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ORIGINAL PAPER

Landfill site suitability analysis using AHP for solid waste management in the Guwahati Metropolitan Area, India

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Abstract

Landfilling is a convenient method to tackle waste problems, in developing as well as developed countries. Determining a minimally environmentally deleterious garbage dump site is a challenge considering that a bevy of socio-economic, environmental and legal parameters often exists in developing countries. Guwahati is a city in India that faces the hindrance of not having a suitable landfill site. The existing landfill site, Boragaon, does not fulfil the prescribed parameters listed by the Central Public Health Environment and Engineering Organisation (CPHEEO) and the Central Pollution Control Board (CPCB). The main objective of this study was to provide alternative sites in the Guwahati Metropolitan Area (GMA) using geographic information systems (GIS) and multi-criteria decision analysis (MCDA)–based analytic hierarchy process (AHP) methods. Seven criteria were considered in site selection. These were land use, slope, elevation and proximity to wetlands, rivers, roads and the airport. Results indicate that 7.5% of the area was most suitable, 22.8% highly suitable, 43.8%, 22.2% and 3.6% areas were of moderate, low and least suitability respectively. On the basis of the area covered by each location, 5 landfill sites were identified to potentially relocate the existing site. The study highlights the problem of waste management in low- and middle-income cities.

Keywords Site suitability analysis · Multi-criteria decision analysis · Analytic hierarchy process · Solid waste management · Guwahati Metropolitan Area

Introduction

The world's cities currently generate 1.3 billion tonnes of solid waste per year, amounting to 1.2 kg/capita/day (World Bank 2012). Rapid growth and urbanization have led to a sharp increase in the generation of waste (Boroushaki and Malczewski 2010; Demesouka et al. 2013; Halahla et al. 2019; Salemi and Hejazi 2017). People discard products that outlive their primary purpose and coupled with consumerism and growing affluence; the waste generation has become an issue of massive proportions. Improper waste disposal adds to environmental pollution as well as aggravating public health risks (Palomar et al. 2019; Omoloso et al. 2020). Thus, sustainable solutions to tackle such waste are a pressing requirement. An efficient management system has to be designed wherein complexity, uncertainty, multi-objectivity and subjectivity (Sumathi et al. 2008; Khan and Samadder 2014) associated with waste matter disposal can be arrived at with minimal adverse environmental effects. Urban solid waste management (SWM) is considered as one of the most serious environmental problems confronting municipal authorities in developing countries, but oftentimes, scant attention is accorded to waste minimization strategies and eventually, all waste is sent to dumpsites for final disposal (Richter et al. 2019; Leao et al. 2004; Mahini and Gholamalifard 2006; Oteng-Ababio 2011; Yazdani et al. 2017).

In a waste management hierarchy scenario (waste reduction, reuse, recycling, composting and landfilling), it is landfilling that lies at the bottom of the list in terms of attention accorded (Mahini and Gholamalifard 2006; Rahman et al. 2008; Gbanie et al. 2013). Landfilling is a waste disposal method in which waste is spread into thin cells initially, compressed it into small volumes and then finally covered by a soil layer (Sumathi et al. 2008). Although there are numerous waste reduction procedures such as reuse and recycle at source, it is landfilling that is considered as the most accepted method (Richter et al. 2019; Sumathi et al. 2008; Afzali et al.

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2011; Spigolon et al. 2018) especially in developing countries like India. Nonetheless, there have been hindrances in finding suitable sites for final waste drop off given the scarcity of land, social and political acceptance (Lin and Kao 1999; Kontos et al. 2003; Chang et al. 2007), economic aspects (Chabuk et al. 2017) and mounting population pressures particularly in developing countries (Aderoju et al. 2020).

Geographic information system (GIS) serves as a digital database management system that helps storing, retrieving and analyzing data from various sources and displaying results with ease (Siddiqui et al. 1996; Sumiani et al. 2009; Gbanie et al. 2013). Multi-criteria decision analysis (MCDA) has the advantage to evaluate varied criteria including blending expert opinion with factual information (Al-hanbali et al. 2011). Analytic hierarchy process (AHP) is one of the most widely accepted MCDA approaches and has been widely used in identifying potential landfill sites (Babu and Sivasankar 2015; Chabuk et al. 2017; Kaoje et al. 2016; Khan et al. 2018; Rinsitha et al. 2014; Rana et al. 2017; Sharma et al. 2018).

GIS along with MCDA provides tools enabling analysts to overlay different qualitative and quantitative criteria systematically in a single platform and these have been particularly favoured in waste management analyses (Achillas et al. 2013; Antonopoulos et al. 2014; Aderoju et al. 2020; Chamchali et al. 2019; Eghtesadifard et al. 2020 Soltani et al. 2015; Sotamenou 2019). MCDA methods offer a set of preferable solutions (albeit not necessarily the best) that enable an optimal decision to be taken. Ultimately, the decision taken would depend on circumstances as well as experience and personal judgement (Morrisseya and Browne 2004; Brent et al. 2007) of decision-makers.

In India, attempts have been made to improve waste management practices in response to SWM rules, 2016, including, in recent years, the Central Public Health Environment and Engineering Organisation (CPHEEO) and Central Pollution Control Board (CPCB) guidelines in constructing sanitary landfills. Waste management practices in secondary cities like Guwahati are hardly scientific.

This study seeks to identify potential suitable landfill sites for the disposal of municipal solid waste in Guwahati Metropolitan Area (GMA) under Guwahati Metropolitan Development Authority (GMDA), the largest city in north east India.

The study is organized as follows: the study area is briefly described along with the status of disposal of municipal solid waste. The database and methodology pertaining to multi-criteria decision analysis are detailed in the subsequent section and contextualized vis-à-vis existing methods employed in similar studies elsewhere. The criteria selected as inputs to the AHP exercise, grouped into constraints and decision criteria, along with the rationale behind their selection are also addressed in this section. The next section deals with the results and discussion, followed by the conclusion.

