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Solid waste management using GIS-based analysis - A case study: tourism region of Medinipur coastal belt, West Bengal

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ABSTRACT:

Tourism is one of the rapidly growing economic sectors in developing countries that have attracted a huge influx of people and intensified the developmental activities. Massive solid wastes as a byproduct are generated from the construction sites of economically viable hotspots, which create serious environmental and health hazards because of filthy management practices and lack of treatment plan for sewage and solid waste management.

Digha coast in the West Bengal a large number of hotels, temporary buildings promoting the tourism and other commercial activities have been constructed on the dunes and low-lying areas. Such sites lack the proper treatment plan for sewage and solid waste management. The present study focuses on the selection of suitable sites in Digha and its surroundings within the Medinipur the coastal belt for solid waste management using the multi-criteria decision analysis. The analysis was done by involving eight criteria viz. land use, geomorphology, soil and land capability, groundwater depth, distance from hotels road and rail line and distance from coastal regulatory zone (CRZ) boundary. The thematic layers prepared for selected criterion were prepared and assigned the weightage and suitability scores using the analytic hierarchy process (AHP). Finally, weighted overlay analysis was performed in the geographical information system (GIS) environment to find suitable sites for waste disposal and management plants. Undoubtedly, the data generated will facilitate administrator, policymakers, and stakeholders in planning sustainable growth of tourism sector in an environmentally friendly manner by sustaining their sources.

KEYWORDS: Multi criteria decision analysis (MCDA), GIS, AHP, Solid waste

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INTRODUCTION

In recent times, the tourism sector is growing rapidly because of its ability to create huge economic opportunities for the local residents and country both. The rapid expansion of the tourism sector in the eco-sensitive areas in an unplanned way has become the major concern, particularly in developing countries as it creates pressure on the environment and generates a vast amount of solid wastes from lodgings and recreational[1]. The management of solid wastes is a critical issue in tourist areas, especially around the coasts that affect the local landscape and marine environment both[2,3]. Therefore, to protect such ecologically sensitive areas and create a balanced environment with the anthropogenic activities, management of the solid waste in a proper way is required[4,5]. For collecting, recycling, treating and disposing of the solid waste, establishment of the waste treatment plant with the option of improving the facility over time at the suitable location is essential. To identify the suitable sites for disposal of solid wastes, GIS-based multi-criteria decision analysis (MCDA) is one of the important approaches evidenced by the various studies[6]. Geographic Information System (GIS) based MCDA uses a variety of geographically referenced data and a set of alternatives with a series of evaluation criteria. Multi-criteria Decision Analysis (MCDA) has the advantage of blending expert opinion with factual information. The Analytic Hierarchical Process (AHP) [7] is a popular method used for MCDA, because this technique within the GIS environment is straight forward. AHP provides a framework that enables to make effective decisions on the complex issues by simplifying and expediting the natural decision-making processes[8]. It evaluates various thematic maps based on the attribute values and preferences of the decision makers. The past studies have witnessed that the integrated approach of AHP with GIS is a powerful tool to solve the problem of landfill site selection[9,10,11]. Instead of the developed countries, this technique is also applied in various cities of the developing countries like Nigeria, Ghana, Tigray, Ethiopia, Benue, Morocco[4, 11,12,13,14, 15,16,17]. In India, there are many studies using the AHP model for solid waste management in municipalities, tourist spots and eco-sensitive area of Yamuna river bank, Aurangabad, Kottayam, Rajarhat, Gopalpur, Hosur, Sakkottai, Shillong etc. [10,18,19,20,21,22,23]. Digha is one of the major tourist spots in the West Bengal province that earns second highest revenue from tourism in the state. Because of massive tourist influx in this coastal region, a large number of hotels and recreational facilities have been constructed to accommodate the tourists as well as the commercial stalls and complexes[24]. However, with the increase of tourist pressure, the generation of solid waste is increasing day-to-day basis due to no proper dumping site and well management plan for the treatment of solid wastes till date. Therefore, to mitigate, finding a suitable site for dumping solid waste is the utmost concern for maintaining the ecological balance and sustainability of the tourist spot[25]. The present study aims for the identification of suitable sites for solid waste disposal and management by considering the upward growth of the planned tour in the Medinipur coastal belt. The AHP based multi-criteria decision analysis considering experts opinion was used for identification of the site based on the suitability analysis[26]. This study would be helpful for the local authorities and the stakeholders for sustaining the growth of tourism and economy both by managing environmental stability.

