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An assessment of suitable landfill site selection for municipal solid waste management by GIS-based MCDA technique in Siliguri municipal corporation planning area, West Bengal, India

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Abstract

Identification of suitable landfill sites for urban wastes with ease and economic benefits in the metropolitan area is a complex task. Most of the developing countries consider wastelands outside of the urban areas are the ideal places to dispose of urban wastes. Landfill site selection is an essential planning procedure that helps to avoid environmental concerns such as water contamination, public health degradation caused by unsanitary landfills. So, employing a geographic information system (GIS) and multi-criteria decision analysis (MCDA), this study was carried out to find an appropriate planning waste dump site. Nine thematic layers were evaluated as key criteria, including elevation, slope, geology, lineament, land value, distance from river, roads, residence, and Land use and land cover (LULC) weights assigned using Analytical Hierarchical Process (AHP) method analysis. The relative relevance of each parameter was calculated using Saaty's 1 to 9 priority scale. The consistency ratio was used to check the weighting of each parameter, allowing the efficiency of the chosen parameters to be justified. The overlay analysis of all parameters with aid of GIS provides suitable sites that were marked and refined after the comprehensive field visits were performed. According to the findings, in the study area, 35.61% area is very low suitable for landfilling, 32.64% area is low suitable, 19.37% area is moderate suitable, 8.90% area is highly suitable and certainly, 3.48% area is very high suitable by Natural breaks classification. The very high suitable site belongs to Dhadagoch, Gadheaganj, and its surroundings in the study area. Nevertheless, the present study can help urban planners and concerned authorities to better succeed in urban waste management in the Siliguri municipal corporation planning area.

Keywords: MCDA, Geographical information system, Landfill site selection, Multicollinearity test

1 Introduction

The term "solid waste" refers to the garbage and unwanted solid materials generated in the house, company, industrial sector, and street sweeping (Yang et al., 2013; Ali & Ahmad, 2020). The organic and inorganic both can be found in municipal solid trash, which is divided into four categories based on its origin: home, commercial, industrial, and constructional or institutional garbage (Ali & Ahmad, 2020). Solid waste management is the process of generating, collecting, transporting, and disposing of solid waste (Mojiri et al., 2014). Municipal solid waste is a critical challenge for underdeveloped nations, where the solid waste management technique is not very active, due to rapid urbanization and a lack of human understanding (Gorsevski et al., 2012; Hasan, 2004;). Illegal dumping,

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disposal sites, burning are examples of solid waste disposal methods in our country (Ali & Ahmad, 2020). For both environmental and public health concerns, waste disposal is essential (Porta et al., 2009).

The current waste management situation in all developing countries is comparable, with large amounts of garbage being generated, fetched, transported, disposed, and unscientific landfilling all being common elements (Guerrero et al., 2013; Ali & Ahmad, 2020). India, being a growing country, faces similar concerns and problems with significant environmental consequences (Ali & Ahmad, 2020). The majority of Indian metropolises, such as Mumbai, Delhi, Kolkata, and Chennai, produce large quantities of garbage daily, but there is no effective waste management in place, such as sanitary landfills (Dhokhikah & Trihadiningrum, 2012). In Siliguri, the problem of solid waste management and appropriate disposal is a common occurrence. In recent, this city generates 400 t of solid trash per day in 2021 and the solid waste creation in this city will increase day by day such as 455 t per day in 2031 and 573 t per day in 2041, which would be a significant environmental threat as projected by CRISIL Risk and Infrastructure Solutions Limited (Ladda et al., 2015; Office of District Magistrate, 2021). Furthermore, a field survey revealed that two sites were already full, and the area available for dumping had ran out, leaving no space for future dumping. As a result, the current disposal strategy and existing dumping sites will become outdated in the not-too-distant future due to their inability to cope with the volume of garbage generated. So, it is a source of concern due to a lack of land availability for disposal by identifying a suitable site for a dump the waste while also considering the environmental benefit and there has been an example of people living in close proximity to landfill developing health problems, if waste is not properly handled and disposed (Martine, 2000). So a landfill site is necessary for solid waste dumping in this planning area. As a result, concentrating on the amount of waste produced is a wise decision.

According to the expert opinion, several landfill site selection strategies and procedures have been reported in the past based on several manual interpretations of various thematic layers.

Researchers have used quantitative approaches in contemporary periods, viz. artificial neural networks, logistic regression analysis, fuzzy logic, multivariate regression analysis including F-MCDA and F-AHP to delineate landfill site selection zone (Lukasheh et al., 2001). Machine learning approaches are now widely used to predict various natural disasters such as floods, wildfires, earthquakes, and doughtiness, as well as to select various types of potential sites such as ecotourism site, suitable crop site, and site for landfill also (Adeleke et al., 2021). But there is a lack of proper technique to delineating the potential landfilling site regarding municipal solid waste.

So, one of the most difficult tasks that faced by town and urban planning agency is choosing a prospective landfill potential area (Rushbrook & Pugh, 1999). Multiple decisions must be made at the same time in order to reduce the impact without jeopardising social, economic, environmental, or technical factors (Kontos et al., 2005, b; Zotos et al., 2009). The development of a landfill is critical as part of a solid waste management strategy. However, the multi-faceted and conflicting nature of landfill sitting, which includes environmental, social, technological, and economic factors, makes finding an appropriate landfill site challenging. In the present study, a geographic information system (GIS) and an analytical hierarchy process (AHP) multi-criteria decision analysis used to choose a landfill location by minimizing conflicting interests. Environmental and socio-economic factors including elevation, slope, geology, lineament, land value, distance from river, roads, residence, and Land use and land cover were weighted in order to create a landfill site, because it gives a logical strategy for selecting a scientific site for an urban solid waste dump (Asefa et al. 2021). Hence, the study about Suitable landfill site selection for waste management in Siliguri Municipal Corporation Planning Area is done by following GIS-based MCDA technique.

2 Study area

In the Darjeeling Himalayan foothills, Siliguri Municipal Corporation is one of West Bengal's most rapidly increasing and fastest-growing urban centers. It started as a little village of fewer than 800 people in 1901, but by 1949, it had grown to a municipality town with 32,480 populations. In the year 1994, it was converted to the rank of Municipal Corporation and in 2021, the total population was 6, 89,675 (Office of District Magistrate, 2021). The government of West Bengal established the Siliguri Jalpaiguri Development Authority (SJDA) in the year 1980 for the development of Siliguri city and its adjacent area. In Siliguri, the problem of solid waste management and appropriate disposal is a common occurrence with its growing population. It has been found that from the dawn of independence, the city's population has steadily expanded (Fig. 1) and solid waste production is proportionally increasing (Fig. 2), but space is limited. Keeping in consideration such an adversity, dumpsites are gradually increasing and located randomly throughout the city and not in the correct management status. Though there are existing landfill sites (Fig. 3) in the Siliguri Municipal Corporation planning area, they are not well planned and are also not cost-effective. Therefore a scientific and logical revision in the waste disposal management is urgently

