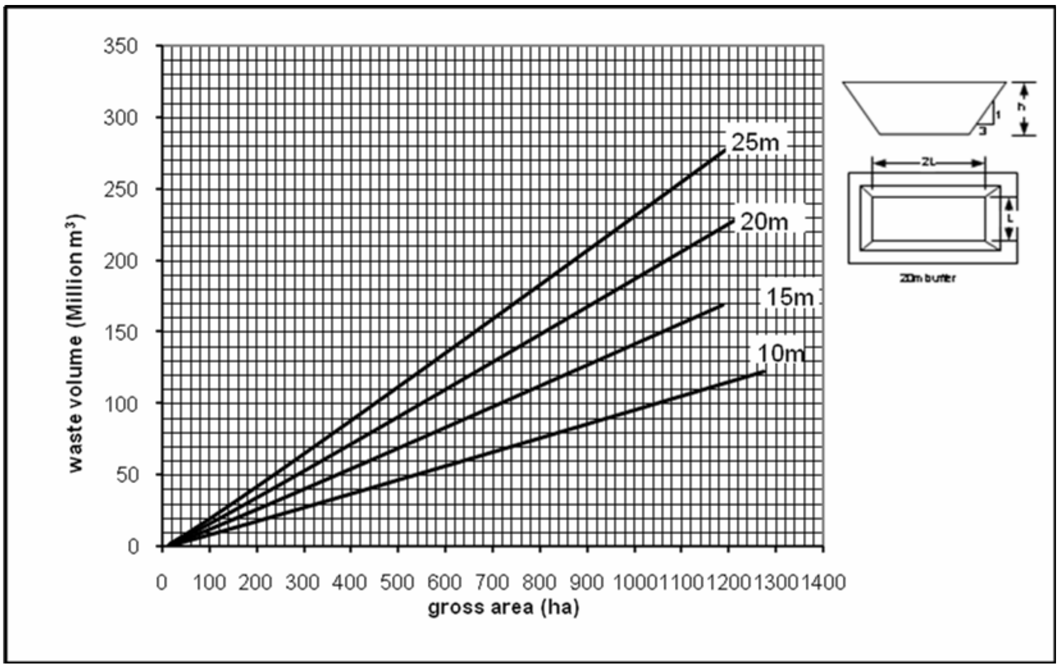


Fig. 8. Landfill area estimation graph

In this study, an inverted truncated pyramid shape with 20 meter buffer around the top surface is assumed to be landfill capacity. The *tumulus* is assumed to have a rectangular bottom base (2L × L) with side slope 3:1. A graph with volume of the *tumulus* vs. area in the landform for different depth is developed and shown in Figure 8. Previously estimated waste volumes were then used in the graph to get the final landfill area. Using this graph landfill area can be determined for any specific year. A sanitary landfill should have a substantial length of operating life. Generally a well designed sanitary landfill life lasts 5–20 years. The longer the landfill life the better will be the economic and environmental benefits.

In this study Landfill area requirement is taken and compared for different depths and waste scenarios from the developed graph for different waste management scenario. Figure 9 presents the estimated landfill demand at the end of 2025 with different landfill depths for different waste scenarios.