Study area

Occupying Kamrup (Metropolitan) district, the GMA extends from 91° 34′ E to 91° 52′ E longitude and 26° 4′ N to 26° 13′ N latitude covering an area of 263 sq. km. It borders the Khasi and Jaintia hills of Meghalaya to the south, the Boga Gosai Parbat, an extension of Khasi hills to the east. On the west, the GMA is flanked by Jalukbari-Azara plain where the Deepor Beel and adjoining low-lying areas lie and to the north by a flat plain interrupted by small hillocks. The city is situated on undulating terrain with altitude varying between 49.5 and 55.5 m.a.s.l.. Sarania hill, Nabagraha hill, Nilachal hill and Chunsali hill are hillocks that cover the central part of the city. The GMA includes the Gauhati Municipal Corporation (GMC) area, the North Guwahati town committee area and some revenue villages namely, Silasundari Ghopa Mouza, Pub Barsar Mouza, Dakhin Rani Mouza, Ramcharani Mouza and Beltola Mouza.

Geomorphologically, a peneplain area (Devi 2008), the GMA is divided into major geographic units—flood plain, alluvial plain, denudational hill and inselbergs. The Deepor Beel wetland is located in the flood plain region towards the south western part of the city. The wetland (locally known as a *beel*) is estimated to cover 9.2 km^2 though the actual waterbody is only 4.1 km^2. During monsoon season, it spreads over an area of 40.14 km^2, while the depth ranges from about 1.5 to 6 m depending on the season (Planning Commission 2008). The wetland serves as an essential water storage basin for the city of Guwahati and helps in reducing the impact of flash floods.

Waste management in Guwahati is managed by the GMC. The land availability under GMC has been exhausted in terms of remaining space suitable for landfilling and therefore, the GMA has been considered in this study. Moreover, in the present Pachim Boragaon landfill site, the waste holding capacity is inadequate for the total waste generated by the city in terms of volume and this underlines the need to siting a new sanitary landfill (Audit Report 2011). Additionally, the site does not meet the site requirements stipulated by CPHEEO and CPCB.

In Guwahati, the current daily quantity of solid waste generation from all sources is about 600 MT or an average of 0.62 kg/day per capita. The Census of India (2011) enumerated the population of Guwahati at 963,429 persons; the latter's population is currently well over a million (United Nations 2018). Around 40% of household in GMC use municipal bins for waste disposal, 35% dispose it in their own residences, 11% dump it on the roadside, only 6% hand over waste to private parties on a payment basis and around 2% burn their waste (Gogoi 2013). Solid waste of the city comprises of biodegradable waste such as food, vegetables, fruit, garden and wood scraps (45–50%), recyclable waste including paper, plastic, textiles, glass, leather, rubber and metals (about 45%) and