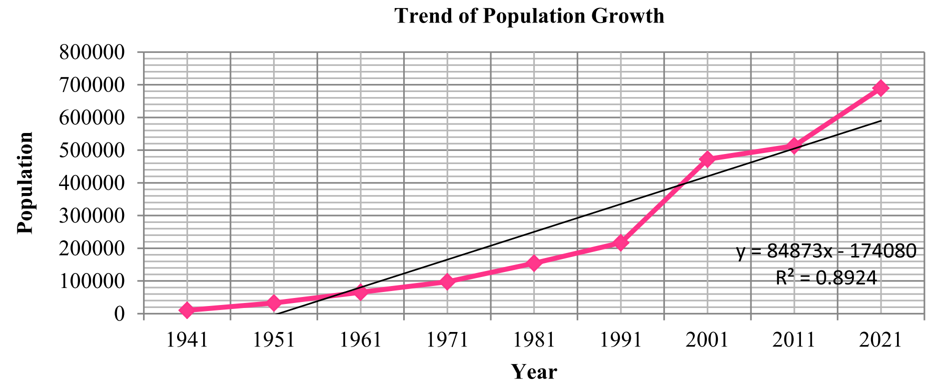

Fig. 1 Trend of Population Growth in Siliguri Municipal Corporation

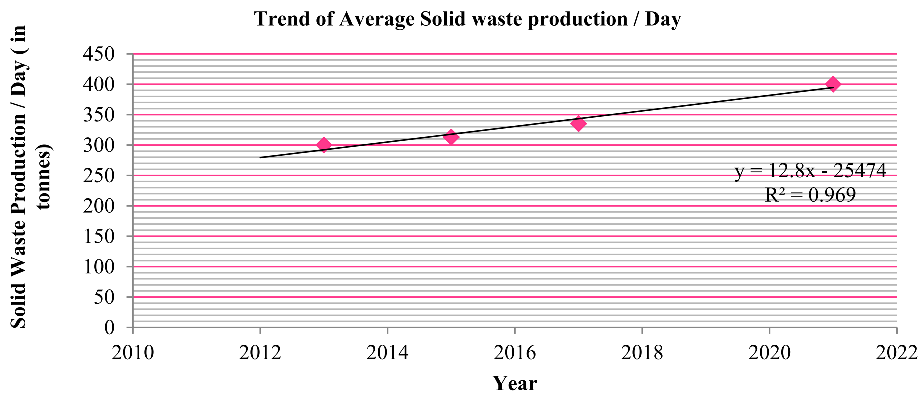

Fig. 2 Trend of Average Solid Waste production / Day in Siliguri Municipal Corporation

needed, and for the same, the Siliguri Municipal Corporation Planning Area was selected for this study. The total area of the Siliguri Municipal Corporation Planning Area is about 272.36 Sq.km. It has a total of 47 wards and out of it, 14 wards are situated in Jalpaiguri district and the rest of 33 wards in Darjeeling district. The latitudinal extension of the study area is 26°36′0″N to 26°47′7″N and longitudinal extension is 88°16′42″E to 88°31′34″E showing in Fig. 3.

3 Data base

For the assessment of landfill site suitability in the Siliguri Municipal Corporation Planning Area, a total of nine thematic layers were used such as elevation, slope, geology, distance from lineament, land value, distance from roads, river, and canal, residence, land use and land cover (LULC) after a large number of literature reviews and experts' opinions. Among these layers, elevation and slope mapping have been prepared with the ASTER Digital Elevation Model (DEM) presented by NASA platform with 30 m resolution cell size. Geology and lineament thematic layer was prepared by Arc GIS tool and data was collected from the Geological Survey of India (GSI). Land use and land cover (LULC) map was prepared by sentinel 2 data type from global ESRI thematic layer with 10 m resolution cell size. After that, a survey was conducted to know the land value evaluation in the Siliguri Municipal Corporation Planning Area with the GPS location tool (Coordinates data). For the distance of the thematic layer from the river and canal, a road network open street data server was performed to prepare these layers, and in the GIS environment, the Euclidian distance tool was used for the buffer zone. Finally, the Google Earth application was performed to identify the point and area vector data for preparing distance from residential area thematic layer. The data source for suitable site selection in the Siliguri Municipal Corporation Planning Area has shown in Table 1.

4 Methodology

4.1 Criteria selection for suitable landfill site

The most important step in any applicability study is to choose appropriate parameters. The selection of parameters is far different from choosing objectives or locations.

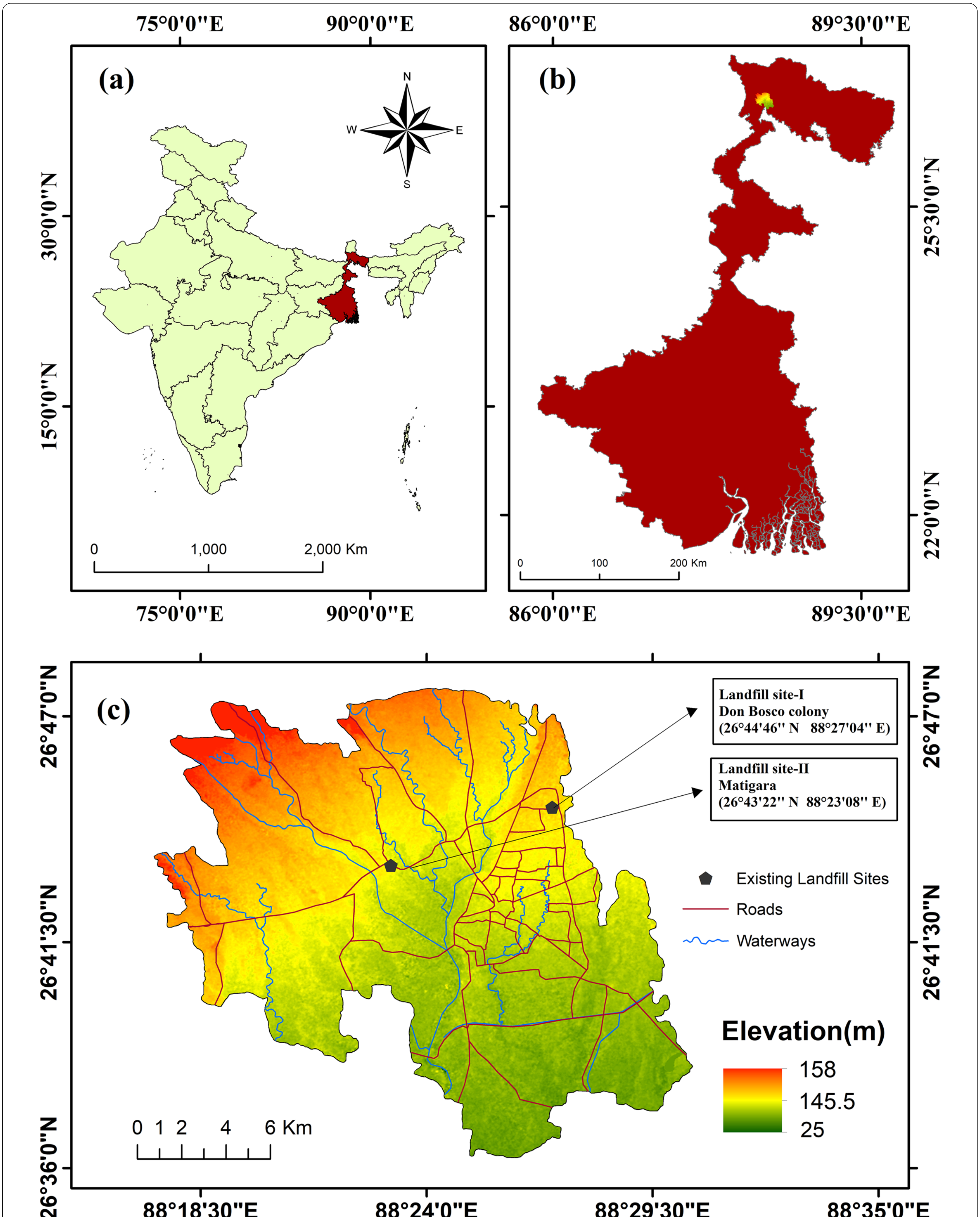

Fig. 3 Location of the study area a. India b. West Bengal c. Siliguri Municipal Corporation Planning Area (study area) with existing landfill site

Table 1 Thematic layers used for landfill site selection, their sources and details

Criteria	Data type	Data details	Data source
Elevation (m)	ASTER global digital elevation model (DEM)	Raster, 30 m resolution	NASA earth data
Slope(Degree)	ASTER global digital elevation model (DEM)	Raster, 30 m resolution	NASA earth data
Geology	Geological survey of India (GSI)	Vector, Shape file	Geological survey of India
Lineament	Geological survey of India (GSI)	Vector layer	Geological survey of India
Land value(Lakh/katha)	GPS-Survey	Attribute co-ordinate data	Field survey
Distance from River & Canal(m)	River network	Open Street Map Data, vector data, shape file	Open Street Map Data
Distance from Road(m)	Road network	Open Street Map Data, vector data, shape file	Open Street Map Data
Distance from Residence(m)	Residential area, Google earth	vector data	Google earth engine
LULC	ESA Sentinel-2	Thematic Raster layer, 10 m resolution	Global Esri Inc

Source: Compilation by the author

Multiple criteria should be considered in this study since land filling is a technique that involves the disposal of urban wastes and the surrounding environment and public health are severely damaged as a result of improper disposal and management. In earlier research, the criteria for appropriateness study of landfill site selection at global sizes vary. After reviewing the literature survey (appendix table 1) for selection of appropriate criteria (Table 2) and following the pollution controls board's guidelines, nine specific and relevant parameters were chosen using GIS-based MCDA techniques to identify suitable sites in the Siliguri Municipal Corporation planning Area.