STUDY AREA

The study includes the coastal block of Purba Medinipur district, West Bengal, covering parts of Ramnagar-I and II and Contai-I and Deshopran blocks, extending longitude from 87°28'57"E to 87°53'15"E and latitude from 21°36'40"N to 21°53'37"N (Figure1.). According to the census 2011, the total geographical area of this coastal belt region is 628.27 km^2. The major beaches in the study area are attractive for tourists that include Digha, New Digha, Shankarpur, Mandarmoni, Tajpur and Junput. The scenic beauty of this place is charming and alluring[27]. The beach is girdled with casuarinas plantations along the coast enhancing its beauty. As per the census 2011, the total human population is 6,70,671. Around1 lakh foreign and 25 lakh domestic tourists every year visit this coastal area.

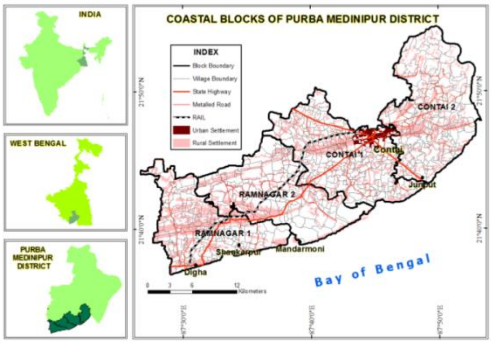
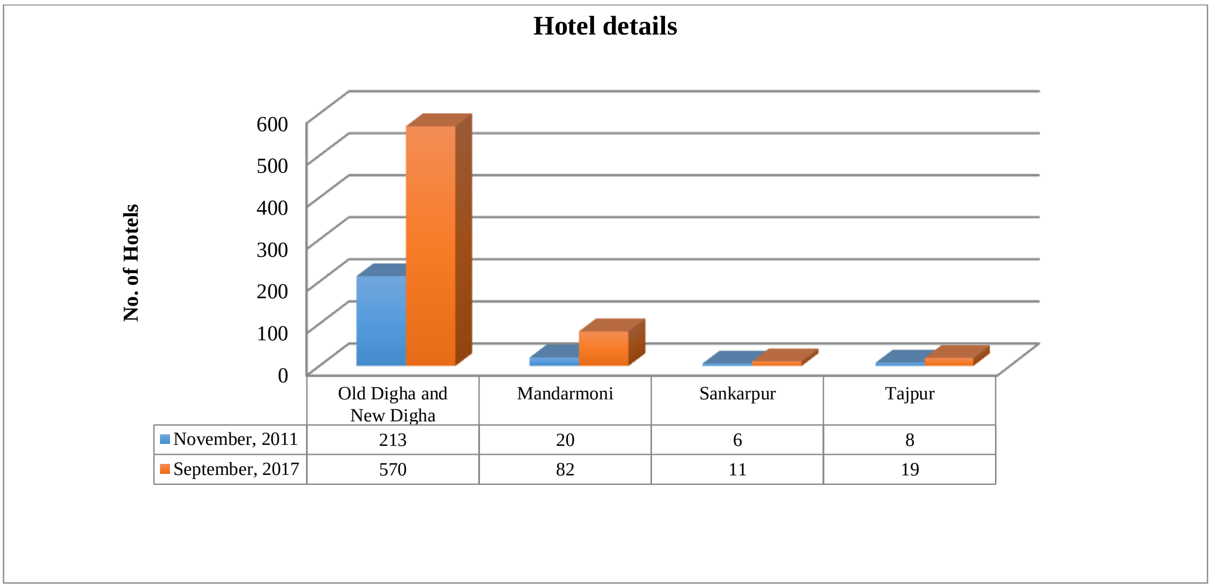


Figure1. Location map of the study area with major transport networks

The numbers of hotels are noticeably increasing over time (Graph.1). Many large hotels have been constructed on the dunes and a large number of makeshift hotels and shops are available in the low-lying areas. These infrastructures do not have any sewage management system the only land has been acquired for solid wastes management (in New Digha area), which is a matter of concern from environmental and health point of view. The amount of solid wastes generated during the peak tourist season is increasing at an alarming rate compared to the normal days. Hotels and restaurants are the main sources of waste generation.