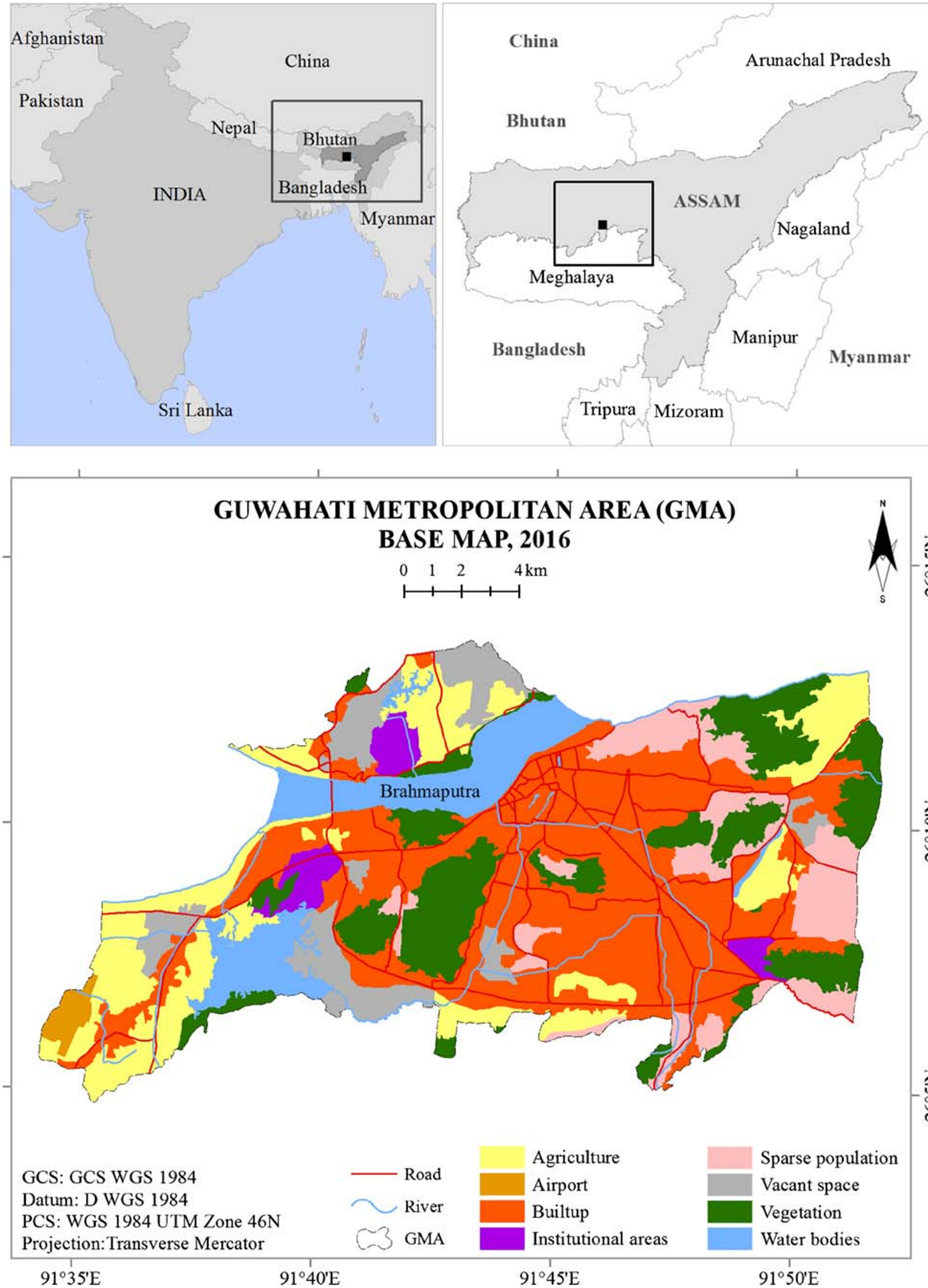

Fig. 1 Location of the study area

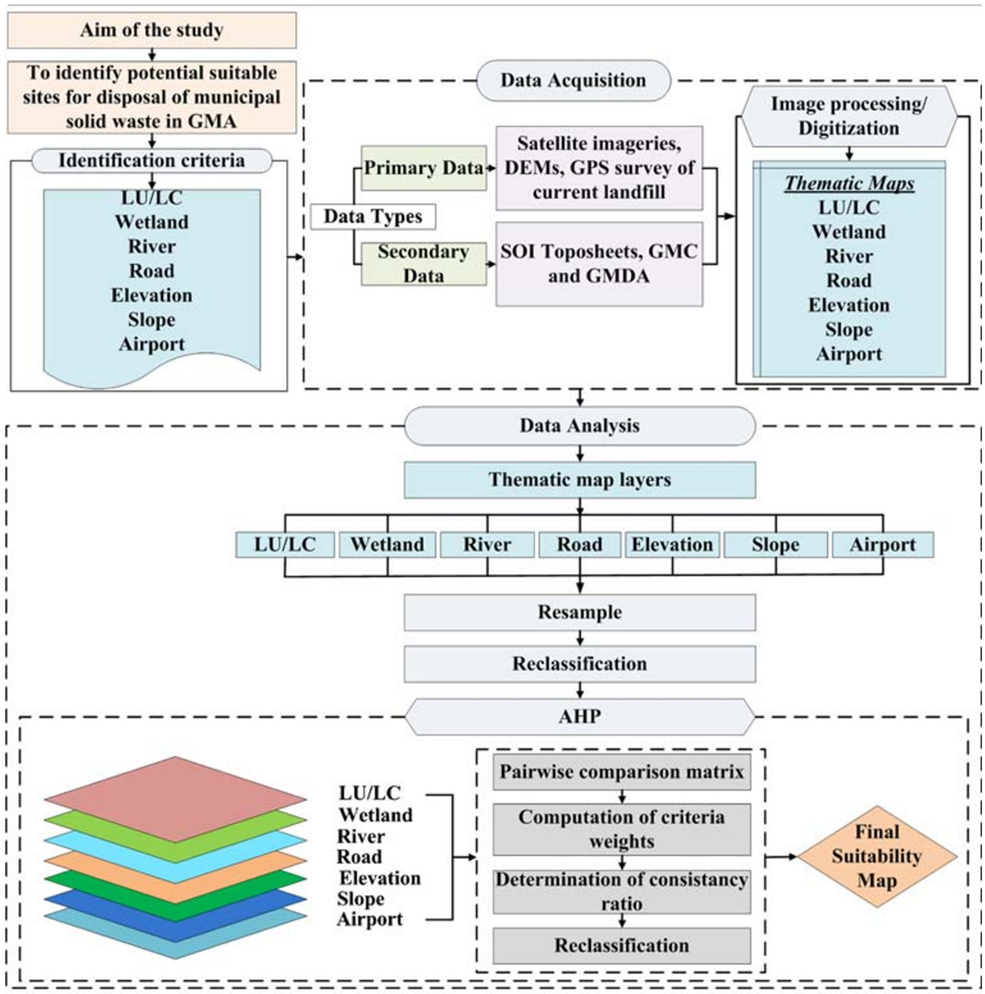

Fig. 2 The seven thematic criteria used in the analyses

the rest is non-biodegradable waste and consists of inert materials (PCB Assam 2013). The waste collected by GMC is finally disposed of at the Paschim Boragaon landfill site without segregation. It shares a common boundary with an important and ecologically sensitive wetland, Deepor Beel, the sole Ramsar wetland in Assam. In fact, pollution through seepage has endangered the various species that depend on it. The future of the SWM project is at risk as the site is in close vicinity of Deepor Beel and is against the violation of Wetland Rules, 2010 (Audit Report 2011; Final Draft Report 2015).

Waste management practices in Guwahati seem inadequate and need urgent attention; the actual regulatory and legal framework does not correspond to current needs, and monitoring and enforcement capacity in various agencies are rather weak. Distribution and allocation of waste bins at the improper location, no separate bins for recyclable waste, pollution of natural water streams due to waste collection centres proximity and open nature continue to be problematic issues (Nair 2010). The city is located in the highest seismic hazard risk zone in India with high-magnitude earthquakes having occurred in the region in 1987 and 1950 (Saikia 2005). Additionally, the city is prone to urban flooding during the monsoon months and landslides in the hills abutting the city, not infrequently, cause losses to lives and property.