4.2 Multicollinearity test

Multicollinearity is a useful tool as it recognizes the correlation between the variables in the model. It is found that it never affects on model's predictability

Table 2 landfill site selection criteria and reason behind their selection

Criteria	Reason behind selection
Elevation (m)	Land elevation has an inverse relationship with landfill suitability, the appropriateness of an area for a dumpsite decreases at the increase of land height (Kontos et al., 2005, b; Ali and Ahmad, 2020). Because the contamination and Leachate flow are maximum in steep slope which is unfavorable for landfill. (Ali and Ahmad, 2020; Ebistu and Minale, 2013). Soft garbage bags can be scattered by the wind from high elevations therefore, lower elevation or flat areas are favored for appropriate landfill locations (Abediniangerabi and Kamalirad, 2016; Hazarika and Saikia, 2020; Ali and Ahmad, 2020).
Slope (Degree)	Slope is a crucial parameter for landfilling. The slope of a landform determines the surface runoff characteristics, flow velocity, water content in the soil, and erosion potential of an area. A steep slope can spread the waste material so, the gentle slope is preferred most suitable for the potential landfill site.
Geology	Geology determines the infiltration rate and hence low infiltration formation is considered as suitable for land filling because it arrest the leaching contaminant from landfill site to the ground water.
Lineament	Lineament refers to the linear faults on the earth's surface, its secondary porosity and permeability of the rock structure. Fractures are sometimes directly linked to groundwater, which might be a source of pollution in both surface and groundwater. So, landfills should be located far away from faulty regions as feasible.
Land value (Lakh/katha)	Reciprocal relationship exists between land fill site and land value
Distance from River & Canal (m)	The appropriateness of a landfill site is directly related to its proximity to rivers and canals. In India, it is illegal to dump solid waste near any water surface, whether it can be a river or a lake. (CPCB 2008). Landfills near streams, canals, and other bodies of water are typically avoided to limit the risk of contamination of surface water (CPHEEO 2016). Therefore, the maximum distance from any water body is highly weighted for site selection whereas the minimum distance from river or canal is considered unsuitable for site selection.
Distance from Road (m)	For the transportation of wastages from the urban area to the outside road, connectivity is an important factor, close to road preferred more suitable than far away from road connectivity.
Distance from Residence (m)	Residential area in any metropolitan city or town is a most important as well as a sensitive essential element. Various environmental pollutions were generated by Landfill and affect the local residence or settlement areas. To locate the landfills within cities or towns is unsuitable because of unfavorable odor and noise. For this, more distance from residence is most appropriate for landfill and closer distance to residence area is inappropriate.
LULC	To locate water body, natural vegetation, agricultural land, bare land, and settlement area LULC is important because it is very sensitive to select a land fill site for waste dumping.

Source: Compilation by the author

and reliability. The model's prediction accuracy will be reduced if there is linear collinearity between the conditioning factors (Rahmati et al. 2016). In the case of landfill site selection modeling, it is important to check the Multicollinearity between the factors to increase the model accuracy. There are several methods used for the multicollinearity test, in this present study Variance Inflation Factor (VIF) method is performed to analyze the statistical collinearity among the conditioning factors (Appendix table 2). Statistically, the level of Tolerance should not be less than 0.1, and the percentage of VIF should be less than 10. If these two conditions are perfect then it is said to be that there is no linear collinearity between the conditioning factors. The following formula is used to calculate the VIF.

Tolerance of the ith predictor variable $(Ti) = 1 - R_i^2$

$$\text{VIF of the j}^{\text{th}}\text{predictor variable } (\text{VIF}_\text{j}) = 1/\text{T}_\text{i}$$

(Where R_i^2 represents the coefficient of determination of the regression equation)

To evaluate the problem of multicollinearity among the parameters, there is randomly selected 1000 points ($N = 1000$) in a suitable landfill site of the study area applying the 'Create Random Points' tool and randomly generated point data was extracted by 'Extract Values to Points' tool from each parameter in Arc GIS environment. Collinearity statistics (Table 3) of the selected 9 suitable landfill parameters indicate that the coefficient value of Tolerance and VIF of all the variables has been assigned more than 0.1 and less than 10% respectively (Chen et al. 2018; Arabameri et al. 2019), it is indicating all parameters are the individual difference and there is no high correlation among the factors.

4.3 Assessment of MCDA technique with AHP method

AHP technique is the most important method for the decision-making process by assigning the weight of the individual criterion. This method is first introduced by Saaty in 1980. There are several subjective and objective methods in MCDA technique and, in this present study AHP method severely used for suitable landfill site selection (Şener et al. 2011; Gbanie et al. 2013; Khan and Samadder 2015; Guler and Yomralioglu 2017; Chabuk et al. 2017; Mainul Sk et al. 2020). The weightage value of each criterion has been assigned according to Saaty's relative importance scale which has been shown in Table 4 (Saaty, 1980). The calculation part of the AHP method has been evaluated sequentially with four respective processes. The processes which are involved in the AHP method are the pairwise comparison matrix process, weight normalization tabulation, weights estimation, and the last stage of the method to check consistency (Ghosh et al. 2020). The weights of all nine parameters are assigned depending on a lot of expert judgments, multiple literature reviews, and field experience (Das 2019; Saha and Agrawal 2020; Chakraborty and Mukhopadhyay, 2019; Souissi et al. 2019; Khosravi et al. 2019;).

4.3.1 Pairwise comparison matrix calculation: (Aksoy & San, 2019)

To evaluate the comparison matrix in the AHP method relative importance has been assigned between each parameter. In the matrix table, minimum input value 1 means there was equally important and maximum input value 9 means there were extremely important between the criterions. Land value has been assigned maximum relative importance because it has the potential to develop the location where waste dumping ground cannot reside and the residential zone

Table 3 Collinearity statistics of Land fill suitable site selection parameters

Factors	Elevation	Slope	Geology	Lineament	Land value	River	Road	Residence	LULC
Tolerance	0.742	0.986	0.870	0.874	0.484	0.912	0.764	0.598	0.826
VIF	1.347	1.014	1.149	1.144	2.064	1.096	1.309	1.672	1.210

Source: Computed by the author

Table 4 Saaty's relative importance scale value

Less important				Equal important	More important			
Extremely	Very strongly	Strongly	Moderately	1	Moderately	Strongly	Very strongly	Extremely
1/9	1/7	1/5	1/3		3	5	7	9

2, 4, 6, 8 are the intermediate values between the two adjacent judgments in a pairwise comparison matrix

Source: Saaty's scale, 1980

was chosen second relative important because dumping ground spread various pollution. The minimum importance was given to LULC because it depends on other parameters as it can be social as well as a physical dimension, thus the pairwise comparison matrix table (Table 5) and sub criteria matrix table (Appendix table 3) was prepared and their weights has been developed shown in Table 6. For the pairwise matrix following formula is generated

$$P_x = \begin{bmatrix} x_{11} & x_{12} & x_{13} & \cdots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & x_{n3} & \cdots & x_{nn} \end{bmatrix} \quad (1)$$

Where P_x represents the pairwise comparison matrix, x_{nn} is denoted the factors of P_x.