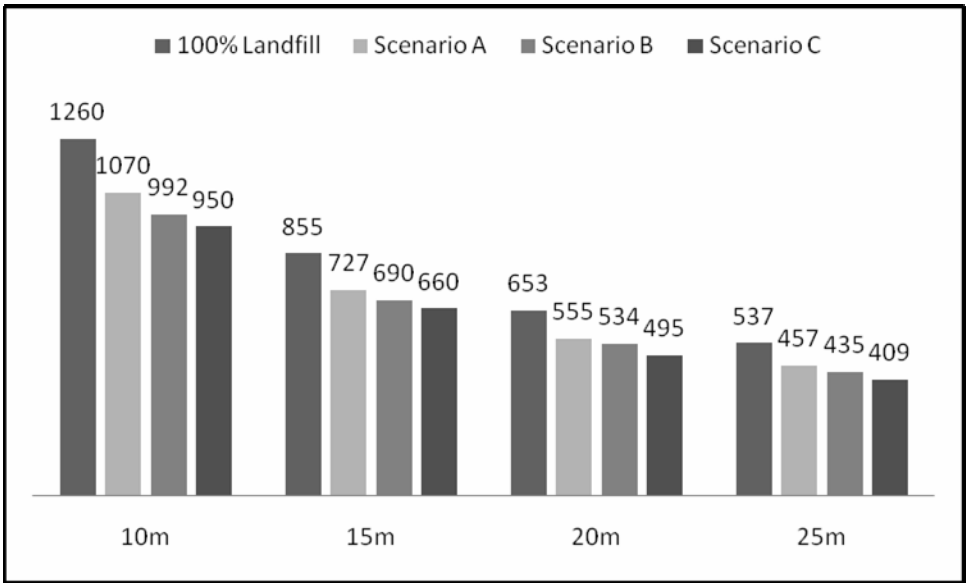
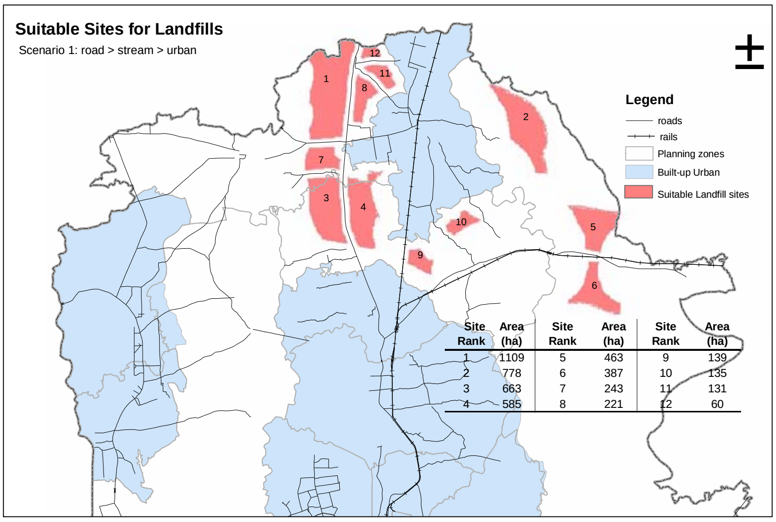
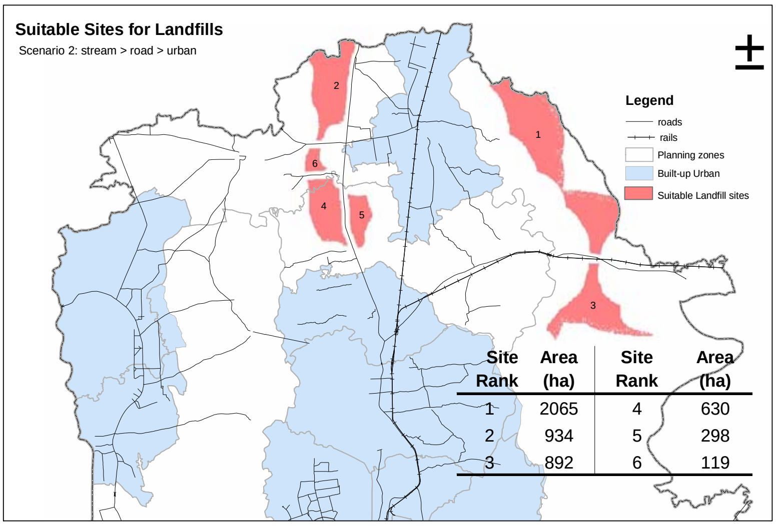


Fig. 9. Landfill area demand (ha) for different scenario in Dhaka city at the end 2025

4.4 *Selection of landfill sites through objectivity*

Having set-up of exclusionary criteria, decision factors, standardization of factors, and weighting of factors, using multi-criteria evaluation (MCE) for land suitability analysis, final suitability map is produced through weighted linear combination (WLC) method. Three simulations have been run for the three scenarios and finally three suitability maps have been produced. In the final suitability maps suitable areas have been produced on a scale of suitability ranges 0 to 255. Then the best suitable areas (sites) have been identified through analysis and ranking of the sites has been done for landfill development. Finding of the best suitable areas depends upon the objectives or goals of the land suitability analysis. For example, decision makers might be interested on a single site having a specific area, or they might be interested in finding best areas. In this study areas of which suitability ranges between 200–255 have been selected. Again, if objective or goals is not fulfilled by first trial, decision makers then rethink of threshold