Methodology

Data

For the generation of thematic layers, satellite imageries, topographical maps and ancillary data from sources like GMC and GMDA officials were used. Other sources include Master Plan for Guwahati Metropolitan Area—2025 (parts 1 and 2), Delineation of New Guwahati Metropolitan Region and Review and Revision of Master Plan, Volume I: Existing Situation and Analysis, Final Draft Report 2015, Guidelines and Check-list for evaluation of MSW Landfills proposals with Information on existing landfills, CPCB, 2008 and Swachh Bharat Mission Municipal Solid Waste Management

Table 1 Datasets used in the study

Sl. no.	Map layer	Data sources
1	Base map	Topographical map (1:50,000) LANDSAT - 8 satellite imagery (30 m)
2	Landfill location	GMC Office Project management unit (PMU) Google Earth
3	LU/LC	LANDSAT - 8 satellite imagery (30 m) GMC Office (PMU)/ GMDA Google Earth
4	Road map	Digitized from topographical map (1:50,000) GMDA
5	Slope map	ASTER - DEM (30 m)
6	Elevation	ASTER - DEM (30 m)
7	Wetland	Digitized from topographical map (1:50,000) GMDA
8	River	ASTER - DEM (30 m)
9	Airport	Topographical map (1:50,000) Google Earth

Manual, CPHEEO, Ministry of Urban Development, 2016 (parts 1, 2 and 3).

Multi-criteria decision analysis

Multi-criteria decision analysis embodies a set of sequential procedures for analyzing complex decision problems; they are divided into smaller more understandable parts, analyzing each part and integrating the parts in a logical manner to produce a meaningful and relevant solution (Malczewski 1997).

AHP is one of the most widely used MCDA methods that was developed by Saaty (1980). It is a technique used to analyse and support decisions in which multiple and competing objectives are involved and where multiple alternatives are possible. It is a process wherein, a complex decision problem is decomposed into simpler decision problems to form a decision hierarchy (Erkut and Moran 1991). The ultimate goal of decision-making is to reach the highest level of the hierarchy; accordingly, the hierarchy decreases from general to more specific until a level of attributes arrived. AHP integrates subjective judgements of the decision-maker as well as empirical data to achieve and facilitate optimal decisions (Chabuk et al. 2017).

Evaluation criteria

A set of evaluation criteria, which includes attributes and objectives, should be designated (Keeney and Raiffa 1976) for optimal site selection. It should comply with the existing governmental regulations and at the same time must minimize economic, environmental, health and social costs (Siddiqui et al. 1996).

Considering the environmental attributes of Guwahati, 7 criteria were selected as inputs to the AHP exercise (Figs. 1 and 2).

The 7 criteria were adopted based on a perusal of recent studies (Asefi et al. 2020; Rezaeisabzevar et al. 2020; Özkan et al. 2019; Moeinaddini et al. 2010; Sisay et al. 2020) as well as considering the requirements laid down in the CPCB, 2008 and CPHEEO 2016a, b, c guidelines and parameters. These criteria were grouped into constraints and decision criteria. While the constraint criteria include land use, elevation and slope; the decision criteria include proximity to roads, the river, wetlands and the Guwahati airport. The AHP toolbox in the ArcGIS software (www.esri.com) was used in the study.

AHP itself acts as a useful mechanism to ascertain the consistency of the evaluation criteria and minimize bias in decision-making (Samah et al., 2011; Sisay et al., 2020) Therefore, this study employed the consistency ratio of AHP to cross-check the consistency of the results.

Ranking method

Standardization of each criterion was made considering the suitability of the criterion and ranking in the order of decision-maker's preferences, along with the opinions of experts and a perusal of previous studies. The weights were determined and the score of alternatives was evaluated to derive the rank of the alternatives. Each layer was classified into 4 classes ranging from 1 to 4, with 1 indicating the least and 4 the highest preference respectively (Tables 1 and 2).

Pairwise comparison method

Pairwise comparisons were used to assign scores and weights for the criteria and to generate a ratio matrix. The AHP accepts

Table 2 Suitability scores

Score	Suitability
1	Very low
2	Low
3	Medium
4	High

Table 3 The 9-point weighing scale for pairwise comparisons

Intensity of importance	Description	Suitability class
1	Equal importance	Low suitability
2	Equal to moderate importance	Very low suitability
3	Moderate importance	Low suitability
4	Moderate to strong importance	Moderately low suitability
5	Strong importance	Moderately suitability
6	Strong to very strong importance	Moderate high suitability
7	Very strong importance	High suitability
8	Very to extremely strong importance	Very high suitability
9	Extremely importance	Highest suitability

Source: Saaty (1980)

pairwise comparisons as input and produces relative weights as the output. The method uses a scale with values ranging from 1 to 9 with 1 indicative of or lowest and 9 of highest suitability respectively (Table 3) (Saaty 1980)

For the computation of weights, firstly, the summation of the values in each column of the matrix is required. Thereafter, each element in the matrix is divided by its column total and then computation of the average of the elements in each row of the normalized matrix is made by dividing the sum of normalized scores for each row by the number of criteria. This provides an estimation of the relative weights of the criteria being compared.

Consistency ratio (CR) is used to determine if the comparisons are consistent or not. It involves the following steps:

a. A weighted sum vector is calculated by multiplying the weight for the first criterion times the first column of the original pairwise comparison matrix, then multiplying the second weight times the second column, the third criterion times the third column of the original matrix, finally summing these values over the rows,
b. Consistency vector is derived by dividing the weighted sum vector by the criterion weights determined previously,
c. Compute lambda (λ) which is the average value of the consistency vector and consistency index (CI), and it provides a measure of departure from consistency:
   $CI = (\lambda - n)/(n\text{-}1)$
d. Calculation of the CR:
   $CR = CI/RI$
e. Random index (RI) is the number of elements being compared (Tables 4 and 5). If CR is < 0.10, the ratio indicates a rational level of consistency in the pairwise comparison; however, if CR ≥ 0.10, the values of the ratio indicate inconsistent judgements.

Results and discussion

The study used various parameters such as land use, hydrological (surface water and wetland proximity), topographical (slope and elevation) and economic (road and airport proximity) to assess the suitability of the existing current dumpsite in Guwahati and explored the feasibility of potential landfill sites in the GMA. To generate map layers, various spatial analysis tools (buffer, clip, extract, overlay, reclassify, proximity, etc.) were employed in a GIS. Suitability scores and relative weights were assigned based on (i) norms followed in recent studies and their relative importance in the process of decision-making (Sisay et al. 2020; Richter et al. 2019; Alavi et al. 2012; Mipun et al. 2015) and (ii) local conditionalities. For instance, land use criteria have been ranked the highest considering that the million city of Guwahati faces acute land scarcity emanating from unplanned urban growth and a dearth of open spaces within municipal limits. Hence, it was felt prudent to extend the study area to the GMA.