Graph.1: Number of Hotels in year 2011 and 2017

Source: Data collected by field survey

METHODOLOGY

Data Collection

The present study used spatial and non-spatial data both from primary and secondary sources that includes: (a) topographical sheets at 1:50,000 scale published by Survey of India, (b) Landsat ETM + Satellite Images and Google Earth data of the years 2015 for land use mapping (c) soil map (1992) published by National Bureau of Soil Sciences and Land Use Planning (NBSS&LUP) (d) Groundwater Year Book (2013-14) of West Bengal, (e) geomorphological map (2005-06) from Bhuvan portal (http://bhuvan.nrsc.gov.in) (f) Coastal Regulation Zone (CRZ) boundary (2011) from Ministry of Environment and Forest, Government of India (g) the field survey data.

Methods

This study used eight criteria for overlay analysis using weights derived in AHP model based on the experts' opinion to select a suitable site for solid waste management (Abed et al. 2011). These criteria include land use, geomorphology, soil and land capability, groundwater depth, the distance of hotels from road and rail line and distance from the costal regulatory zone (CRZ) boundary.

AHP for Weight Estimation

AHP is a procedure of pair wise comparison between different classes of selected criterions or factors. The result of the comparison is described in terms of an integer value ranging between 1 (minimum value) to 9 (extreme value), where greater values indicate that the chosen class of selected factors are more important for suitable sites compared to those whose values are less. In this study, the different classes of eight criterions or factors were considered. The weights were calculated from a pair-wise matrix derived by taking the average value of ratings of each criterion as provided by the opinion of the experts.

Consistency Ratio

Consistency ratio is estimated to analyze the sensitivity of AHP method and ranking of the criteria for suitability analysis. Considering the weights, the consistency ratio (CR) is calculated using the following expression.

Consistency ratio (CR) = Consistency index (CI)/ Random Consistency index (RI)

Where CI and RI are estimated from the criteria matrix (for details see Saaty1980). To calculate the CR, the value of 0.04 was found for CI and 1.41 for RI. Using these values, CR was calculated and it was found 0.03, which is much less than 0.10 that indicates that the comparison matrix is acceptable[28].

Rating of Classes of Selected Factors

For assigning a rating, all criteria were normalized and categorized into different classes. Based on the positional suitability of the location, in the present study, weights were assigned to each criterion. Integers starting from 1 to 6 were used for rating each category. The range depends on the number of classes for a particular factor identified in the study area. For example, if there are 6 classes for the criterion ‘Soil’ and ‘Land capability’ ratings from 1 to 6 were assigned, where 6 indicated the most suitable site and 1 was the least suitable. The ratings of all classes for each factor are given in Table: 1.

Table: 1 Weights of selected factors and suitability

Factors	Class	Rating	Level of suitability	Influence (%)
Land use	Waterbody	1	Very low to low	33.74
	Aquaculture	2	Very low to moderate	
	Settlement area	3	Low to moderate	
	Wetland	4	Moderate to high	
	Crop land (single)	5	High to very high	
	Land with or without scrub	6	Very high	
Soil & Land capability	Very Fine VerticHaplaque, II	1	Very low to low	21.76
	TypicUstipsamments, III	2	Very low to moderate	
	Fine VerticHaplaquepts, III	3	Low to moderate	
	Fine TypicHaplaquepts, III	4	Moderate to high	
	AquicUstipsamments, V	5	High to very high	
	Fine AericHaplaquepts, V	6	Very high	
Ground Water Depth (meters below ground level)	<4	1	Very low to low	15.36
	4 - 4.5	2	Low to moderate	
	4.5 - 5	3	Moderate to high	
	5 – 5.5	4	High to very high	
	>5.5	5	Very high	
Geomorphology	Inactive Fluvio-Tidal Flat	1	Very low to low	11.16
	Ancient Dune Complex	2	Low to moderate	
	Active Marine Coastal Plain	3	Moderate to high	
	Older Beach Ridge	4	High to very high	
	Ancient Intertidal Flat	5	Very high	
Distance from Hotels (meter)	100	1	Low	6.23
	300	2	Moderate	
	500	3	Highly	
Distance from Road (meter)	50	1	Low	5.54
	100	2	Moderate	
	150	3	Highly	
Distance from Rail line (meter)	50	1	Low	3.21
	100	2	Moderate	
	150	3	Highly	
CRZ Boundary from High tide line (meter)	100	1	Low	3.00
	300	2	Moderate	
	500	3	Highly	