4.3.2 Calculate normalizing of the weights

The normalized pairwise comparison matrix (Table 6) is prepared with the following equation.

$$NW = \left(\frac{GM}{\sum_{n-1}^{N} GM_n} \right) \quad (2)$$

Where NW is denoted the estimation of Normalized weights and GM_n is representing geometric mean calculation of nth row in P_x.

4.3.3 Consistency index (CI)

According to Saaty's AHP method, the consistency index formula is

$$\mathrm{CI} = \frac{(\lambda_{max} - n)}{n - 1} \quad (3)$$

Where, λmax is denoted eigenvalue of the comparison matrix and multiplication of P_x by weight of each

Table 5 Pairwise comparison matrix of nine thematic layer for landfill site selection

	EL	SL	GL	DL	LV	DC	DR	DS	LULC
EL	1.000	0.500	3.000	0.333	0.250	0.500	0.333	0.200	2.000
SL	2.000	1.000	3.000	0.500	0.250	3.000	2.000	0.250	3.000
GL	0.333	0.333	1.000	0.333	0.200	0.333	0.500	0.200	2.000
DL	3.000	2.000	3.000	1.000	0.500	3.000	4.000	0.500	4.000
LV	4.000	4.000	5.000	2.000	1.000	3.000	4.000	2.000	5.000
DC	2.000	0.333	3.000	0.333	0.333	1.000	1.000	0.333	2.000
DR	3.000	0.500	2.000	0.250	0.250	1.000	1.000	0.333	2.000
DS	5.000	4.000	5.000	2.000	0.500	3.000	3.000	1.000	5.000
LULC	0.500	0.333	0.500	0.250	0.200	0.500	0.500	0.200	1.000

Where, EL, SL, GL, DL, LV, DC, DR, DS and LULC denotes elevation, slope, geology, Distance from lineament, land value, Distance from river & canal, Distance from road, Distance from residence and land use land cover respectively

Source: Computed by the author

Table 6 Normalized pair-wise comparison matrix of nine thematic layers for suitable landfill site selection

	EL	SL	GL	DL	LV	DC	DR	DS	LULC	Weight
EL	0.048	0.038	0.118	0.048	0.072	0.033	0.020	0.040	0.077	0.055
SL	0.096	0.077	0.118	0.071	0.072	0.196	0.122	0.050	0.115	0.102
GL	0.016	0.026	0.039	0.048	0.057	0.022	0.031	0.040	0.077	0.039
DL	0.144	0.154	0.118	0.143	0.144	0.196	0.245	0.100	0.154	0.155
LV	0.192	0.308	0.196	0.286	0.287	0.196	0.245	0.399	0.192	0.256
DC	0.096	0.026	0.118	0.048	0.096	0.065	0.061	0.066	0.077	0.072
DR	0.144	0.038	0.078	0.036	0.072	0.065	0.061	0.066	0.077	0.071
DS	0.240	0.308	0.196	0.286	0.144	0.196	0.184	0.199	0.192	0.216
LULC	0.024	0.026	0.020	0.036	0.057	0.033	0.031	0.040	0.038	0.034

Where, EL, SL, GL, DL, LV, DC, DR, DS and LULC denotes elevation, slope, geology, Distance from lineament, land value, Distance from river & canal, Distance from road, Distance from residence and land use land cover respectively

Source: Computed by the author

criterion reveals consistency vector which is 9.564 in this study, n is the total number of factors. Thus, the calculated consistency index value (Table 7) is 0.070. Based on the CI value we have to find out the consistency ratio (CR).

4.3.4 Consistency ratio (CR)

According to Saaty's AHP method, the consistency ratio formula is (eq.4). The constant value of RI (Table 8) for nine parameters is 1.45

$$CR = \frac{CI}{RI} \tag{4}$$

Therefore, to keep the judgment consistent, the consistency ratio value should be less than 0.1 or < 10%. Here the calculated Consistency Ratio (CR) is 0.048 which is perfectly consistent. So, the whole judgment of the pairwise matrix of AHP is valid in suitable site selection for waste management in the Siliguri Municipal Corporation planning Area.

4.4 Sensitivity analysis

Sensitivity analysis is useful for determining the importance of influential factors (Noori et al. 2009). The sensitivity analysis method was used in this present research to validate and evaluate the consistency of the AHP theoretical outcomes. To recognize the impact of each thematic layer on the final suitable landfill site selection zonation map. The sub-category of each criterion was identified and estimated to check the influence of subcategories on allotted rank and weights in the final suitability zonation map. Sensitivity analysis can be interpreted in two methods map removal sensitivity analysis (Lodwick et al. 1990) and single parameters sensitivity analysis (Napolitano and Fabbri 1996).

Table 7 Consistency check result of all thematic layers aggregated in landfill suitability zonation

λ_{max}	N	RI	CI	CR	Consistency
9.56	9	1.45	0.070	0.048	CR < 0.1(yes)

Source: Computed by the author

4.4.1 Map removal sensitivity analysis

Map removal sensitivity is the important sensitivity analysis for evaluating the potentially suitable landfill site by removing any parameters and producing a new suitability map each time. In this study, nine important thematic layers have been allotted. With this sensitivity analysis, each time overlaying suitability map produces by removing one thematic layer. This method has been identified the importance of influencing factors. The mathematical calculation has been done by the following formula

$$SI = \frac{\left|\left(\frac{\mathrm{LSA}}{N}\right) - \left(\frac{LSA'}{n}\right)\right|}{LSA} \times 100 \tag{5}$$

Where SI implies sensitivity index related with a factor when it is excluded, LSA denotes landfill suitability analysis adopted by using all thematic layers, LSA' denotes landfill suitability analysis adopted by excluding one thematic layer, N is the total number of thematic layers used to produce LSA and n is the number of thematic layers considered to produced LSA' map.

The map removal sensitivity analysis (Table 9) reveals that land value (sensitivity variation 34.644%) was the most influential parameter in landfill suitability mapping estimation. However, distance from lineament, river, road, and residence was identified as a moderate influential factor. The sensitivity analysis (Table 10) also explains that

Table 9 Descriptive statistics of map removal sensitivity analysis of suitable landfilling zone

Thematic layers	Sensitivity variation in %			
	Min	Max	Mean	SD
Elevation	0.010	1.262	0.833	0.165
Slope	0.000	1.431	0.406	0.256
Geology	0.100	1.022	0.650	0.189
Distance from lineament	0.001	1.928	1.230	0.431
Land value	0.001	221.230	34.644	24.739
Distance from River	0.033	1.349	1.000	0.186
Distance from Road	0.269	1.270	1.011	0.110
Distance from residence	0.012	2.506	1.924	0.411
LULC	0.015	0.964	0.676	0.138

Min Minimum, *max* Maximum, *SD* Standard deviation

Source: Computed by the author

Table 8 Random consistency index value

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Source: Saaty's Random Consistency index, 1980

Table 10 Percentage of changes of suitable land filling zone with map removal sensitivity

Thematic layers	Suitable landfill zone classes (%)				
	Very low	Low	Medium	High	Very high
Elevation	−3.131	1.734	5.476	−1.366	−9.489
Slope	−2.599	2.033	3.612	−0.135	−11.346
Geology	−6.263	5.865	−4.064	7.419	13.534
Distance from lineament	−8.349	16.600	2.052	−21.931	−20.568
Land value	22.626	25.317	−43.347	−55.383	−71.570
Distance from River & canal	−6.696	7.592	−13.827	21.605	19.520
Distance from Road	−9.933	5.674	−4.379	21.195	18.959
Distance from residence	−25.278	5.347	−13.760	109.503	2.924
LULC	−9.911	7.565	4.162	4.673	−1.499

Source: Computed by the author

the removal of land value increases the low as well as very low suitable landfill potential area by 25.317% and very low area 22.626%. On the other hand removal of river and road increases the high suitable landfill potential area by 21.605% and 21.195% and very high 19.520% and 18.959% respectively.