Land use The land use pattern of a region is an outcome of both natural and socio-economic factors and their utilization by humans over time and space (Karthiheyan and Yeshodha 2016). Arid and less suitable agricultural tracts are oftentimes preferred landfill sites (Abediniangerabi and Kamalirad 2016). Dumping site should not be selected close to built-up

Table 4 Random index

Order Matrix	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty (1980)

Table 5 Preferred suitability classes

Sl. no.	Criteria	Suitability class	Area (in sq. km)
1	Land use	Vacant space	21.4
2	Wetland proximity	More than 3200 m away	90.9
3	River proximity	More than 1600 m away	71.2
4	Road proximity	200–800 m	121.3
5	Elevation	35–70 m	186.8
6	Slope	Less than 7 degree	58.3
7	Airport	More than 25 km	57. 3

and vegetated areas, as they adversely affect land value and future development and also to minimize current and future environmental hazards (Clark and Gillean 1974) and their effects. In this study, 8 land use classes were identified: water bodies, built up, institutional, airport, vegetation, sparse population, agriculture and vacant space. Water bodies, built up, institutional, airport class and sparse population were grouped into a single class with the lowest suitability score. Vacant space is used as the most suitable class for siting landfills and therefore, the highest score suitability score was assigned to such areas.

Wetland proximity Dumpsites release noxious gases and chemicals into surrounding water sources, reservoirs, and increase potential threats to all organisms in the vicinity. Wetlands tend to facilitate the transmission of waste and latex, so it is better to locate landfills in places bereft of flood incidence for at least a century (CPHEEO 2016a, b, c). A sufficient distance should be maintained to avoid contamination and hazards through leachate (Gbanie et al. 2013; Mahmood et al. 2017). The polluted runoff coming from landfills has a high capability to contaminate surface water. Locations that are situated at least 200 m away from wetlands are best for disposal (CPHEEO 2016a, b, c). In this study, the zone at the farthest distance from a wetland was accorded the highest suitability score.

River proximity In India, dumping of solid waste on or in close proximity to any water surface is prohibited, be it a river or lake (CPCB 2008). To reduce vulnerability to pollution of surface water from contamination, landfills near streams and rivers are generally avoided. Likewise, landfills must be located 100 m away from rivers (CPHEEO 2016a, b, c). Proximity to rivers has a direct relationship with land suitability in terms of landfill site suitability. Thus, buffer zones at greater distances from river(s) were assigned higher suitability scores in the present study.

Road proximity Distance from roads is always viewed as an important economic factor in site selection (Gbanie et al. 2013; Gunko and Medvedev 2016; Abediniangerabi and Kamalirad 2016). Landfill sites should be close to highways and main roads to minimize construction costs (Abdoli 1993; Lin and Kao 1999). To minimize the interference of solid waste laden vehicles with the main traffic, the lowest distance allocated was the 100-m distance from roads. A distance greater than 1 km from main roads and highways were avoided (Allen et al. 2001) and access to landfill sites by alternative all-weather roads were also factored into the present analysis. A proximity zone between 200 and 800 m was given the highest suitability score, keeping in view the rider that landfills shall not be located within 200 m of major highways, city streets or other transportation routes (CHEEPO 2016b).

Elevation The elevation is considered to be an essential factor in locating landfill sites. Due to the transmission of soft trash bags by the wind at high elevations, it causes environmental pollution and therefore is not appropriate for landfill siting (Abediniangerabi and Kamalirad 2016). Hilly landscapes not only increase construction costs but also become a burden to vehicles transporting waste to landfill locations. High-elevation areas were thus assigned the least suitability and vice versa.

Slope The degree of slope is a crucial factor in landfill siting. Higher excavation costs are entailed in steeper slopes and soil erosion can be problematic in such areas (Koulouri and Giourga 2007; Memarbashi et al. 2017) along with the risk of drainage of pollutants to surrounding areas (Kao 1996).

Table 6 Pairwise comparison matrix

Criteria	Airport	Slope	Elevation	Road	River	Wetland	Land use
Airport	1	0.5	0.33	0.2	0.17	0.14	0.13
Slope	2	1	1	0.33	0.2	0.17	0.14
Elevation	3	1	1	0.33	0.25	0.2	0.17
Road	5	3	3	1	0.5	0.33	0.25
River	6	5	4	2	1	0.5	0.33
Wetland	7	6	5	3	2	1	0.5
Land use	8	7	6	4	3	2	1
Total	32	23.5	20.33	10.86	7.12	4.34	2.52

Table 7 Normalized pairwise comparison matrix and computation of criterion weights

Criteria	Airport	Slope	Elevation	Road	River	Wetland	Land use	Computation of weight criterion
Airport	0.03	0.02	0.02	0.02	0.02	0.03	0.05	0.03
Slope	0.06	0.04	0.05	0.03	0.03	0.04	0.06	0.04
Elevation	0.09	0.04	0.05	0.03	0.04	0.05	0.07	0.05
Road	0.16	0.13	0.15	0.09	0.07	0.08	0.1	0.11
River	0.19	0.21	0.2	0.18	0.14	0.11	0.13	0.17
Wetland	0.22	0.26	0.24	0.28	0.28	0.23	0.19	0.24
Land use	0.25	0.30	0.29	0.37	0.42	0.46	0.4	0.36
Total	1	1	1	1	1	1	1	1

Thus, the steeper the slope, the lower is the suitability and lesser is the preference for a landfill site and vice versa (Akbari et al. 2008). Slopes less than 10% are most suitable for solid waste dumping (Leao et al. 2004; Sener et al. 2011). Accordingly, areas with a minimal slope were preferred for the GMA and tracts with less than 7% were given the highest suitability scores.