RESULTS

Land Use

Land use is one of an important factor in the selection of a suitable site for solid waste disposal and management. The study area is predominantly a mono-cropped coastal area with double cropping practiced in patches. Ancient dune belt with 'cashew nut' plantation and pisciculture (prawn cultivation) in tidal mud flats is common. Dune with or without scrub are wastelands found in the northern part of Ramnagar I and II and central portion of Contai I and II blocks. The major land use classes are aquaculture/pisciculture, brick kiln, canal, urban settlement, rural settlement, single cropland, double cropland, lakes/ponds, land with/without scrub, wetland, plantation, river/stream, etc. Land use/cover of the area was carefully prepared from the Landsat ETM+ data and validated with field survey and Google earth data. Kinds of literature have suggested that the most suitable site for solid waste disposal and management plant are wasteland (land with or without scrub), single cropland and wetland[28]. These land classes were rated from high to very high prospect zones whereas water body, aquaculture, and settlement areas were rated from low to moderate prospect zones for solid waste disposal and management plant.

Soil and Land Capability

The soil type of the study area is mainly alluvium soil laid by the rivers of Haldi and Rupnarayan. It is fine loamy in texture, rich in salt impregnated due to diurnal tidal flow of the seawater through creeks and sub-tributaries. This is neutral to slightly alkaline in nature. On the basis of nature of soil mainly erosion (e), wetness (w) and soil rooting zone (s) factors, the area was grouped into three land capability classes; II, III, V. In the present study area, the land capability class V (Fine Aeric Haplaquepts and Aquic Ustipsamments) is from high to very high prospect zone. The classes II and I were considered as low to moderate prospect zones.

Ground Water Depth

In the present study, pre-monsoon (April), depth to groundwater table data was taken, which ranges between <4 to >5.5 m.b.g.l (meters below ground level). The areas where depth to the ground water table is 5 – 5.5 m.b.g.l are high to very high prospect zones whereas areas where depth is <5 to <4 m.b.g.l are very low to low prospect zone for solid waste disposal and management plant.

Geomorphology

In the study area, five geomorphological units were found and considered in the study that includes ancient intertidal flats, older beach ridges, active marine coastal plain, ancient dune complex and inactive fluvio-tidal flats. Among these, ancient intertidal flat and older beach ridge were considered from high to very high prospect zones. The other classes' *viz.* active marine coastal plain, ancient dune complex and inactive fluvio-tidal flat were considered from very low to low prospect zone for waste disposal and management plant.

Distance from Hotels

Since the study area is a tourist hotspot, major solid waste is generated from the hotels. The survey data collected from the study area revealed that New Digha, Old Digha, Mondarmoni, Shankarpur and Tajpur have approximately 682 hotels as on September 2017 (Figure2.). Out of 682, only 26 are maintained by different government agencies. Considering the location of hotels in this coastal belt, the area located beyond 500 meters from hotels are considered as high potential sites for waste disposal and management, while areas located within 100 m to 300 meters around the hotels were considered as low potential sites.

Distance from Road and Rail Line

The major road is NH 116B presently under contraction that connects Kolaghat and Contai (M) road has been extended up to Digha. The South Eastern Railway (broad gauge line) connects Howrah to Digha. The complete study was classified into three zones by considering distances of 50m, 100m and 150m respectively away from the road and the rail line for selection of the suitable site. The areas 150 meters away are considered as high prospect zone and areas within 50m is opted as low potential due to the closeness of land to the transport network and economically productive.