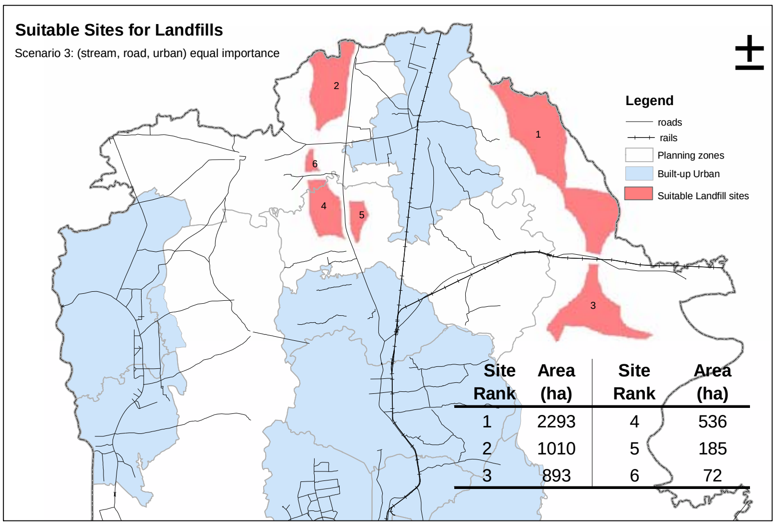


Fig. 10. Candidate sites for landfill development in Dhaka city: scenario 1, 2, 3

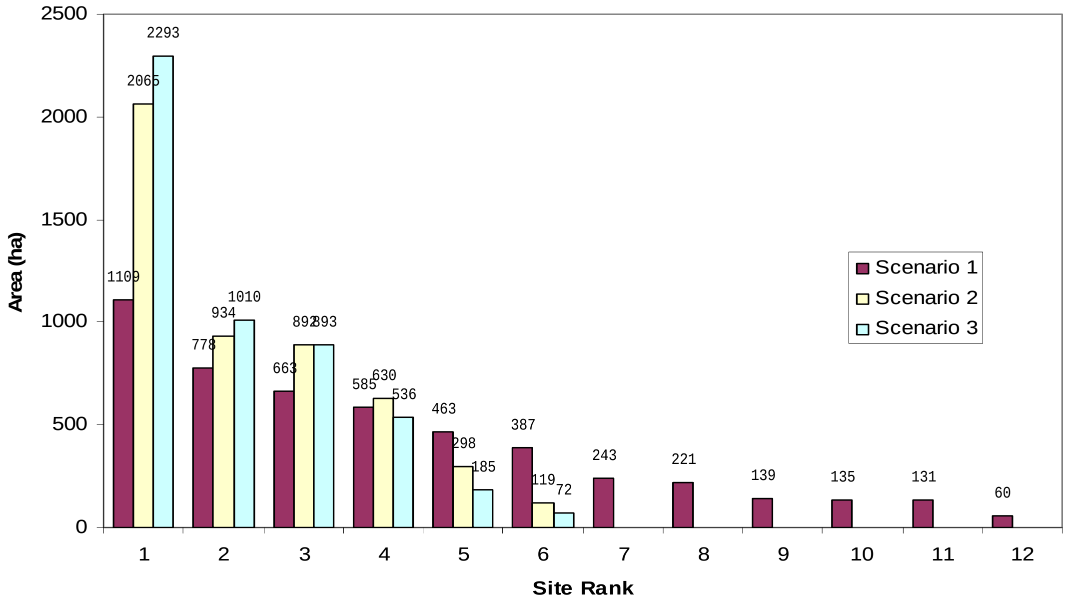


Fig. 11. Comparison of candidate landfill sites in three scenarios

values until fulfillment of goal. In addition, it is possible that goal cannot be achieved (no land is available) even considering a low level of strictness. In the present study several trail have been run for finding best suitable lands for landfill development in Dhaka city. Finally and arbitrarily 5,000 hectare has been chosen as the threshold value to find the best suitable lands. As small and scattered parcels would not be suitable for landfill development, a further screening is done masking out all the scattered parcels and areas having an area less than 50 hectares. Then remaining continuous areas have been ranked in descending order according to their area. Resulting suitable parcels for possible landfill development in Dhaka city in three scenarios are shown in Figure 10.

It is important to note here that all the candidate sites found from the analysis concentrated in one part of the study area. There exist little differences in available land with three scenarios. This happened because (1) there is no sufficient land in other regions meeting suitability criteria, and (2) the land is far away from existing road network. A comparison of available lands and there variation in three scenarios is shown in Figure 11.

5. Conclusions

MCE land suitability analysis and results show that required landfill demand can be met with the available land in Dhaka city. Suitable landfill areas might be available of size less than 50 hectares as land areas less than 50 hectares have been excluded form the analysis. However, all the suitable areas in three scenarios are located in one part of the study area which warns that if the delineated areas are used for landfill development, transport cost for waste disposal from distant part of the city will be higher for waste management. Spreadsheet calculation also shows that with an increase of recycling and composting of waste significantly reduces landfill demand. This study is attempted for preliminary landfill siting. Further study with changing criterion for selection of landfill sites may give different scenarios of the available lands for waste disposal.

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