Airport proximity Landfills attract birds and dust flows that are a hindrance and risk to air traffic and hence, distance is a factor in their siting (Daneshvar 2004; Monavvari et al. 2012). Ideally, a landfill should not be set up within a 20 km from an airport, though such a distance can be difficult to adhere to in certain cases. In this analysis, the distance from the Lokpriya Gopinath Bordoloi International Airport was factored in.

Computation of AHP

AHP was calculated as follows (Tables 6, 7 and 8):

$$\text{Calculation of lambda } (\lambda) = (7.26 + 7.09 + 7.00 + 7.16 + 7.29 + 7.37 + 7.36/7) = 7.22$$

$$\text{CI}-0.04; \text{RI}-1.32; \text{CR}-0.3$$

The CR of the present study is 0.03 and it is < 0.10; therefore, it indicates that the weights assigned were satisfactory.

Computation of suitability index

All seven criteria maps were converted into rasters, so that pixel-wise scores could be determined (Jain and Subbaiah 2007). All the criteria maps were integrated and overlaid, and final site suitability map (Fig. 3) was prepared:

$$\text{Suitability map} = \sum[\text{criteria map}*\text{weight}]$$

$$\begin{aligned}\text{Suitability index (SI)} = & \left([\text{airport}]*0.03) + [\text{slope}]*0.04\right) \\ & + ([\text{elevation}]*0.05) \\ & + ([\text{road}]*0.11) + ([\text{river}]*0.17) \\ & + ([\text{wetland}]*0.24) \\ & + ([\text{land use}]*0.36)\end{aligned}$$

The final suitability map was reclassified into 5 classes with different suitability intensities. A 7.5% of the total area had the highest suitability with 19.7 sq. km. of area, 22.8% had high suitability and 43.8%, 22.2% and 3.5% had moderate, low and very low suitability respectively (Figs. 3, 4 and 5).

On the basis of the area covered by each patch, 5 sites were proposed of which the most suitable site, Gauripur, located in north Guwahati, is also the largest in terms of area (Tables 9 and 10).

Our results are in consonance with previous studies wherein one or a few suitable landfill sites were identified (Shah et al. 2019; Nigusse et al. 2020; Aderoju et al. 2020). Similarly, the identified suitability site extent in this analysis of 7.5% resembled those determined by recent analyses which

Table 8 Computation of the consistency vector

Criteria	Weighted sum vector	Consistency vector
Airport	0.2	7.26
Slope	0.31	7.09
Elevation	0.36	7.00
Road	0.79	7.16
River	1.22	7.29
Wetland	1.8	7.37
Land use	2.62	7.36