4.4.2 Single parameters sensitivity analysis

Single parameters sensitivity analysis is also an important analysis that compares the empirical weight of AHP with the effective weight of sensitivity to evaluate the impact of each thematic layer on suitability landfill site selection. For the calculation of effective weighting factor (W) following equation has been adopted

$$W = \frac{P_r \cdot P_w}{LSA} \times 100 \tag{6}$$

Where $P_{r\text{ and}}$ P_w denote rate and weight of thematic layer respectively and LSA means landfill suitability analysis adopted by using all thematic layers.

Statistically, Table 11 shows the empirical analytical weight and effective weight assigned by single sensitivity analysis. This analysis reveals that elevation, slope, geology, and land value have high influences on suitability mapping estimation. On the other hand effective weight of lineament; river; road; residence; land use and land cover (4.422%; 3.954%; 4.415%; 12%; 3.954% respectively) perform low effected weight compared to empirical weight.

4.5 Weighted overlay analysis

In this technique, all thematic layers are accumulated to construct a composite layer by integration of each particular raster layer and their particular weight in the Arc GIS environment. For the weighted overlay, all thematic

Table 11 Descriptive statistics of single parameters sensitivity analysis of landfill site selection

Thematic layers	Empirical weight	Empirical weight (%)	Effective weight in %				
			Min	Max	Mean	SD	CV
Elevation	0.055	5	1.169	16.122	5.536	1.665	30.074
Slope	0.102	10	2.227	30.315	20.794	3.880	18.660
Geology	0.039	4	1.330	10.217	5.075	1.892	37.282
Distance from lineament	0.155	16	4.014	31.251	11.897	4.422	37.169
Land value	0.256	26	10.734	54.224	32.375	7.605	23.490
Distance from River & canal	0.072	7	1.704	13.702	3.954	1.823	46.105
Distance from Road	0.071	7	2.237	11.860	4.415	1.069	24.216
Distance from residence	0.216	22	6.316	34.364	12.000	3.615	30.125
LULC	0.034	3	1.181	10.359	3.954	1.378	34.859

Min Minimum, *max* Maximum, *SD* Standard deviation, *CV* Coefficient of variation

Source: Computed by the author

layers are converted into raster layers and all layers have to be reclassified with the same cell size for the suitable landfill zonation mapping. Weighted overlay analysis is the best procedure to identify the suitable location; this technique has been used in a different field study. For the landfill suitability analysis, several types of research have been conducted to assess suitable landfill sites employing this approach in the GIS platform viz. (Akbari et al. 2008; Eskandari et al. 2016; Ali and Ahmad, 2020). Landfill site suitability zonation map has been prepared with weighted overlay analysis, this technique can be expressed as follows:

$$\mathrm{WOA} = \sum_{i=1}^{n} x_i \times r_i \tag{7}$$

Where WOA is considered as weighted overlay analysis, x_i is i^{th} criteria weight of the selected particular parameter, r_i is i^{th} criteria rating of the selected particular parameter and n is the selected total parameters used in the landfill suitability zonation map.

4.6 Landfill suitability index (LSI)

Landfill suitability zonation was done by the following expression

$$(\mathbf{EL_w} \times \mathbf{EL_{sw}}) + (\mathbf{SL_w} \times \mathbf{SL_{sw}}) + (\mathbf{GL_w} \times \mathbf{GL_{sw}}) + (\mathbf{DL_w} \times \mathbf{DL_{sw}}) + (\mathbf{LV_w} \times \mathbf{LV_{sw}}) + (\mathbf{DC_w} \times \mathbf{DC_{sw}}) + (\mathbf{DR_w} \times \mathbf{DR_{sw}}) + (\mathbf{DS_w} \times \mathbf{DS_{sw}}) + (\mathbf{LULC_w} \times \mathbf{LULC_{sw}})$$

Where, in this expression subscripted 'w' means the criteria weight and 'sw' means the sub-criteria weight used for each layer interpret. Here, EL is elevation, SL is slope, GL is geology, DL is distance from Lineament, LV is Land value and DC is distance from river and canal, DR is distance from road, DS denotes distance from residence and LULC is for land use land cover. All thematic layers were reclassified with 30 m cell size and converted to raster format and then projected into UTM projection WGS 1984 in Arc GIS desktop10.5 version.

5 Results

The research study used various parameters such as topographical expressions (elevation, geology, slope, LULC), hydrological (distance from river and canal), and socio-economic (land value, distance from road, residence, etc.) to evaluate the suitable disposal sites in Siliguri Municipal Corporation Planning Area. The convincing argument for utilizing these parameters is that they are often and adequately used for determining whether a region is suitable or not for landfills. Using GIS-MCDA techniques, various thematic maps including elevation, geology, LULC, land value, distance from the road, etc. were treated as factors to generate a potential landfill site map.

The parameters (Table 12) are explained in detail in the following sections.

5.1 Elevation

The elevation map was prepared using DEM in the Arc GIS platform. Area elevation is maximum in the northern part of the region (158 m) and minimum elevation has been recorded in the southern part of the region (25 m). Elevation of the study area (Fig. 4) was categorized into five classes: 25-61 m, 61.01-74 m, 74.01-89 m, 89.01-108 m, and 108.01-158 m. The elevation of the present study area gradually decreases from north western to south eastern part. The lowest elevation is the most suited and the highest elevation being the least suitable.

5.2 Slope

In this study categorically less than 1.02 degree slope is preferably the most suitable area for landfill site selection with assigned weight of 0.406 which has been categorized as a very high level of suitability. The 1.03-3.41 slope is also a preferably suitable area for landfill site selection which appoints a weight of 0.302 and has been categorized as high level of suitability, 3.42 - 5.63 slope is also a suitable area for the same which appoints a weight of 0.142 and as been categorized in the moderate level of suitability. 5.64 - 9.21 slope is considered as a unsuitable area for landfill site selection which appoint a weight of 0.101 and has been subsequently categorized as low level of suitability. 9.22 - 43.51 slope has been considered as most unsuitable area for landfill site selection which appoints a weight of 0.050 and has been categorized as very low level of suitability (Fig. 4). Therefore, the steeper slope has less suitability and vice versa. Each buffer zone of the slope has been developed with the help of Arc GIS.

5.3 Geology

According to Geological data obtained by the Geological Survey of India, Duars formation, Baikunthapur formation, Shaugaon formation, present-day deposits, and Jalpaiguri formation are the five types of formation present in this area (Fig. 4). In the Duars formation, rock types such as Boulders, Gravel, Pebbles, Sand, and Silts are present hence the area is barren and uncultivated, it has been considered as most suitable for the landfilling process. The Baikunthapur formation has covered a large amount of the research region and it is composed of silty clay and sand overlain by dark grey to silty loam, indicating that the area has a low infiltration rate, considering the

Table 12 Summary of criteria, AHP weight, Class range, level of suitability, Area in sq. km, Area in %, and rating of each criteria for evaluation of suitable landfill zonation