CRZ Boundary from High Tide Line

As per data obtained from Digha Shankarpur Development Authority (DSDA), all the hotel and commercial sectors, hospitals, public facilities as well as other utility areas in Old and New Digha lie under CRZ III (Figure2.). The entire Shankarpur area lies under CRZ III category. The area within 100 meters of high tide line was considered as low potential site whereas more than 500 meters away as high potential sites.

Detection of Suitable Sites

Suitable sites for solid waste disposal and management plant were demarcated using selected criterions by AHP. The site suitability map as a final thematic layer was prepared by overlying thematic layers of all the criteria. The final layer was classified into six site classes ranging the suitability from very low to very high (Figure3.). In this study, the most suitable sites were found at three different locations for establishing solid waste disposal and management plant. Zone-I site was found in the southern part of Purba Mukundapur village, which is Ramnagar-I block located 500m far away from hotels and CRZ boundary and within 150m distance from the road. This site is a very near and almost highly developed beach like Digha, New Digha and Shankarpur. Zone –II site was found in the eastern part of Kanchibar and Islampur village, which is Ramnagar-II block almost more than 500 meters far from hotels and high tide line CRZ Boundary and within 150 m distance from the road.

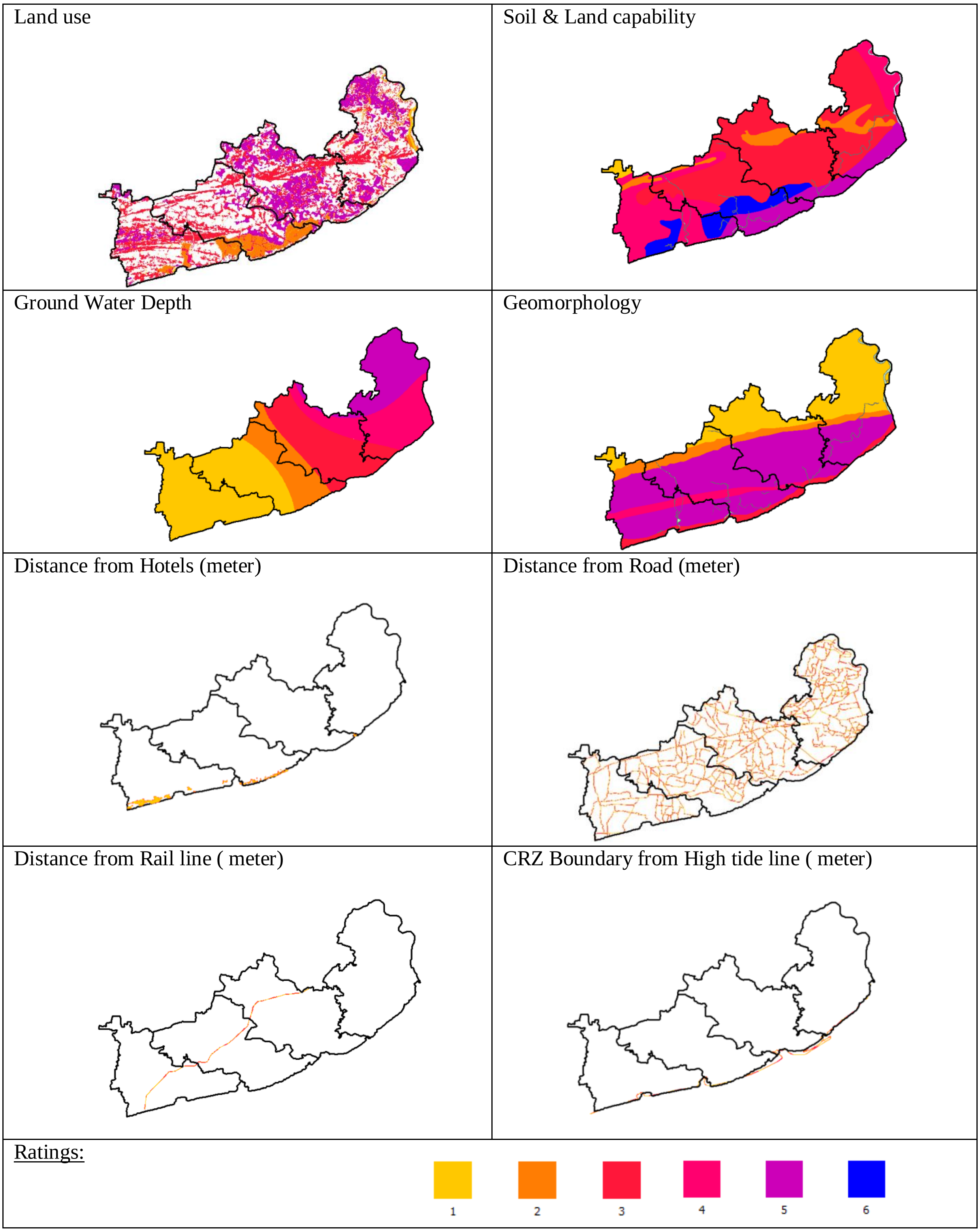


Figure2.Thematic maps of eight criterions selected for analysis