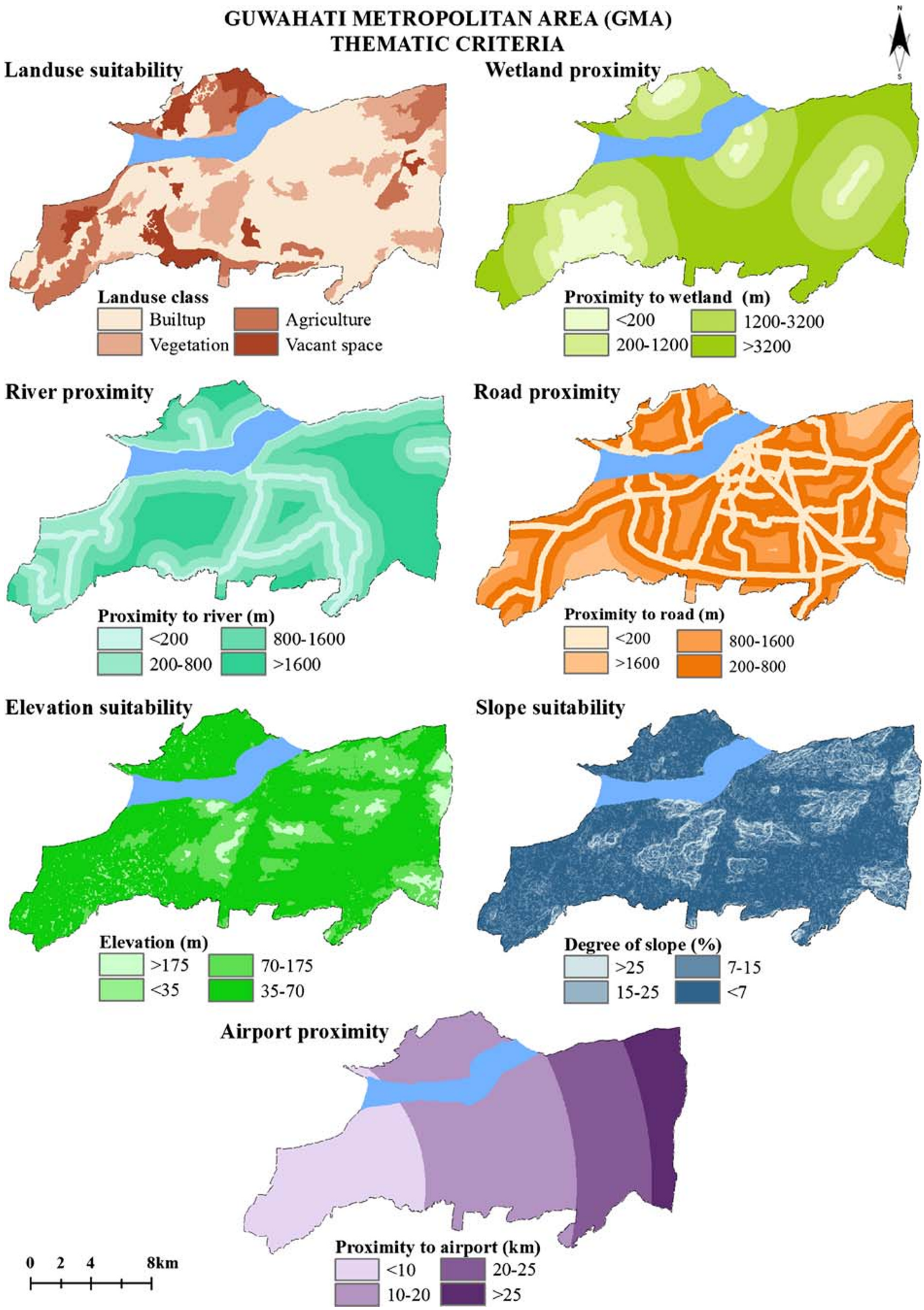

Fig. 3 Methodology adopted for the study

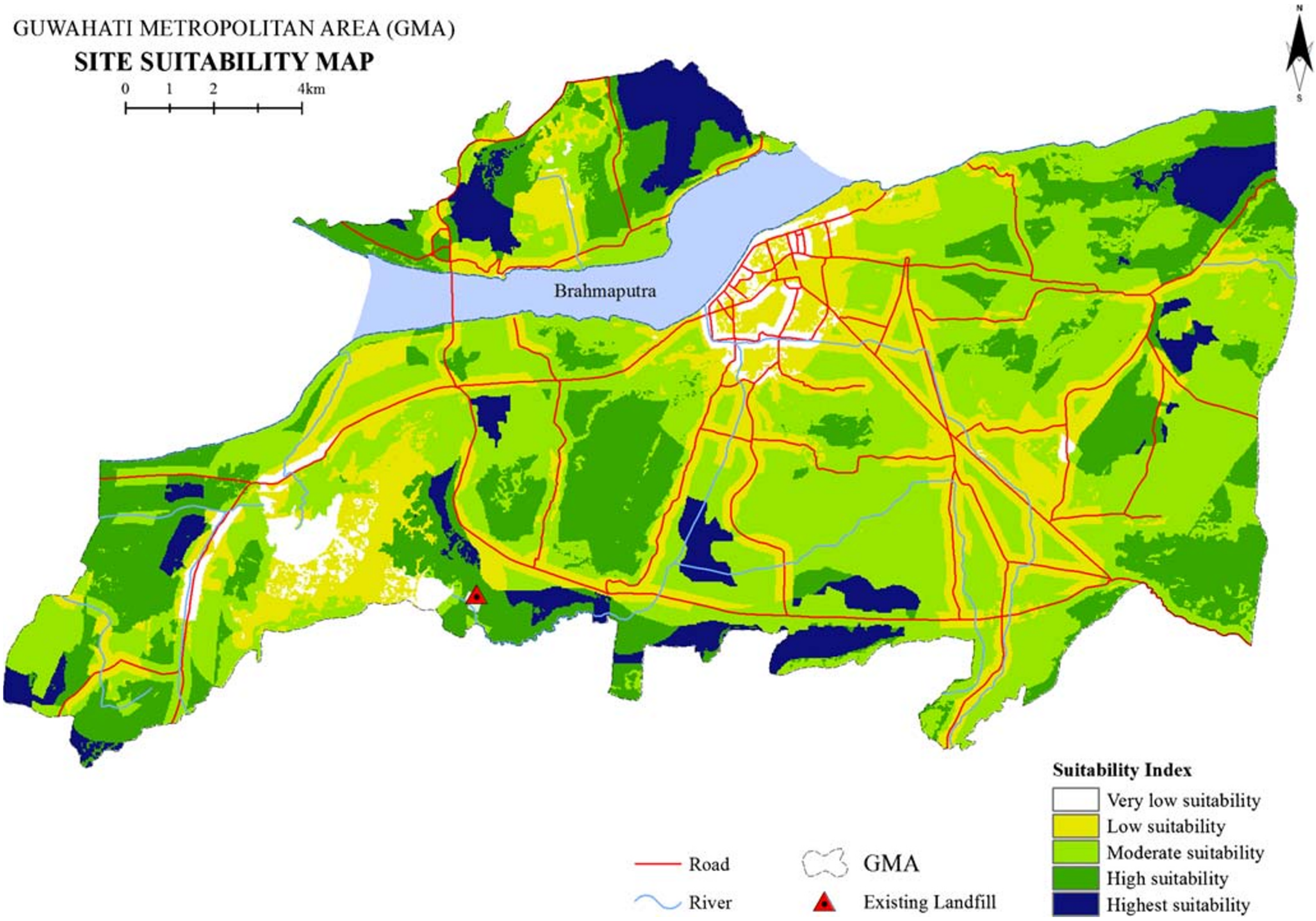

Fig. 4 AHP-based final site suitability map

varied from 7.6 (Nigusse et al. 2020) to 14.5% (Agrawal et al. 2020).

Conclusion

Landfill sites for municipal solid waste disposal were sought for the city of Guwahati using GIS-based MCDA-AHP methods. GIS enables the identification of suitable sites although it is hardly a substitute for ground truthing and field verification. Seven criteria namely land use, wetlands, rivers, roads, elevation, slope and proximity to the airport were used in this analysis. A total of 7.5% (19.7 sq. km) was identified as being of the highest suitability to locate such a landfill site. The study provides alternative potential sites that could aid in relocating the existing site. These sites were selected on the basis of the area covered by each site within the highest suitability zone.

In Guwahati, due to the lack of an efficient solid waste collection and disposal system, people tend to variously dump garbage on open spaces, streets, into open drains, etc., that lead to environmental problems like waterlogging (natural and artificial) and clogging of drains besides creating a generally foul environment. There has been a consistent rise in municipal solid waste due to rapid population growth, mass migration from rural to urban areas, floating population, etc.

The present Pachim Boragaon landfill located on the outskirts of the city shares boundaries with Deepor Beel and poses threats to fish and migratory birds in the wetland. It is used as a mere dumpsite for disposal and no waste segregation and processing is undertaken, giving rise to environmental pollution and posing potential health risks to local residents.