criteria	AHP Weight	Class Range	Level of suitability	Area in sq. km	Area in %	Rating
Elevation (m)	0.055	25 - 61	Very High	16.31	5.97	0.457
		61.01 - 74	High	154.85	56.70	0.230
		74.01 - 89	Moderate	84.20	30.83	0.149
		89.01 - 108	Low	16.16	5.92	0.107
		108.01 - 158	Very low	1.58	0.58	0.057
Slope (Degree)	0.102	0 - 1.02	Very High	270.87	99.18	0.406
		1.03 - 3.41	High	2.17	0.79	0.302
		3.42 - 5.63	Moderate	0.05	0.02	0.142
		5.64 - 9.21	Low	0.01	0.00	0.101
		9.22 - 43.51	Very low	0.00	0.00	0.050
Geology	0.039	Duars	Very High	52.64	19.28	0.353
		Baikunthapur	High	139.82	51.20	0.224
		Shaugaon	Moderate	21.79	7.98	0.161
		Present day deposits	Low	29.90	10.95	0.142
		Jalpaiguri	Very low	28.94	10.60	0.121
Distance from lineament (m)	0.155	0 - 500	Very low	83.25	30.48	0.084
		500.01 - 1000	Low	96.92	35.49	0.125
		1000.01 - 2500	Moderate	62.34	22.83	0.178
		2500.01 - 4000	High	27.00	9.89	0.207
		4000.01 - 8966.59	Very High	3.59	1.31	0.406
Land value (Lakh/katha)	0.256	7.92 – 12.34	Very High	74.89	27.42	0.422
		12.35 – 16.64	High	112.23	41.10	0.236
		1665- 20.56	Moderate	82.30	30.14	0.161
		20.56- 24.61	Low	3.23	1.18	0.116
		24.61- 40.16	Very low	0.44	0.16	0.065
Distance from River & canal (m)	0.072	0 - 200	Very low	169.72	62.15	0.081
		200.01 - 500	Low	71.36	26.13	0.119
		500.01 - 1000	Moderate	21.95	8.04	0.156
		1000.01 - 1500	High	8.04	2.94	0.274
		1500.01 - 2947.03	Very High	2.03	0.74	0.371
Distance from road (m)	0.071	0 - 250	Very High	159.93	58.56	0.509
		250.01 - 500	High	67.53	24.73	0.218
		500.01 - 1000	Moderate	30.14	11.04	0.131
		1000.01 - 1500	Low	13.49	4.94	0.093
		1500.01 - 3521.39	Very low	2.01	0.74	0.049
Distance from residence (m)	0.216	0 - 500	Very low	153.40	56.17	0.083
		500.01 - 1000	Low	68.10	24.94	0.109
		1000.01 - 2500	Moderate	28.43	10.41	0.152
		2500.01 - 5000	High	15.79	5.78	0.241
		5000.01 - 7660.35	Very High	7.37	2.70	0.415
LULC	0.034	Water body	Low	4.59	1.68	0.088
		Natural vegetation	High	36.99	13.54	0.239
		Agriculture area	Moderate	58.52	21.43	0.150
		Bare land	Very High	18.50	6.77	0.466
		Built up area	Very low	154.50	56.57	0.057

Source: Computed by the author

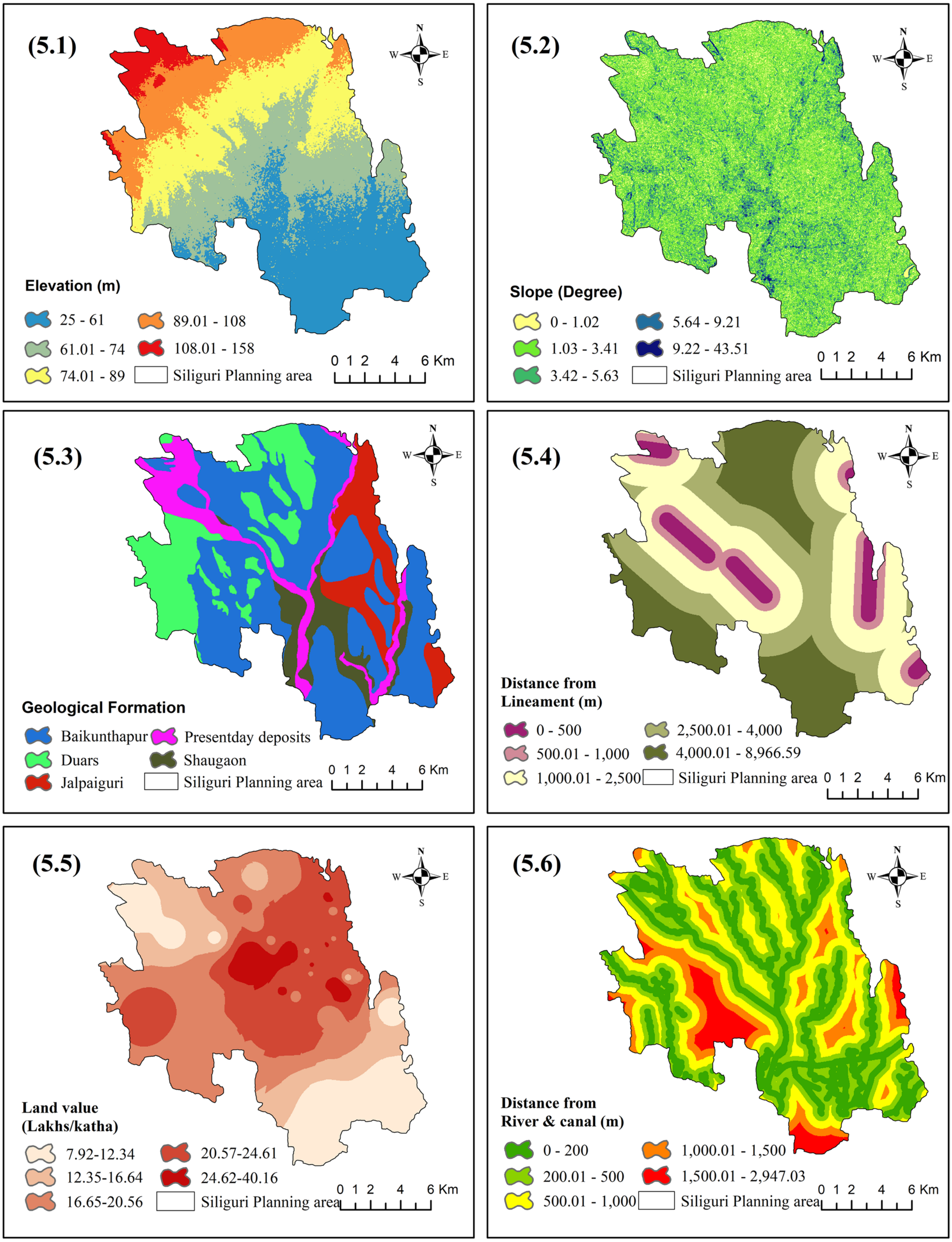

Fig. 4 Raster Layer for Landfill site selection parameter 5.1 Elevation 5.2 Slope 5.3 Geological formation 5.4 Distance from lineament 5.5 Land value 5.6 Distance from River & Canal

formation suitable for landfilling. (Saha and Roy, 2021). Present-day deposits are the most recent formation and the zone is mostly found nearer to the river beds. The Jalpaiguri formation is formed by the floodplains of the Himalayan Rivers and is covered by alluvial plain which is unsuitable for landfills.

5.4 Distance from lineament

In this study, more than 4000 m buffer zone from fractures places has been treated as the most suitable place for landfill. In this particular buffer zone the weight was assigned at 0.406 and categorized as very high level of suitability. The 2500.01 - 4000 m buffer zone from fracture areas has been assigned at a weight of 0.207 and categorized as a high level of suitability. The 1000.01 - 2500 m buffer zone from fracture area has been assigned at a weight of 0.178 and has been categorized as a moderate level of suitability. The 500.01 - 1000 m buffer zone from fracture area has been assigned at a weight of 0.125 and has been categorized as low level of suitability. The buffer zone with 500 m fracture area has been assigned at a weight of 0.084 and has been categorized as very low level of suitability for landfill site selection (Fig. 4). As a result, the maximum buffer zone distance from the lineament is ideal for landfill site selection.

5.5 Land value

The land price in the Siliguri Municipal Corporation Planning Area ranges between 7.9 and 40 lakhs per Katha (1 Katha = 0.00668 ha), (Government of West Bengal, 2020). Land value is an important criterion to select a suitable location for a landfills site. A survey was conducted with a GPS tool to determine the actual land prices in various locations of the study area and x, y coordinates (lat, long) were collected to prepare a spatial mapping with IDW tool in the Arc GIS platform (Ali and Ahmad, 2020). In the periphery of the study area, the price of land has been found to be low with the increase in proximity with the core city (Fig. 4). Therefore, a low price of land is preferred for landfills.