The area is situated very near and almost highly developed beach areas like Mondarmoni and Tajpur. Zone –III site was found in the north eastern part of Karba and south western part of Ghritapura village, which is Ramnagar-I block situated very far away from the developed beach area;

therefore this site was excluded in the study for locating the establishment of the solid waste disposal and management plant.

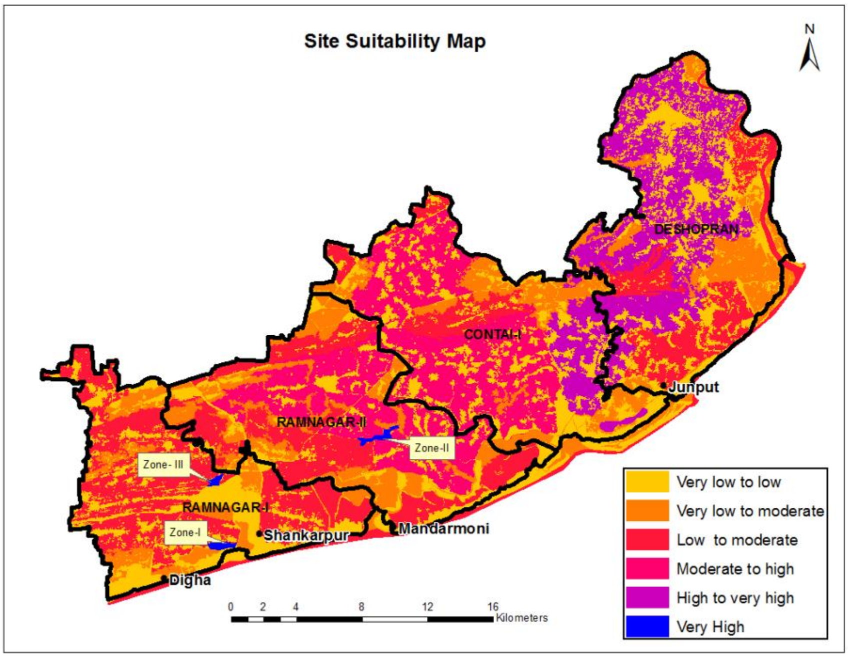


Figure 3.Site Suitability Map

By using the stated criteria, the suitable areas for solid waste dumping site fall in each and every ward. The selected site areas are at the optimum distance from the canal and from major roads. The selection of the optimum site for solid waste dumping should avoid the gradual deterioration of the quality of environmental goods and services significant to tourism[28].

According to the stated criteria and suitability measures, the 1st and 2nd preferences were determined for locating the sites in the wasteland.

Table: 2 Factors with level of suitability for 2nd preference in selecting the location

Factors	Class	Rating	Level of suitability
Land use	Crop land (single)	5	High to very high
Soil & Land capability	Fine AericHaplaquepts, V	6	Very high
Ground water depth	4 - 4.5	2	Low to moderate
Geomorphology	Older Beach Ridge	4	High to very high
Hotels	150 m	3	Highly
Road	150 m	3	Highly
Rail line	150 m	3	Highly
CRZ Boundary	500 m	3	Highly

The 2nd preference (Table:2) is apart from all facilities and there are no recreational facilities. Thus, this preference was chosen to select the location, which is in the eastern part of Kanchibar and Islampur village, Ramnagar-II block.