With rapid industrialization and urbanization, waste management has assumed immense significance. Unfortunately, it is conveniently lost sight of developing countries where oftentimes more pressing matters tend to relegate it to relative obscurity.

The tremendous increase in population and persistent drive for economic progress and development has resulted in a remarkable increase in the quantity of solid waste. While recycling, reusing and reducing are effective in reducing solid waste problems; without additional management measures, including proper landfill siting, these remain insufficient. Not infrequently, MSW in developing countries is dumped on land in an

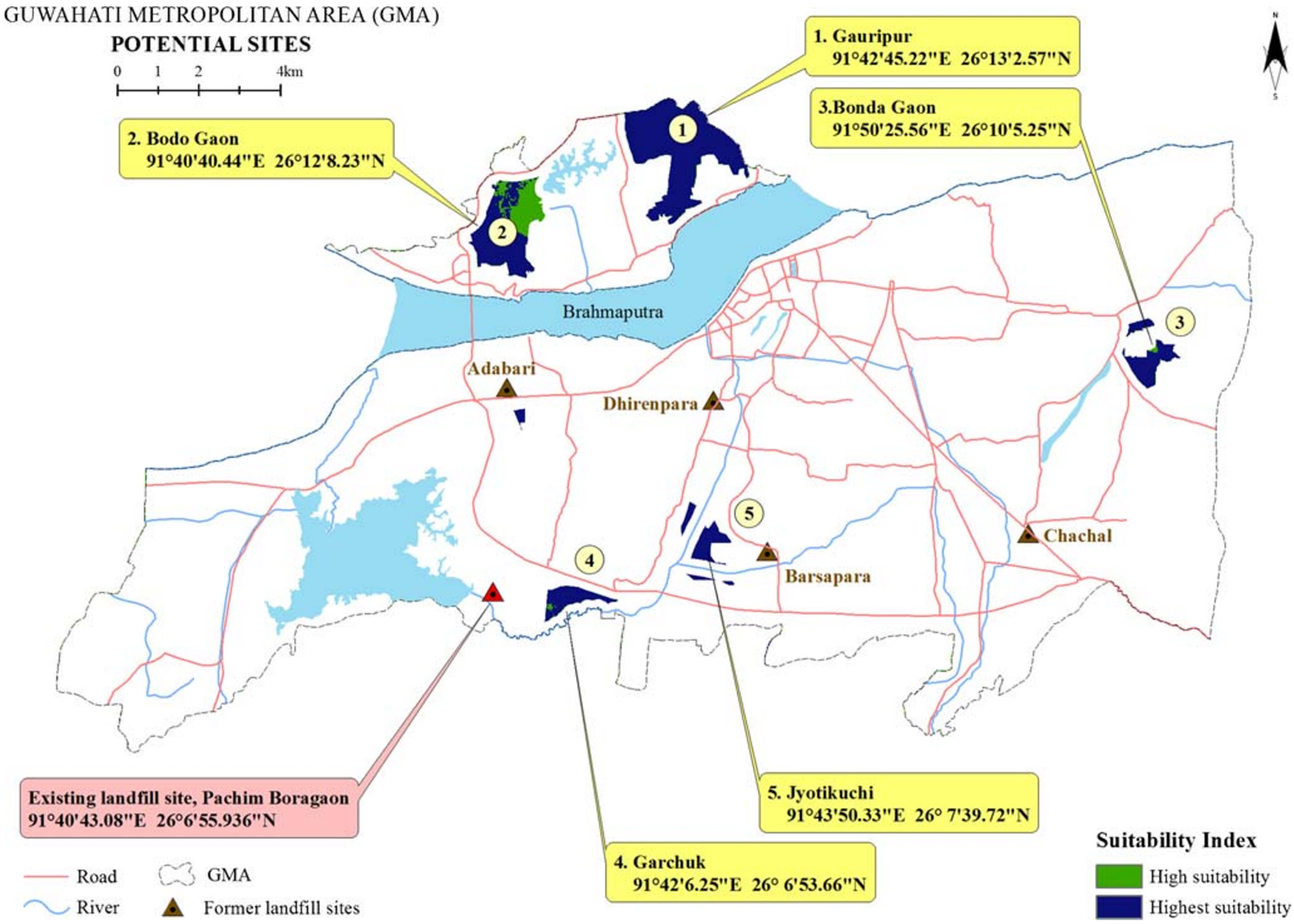

Fig. 5 Optimal landfill sites for the GMA

uncontrolled manner. Selecting landfill sites is a complicated task where environmental, social, technical and economic issues must be taken into consideration and where public opposition to site selection can be a contentious matter. The methodology and approach adopted in this study can be employed in urban areas elsewhere in general and in cities of Northeast India in particular. In the latter, unfortunately, no site suitability analyses are undertaken prior to locating minimally obtrusive landfill sites.

Guwahati is a hub for political, administrative, industrial, educational, commercial and many other activities, is the largest city in Northeast India and is poised to grow further considering the Indian government's Act East Policy. The GMA in many ways epitomizes the problem of waste management in low- and middle-income countries which possess ample room for improvement. For a start, the city's landfill site needs to be shifted to a more suitable location if the GMA is to reap the benefits of an urbanism without these being

Table 9 Area-wise suitability classes

Suitability class	Area (sq. km)	Area in percent
Very low suitability	9.44	3.59
Low suitability	58.46	22.22
Moderately suitable	115.41	43.88
High suitability	59.98	22.80
Highest suitability	19.75	7.51
Total	263.04	100

Table 10 Areas of proposed sites

Site no.	Name of site	Area (sq. km.)
1	Gauripur	4.36
2	Bodo Gaon	2.77
3	Bonda Gaon	0.71
4	Garchuk	0.64
5	Jyotikuchi	0.46
Existing site	Pachim Boragaon	0.24

negated and nullified by inappropriate waste management strategies.

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