5.6 Distance from canal and river

In this study, a distance of more than 1500 m from the river was assigned with a weight of 0.371 which has been considered as very high level of suitability. 1000.01 - 1500 m buffer zone was assigned with a weight of 0.274 which has been considered as high level of suitability. The 500.01 - 1000 m buffer zone has been assigned with a weight of 0.156 and has been considered as moderate level of suitability. The 200.01 – 500 m buffer zone was assigned with a weight of 0.119 while the buffer zone with less than 200 has been assigned with a weight of 0.081 which has been considered as very low level of suitability (Fig. 4). Therefore, in the current study buffer zones located further from the river were deemed more suitable for site selection.

5.7 Distance from road

As waste transportation is an issue, distance from the road is an essential parameter to consider while selecting a suitable site. In the present study, all seasonally accessible roads are taken into considerations viz. the Asian highway, National highways, and State highways. In this study (Fig. 5), less than 250 m buffer zone has been weighed as 0.509; 250.01-500 m as 0.128; 500.01-1000 m as 0.131; 1000.01-1500 m as 0.093, and more than 1500 m buffer zone has been weighed as 0.049. Therefore, buffer zone far away from roads has been considered to hold the lowest weight which is considered as less suitable for landfills. On the other hand, buffer zone close to roads has been assigned the highest weight which has been preferred as high suitability for landfills.

5.8 Distance from residence

In this study (Fig. 5) more than 5000 m buffer zone from residence area has been considered most suitable for landfill and has been assigned a weight of 0.415 and categorized as a very high level of suitability. The 2500.01 - 5000 m buffer zone from residence area is suitable for landfill and has been assigned a weight of 0.241 while categorizing it as high level of suitability. On the other hand, the 1000.01 - 2500 m buffer zone from residence area is improper for landfill and has been assigned a weight of 0.152 while categorizing it as moderate level of suitability. The 500.01 - 1000 m buffer zone from residence areas is unsuitable for landfill and has been assigned at a weight of 0.109 while categorizing it as low level of suitability. The less than 200 m buffer zone from residence area is inappropriate for the landfill which has been assigned a weight of 0.083 while categorizing it as very low level of suitability. Thus, the maximum distance of buffer zone from the residence area is most suitable for landfill site selection.

5.9 Land use and land cover (LULC)

LULC (Fig. 5) thematic layer has been prepared in Arc GIS with five major classes viz. water body, natural vegetation, agricultural land, bare land, and settlement area. LULC has assigned different weights in different categories with respective importance in the Siliguri Municipal Corporation Planning Area. The settlement area and water bodies are deemed as unsuitable for landfilling sites therefore they are assigned less weight (Şener et al., 2010). The appropriate area was performed for a landfill site in bare land has been given a high weight. The settlement of an area is a sensitive place in a city or town that

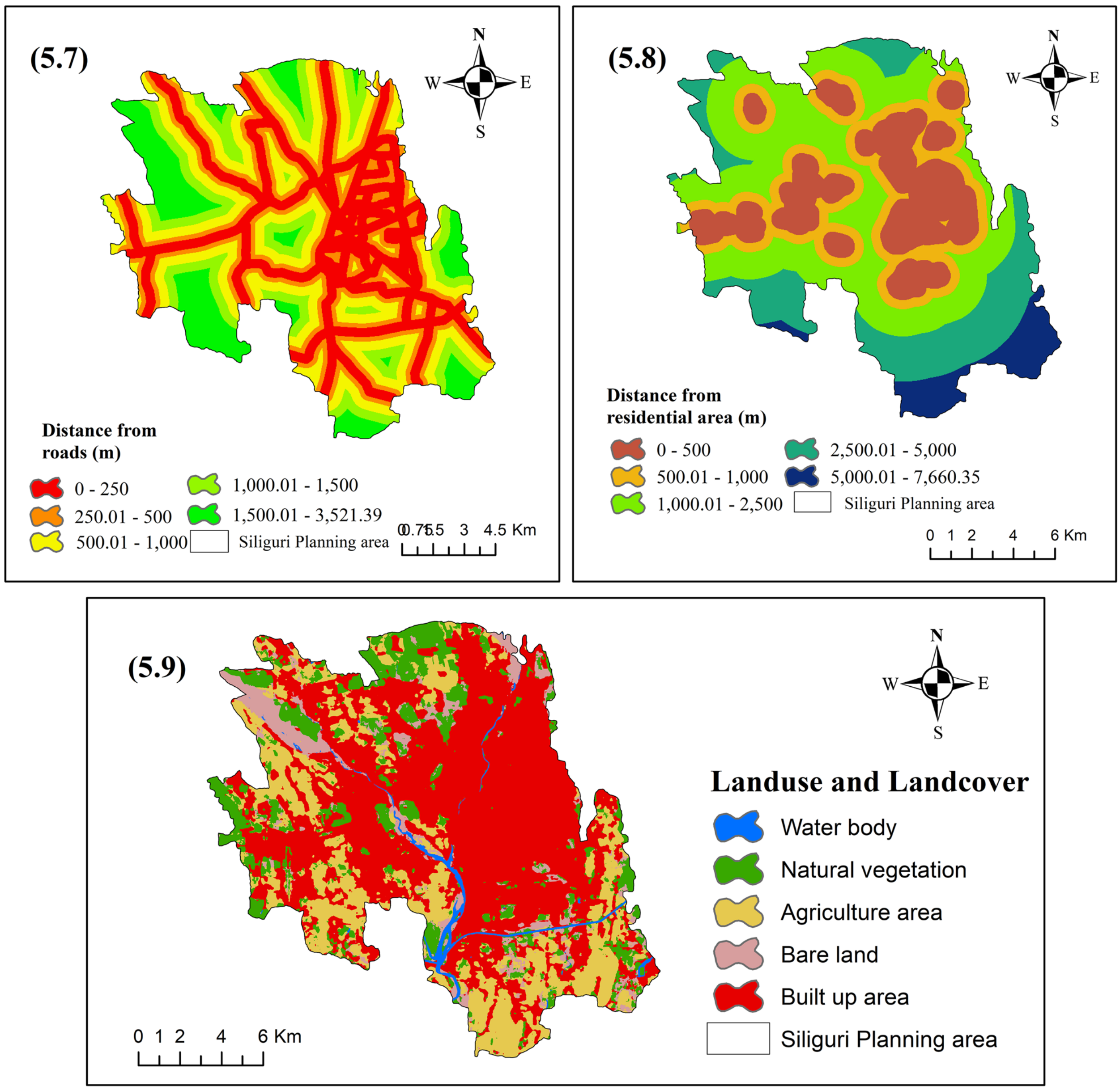

Fig. 5 Raster Layer for Landfill site selection parameter 5.7 Distance from road 5.8 Distance from residential area 5.9 Land use land cover.

is assigned a low weighted of 0.057 and other buffer zone weighted as to their respective importance.

6 Discussions

Landfill suitable site has been assigned with an accumulation of all nine thematic layers in Arc GIS environment with the suitable weight of AHP technique. A pairwise comparison matrix has been developed for the evaluation of the weight of each selected thematic layer. It was obtained from an acceptable consistency ratio (i.e., CR < 0.048). The calculated weight of each criterion has been shown in Table 6, indicates that Land value and Distance from residence have the highest value of suitability weight with 0.256 and 0.216, respectively and LULC and Geology have the lowest value of suitability weight with 0.034 and 0.039, respectively among the nine important criteria. The reason behind the given importance to the land value is that Siliguri is marked as a fast-growing city in West Bengal so the price of land is maximum (24.6 – 40.16 lakh/Katha) in the core area. Therefore it is better to select the outer area as a suitable candidate site where the price of land value is comparatively low from the

Table 13 Results of landfill suitability area with different method

Methods	Natural breaks		Equal interval		Geometrical interval		Quartile	
Level	**Area in Sq. km**	**Area in %**	**Area in Sq. km**	**Area in %**	**Area in Sq. km**	**Area in %**	**Area in Sq. km**	**Area in %**
Very low Suitability	96.70	35.61	99.90	36.78	35.88	13.21	53.90	19.85
Low Suitability	88.65	32.64	110.47	40.68	81.22	29.91	56.73	20.89
Moderate suitability	52.61	19.37	46.09	16.97	76.31	28.10	54.14	19.93
High Suitability	24.16	8.90	12.18	4.49	61.86	22.78	53.58	19.73
Very high suitability	9.46	3.48	2.95	1.08	16.31	6.00	53.23	19.60
Total Area	271.58	100.00	271.58	100.00	271.58	100.00	271.58	100.00

Source: Computed by the author

core city (7.92-12.34 lakh/Katha). Also, distance from the residence has been given importance as landfill sites can create air, soil, and water pollution which are detrimental to humans. Land use Land cover has been given less importance as landfill sites should be away from built-up areas, natural vegetation, water bodies, agricultural land which have been observed mostly in the study area. Only bare land has been found to be best suitable site for landfills. Lineament, Slope, distance from road, river are also considered as an important factor obtain the weight scores. The weights for criteria and sub-criteria are merged into the thematic layer, and a landfill suitability map is generated in a GIS environment using the Land suitability index (LSI). The resultant map was grouped into five categories as “Very low Suitability”,” Low Suitability”,” Moderate Suitability”, “High Suitability”, “Very high suitability”. According to the map, 3.48% of the study area was very high suitable, 8.90% was highly suitable,

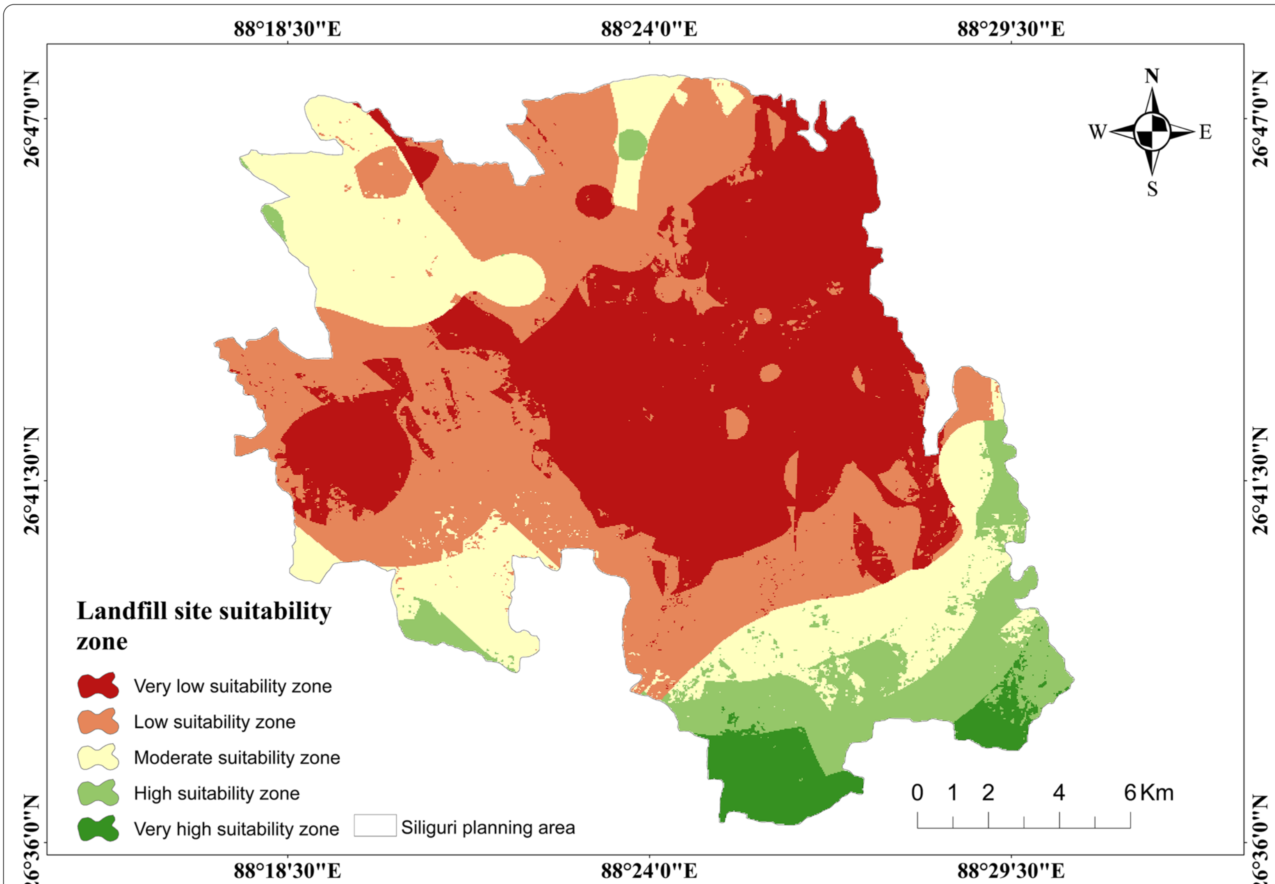

Fig. 6 Landfill site suitability zone in Siliguri Municipal Corporation Planning Area

19.37% was moderate suitable, 32.64% and 35.61% was low and very low suitable area respectively in the Siliguri Municipal Corporation Planning Area following the natural breaks method. The comparative variations of the categorized sites among different method such as Natural breaks, Equal interval, Geometrical interval, and Quartile classification methods are shown in Table 13. In the final suitability map, most of the suitable sites (Fig. 6) are mainly located in the southern and south-eastern parts of the study area which have more potential to absorb solid wastes. Suitable landfill sites are placed in a region with a combination of low elevation, less slope, low land value, far distance from road, river, residence that induce sites as a landfill.

7 Conclusion

The present study provides a scientific solution to identify potential landfill sites for planning solid wastes in the Siliguri Municipal Corporation Planning Area using the GIS-based AHP technique. The importance of GIS-based approaches in identifying and locating such acceptable waste sites was highlighted in this study to fulfill the main objective of the study i.e., identification of suitable sites. The given parameters were weighed using the AHP technique which offers an object-oriented assignment process. They were mapped using GIS method and the final suitability map was prepared by an overlay analysis.

Siliguri, is one of West Bengal's most rapidly developing and fastest-growing metropolises and it needs urgent requirements of scientific and suitable candidate landfill sites instead of conventional methods of dumping for urban wastes. The present study reveals that 3.48% area has been identified as the highest suitable landfill zonation in natural breaks method while 1.08% area has been identified as most suitable zonation in equal interval method. On the other hand, 6% and 19.6% area respectively, have been identified for disposal of urban wastes zone in the geometrical interval and quartile method respectively in the Siliguri Municipal Corporation Planning Area. Based on the analysis, Dhadagoch (Fulbari) has been identified as the highest suitable site for solid waste dumping in the Siliguri Municipal Corporation Planning Area. The other suitable sites are mostly located in the extreme southern, southern western parts of the Siliguri Municipal Corporation Planning Area with greater proximity from the core city and are also connected through Eastern Metropolitan Bypass and National Highways which is marked as economically promising and is considered to minimize the transportation cost. Even if we believe that the findings of this study are correct in terms of selecting suitable dump sites, additional evaluation and field investigations, as well as contact with local citizens, is recommended before making final judgments. The outcomes of the present study provide accurate information to policymakers, urban planners, and also Siliguri Jalpaiguri Development Authority for relocating the existing landfill site. In this sense, the current study might serve as a starting point for further research in other interests associated with the expansion of the Siliguri urban city.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1007/s43762-022-00038-x.

Additional file 1: Appendix Table 1. Literature reviews for Criteria selection of suitable landfill site. **Appendix Table 2.** Collinearity diagnostics of Land fill suitable site selection parameters. **Appendix Table 3.** Sub-criteria of each parameter and the pairwise comparison matrix and their weights.

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Authors' contributions
I certify that all authors indicated on the title page have made important contributions to the study, have read the article, attest to the validity and legitimacy of the data and its interpretation, and have given their consent to its submission. The authors read and approved the final manuscript.

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Availability of data and materials
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Declarations

Competing interests
The authors have no conflict of interest to declare. The co-author has seen and agrees with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication

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