Table: 3 Factors with level of suitability for 1st preference in selecting the location

Factors	Class	Rating	Level of suitability
Land use	Land with or without scrub	6	Very high
Soil & Land capability	Fine AericHaplaquepts, V	6	Very high
Ground water depth	<4 m.b.g.l	1	Very low to low
Geomorphology	Ancient Intertidal Flat	5	Very high
Hotels	150 m	3	Highly
Road	150 m	3	Highly
Railline	150 m	3	Highly
CRZ Boundary	500 m	3	Highly

The 1st preference (Table:3) denotes the portion, which is apart from the different sectors. It is far from the hotel. Within 800 m, there are no recreational facilities. Therefore, for these reasons 1st preference was given to the location for solid waste management plant, which is in the southern part of Purba Mukundapur village, Ramnagar-I block.

DISCUSSIONS

The present study applied GIS-based multi-criteria analysis to select a suitable site for waste disposal and management plant by maintaining the ecological balance and growth of tourism sectors in Purba Medinipur Coastal belt. Based on the selected criteria chosen by a group of experts, the AHP model was used for estimating criteria weights. The site selection for the sewage system and solid waste treatment plant involved the comparison between different options based on the environmental, social and economic impact. There, based on the experience and likely impact of the surrounding environment, the different weights were assigned to all the parameters. The larger the weight, the more important is the criterion. The weights were developed by providing a series of pair wise comparisons of the relative importance of factors to the suitability of pixels for the activity being evaluated. The procedure by which the weights were produced follows the method proposed by Saaty, 1980 under AHP. The ratings of the weights were given based on the pair wise comparison using 9 points continuous scale. These pair wise comparisons were then analyzed to produce weights that sum to 1. The factors and their resulting weights were used as input in the multi-criteria evaluation (MCE) module for the weighted linear combination of overlay analysis if the consistency ratio is less than or equal to 0.1 that signifies acceptable reciprocal matrix[29,30]. The consistency ratio in this study indicated 0.03, which is acceptable. In order to combine all the layers to process overlay analysis, standardization of each data set to a common scale of 1, 2, 3, 4 {value 1 = unsuitable (restricted), value 2 = less suitable, value 3 = moderately suitable, value 4 = highly suitable} was done. Finally, all the parameters were weighted according to their respective percent of influence and overlay analysis was done to produce the suitability map. The output of the overlay analysis was verified with the eight parameters in the GIS environment. After the overlay analysis of the given factors the suitable solid waste dumping site map was produced. In this map, solid waste dumping site selection was chosen by local field survey. Comparing weights of all criterions, the analysis of the site suitability map provided three small patches most suitable for dumping solid waste.

Thus, this study has shown the ability of GIS and Remote Sensing as a veritable tool for analyzing the criteria for decision support. The analysis used the land use, water sources and transport facilities as a determining factor to find the appropriate site for a solid waste dumping site. The results have shown that the four sites are the most suitable places for solid waste treatment and management plant. These sites are easy to access and manage the disposal of solid wastes. These places are far away from any water sources and other variables put into the analysis. They are located in every ward of the town and are open space and swampy. No doubt, the capacity to use GIS and remote sensing technology for the effective identification of suitable solid waste dumping site will minimize the environmental risk and human health problems.

CONCLUSION

Empirically, there are no proper solid waste management activities in many areas of Purba Medinipur Coastal belt and no organized system for collection of solid wastes. A major quantity of generated waste was found dumped on streets, walkways, open drains and open spaces. The GIS-based multi-criteria analysis to find a suitable site for waste disposal and management plant by maintaining the ecological balance and growth of tourism sectors in Purba Medinipur Coastal belt provided the three small patches suitable for dumping solid waste. This study shows the utility of GIS and remote sensing technology for effective identification of suitable sites for solid waste management plant in order to minimize the environmental risk and human health problems of the area. Three suitable sites, the southern part of Purba Mukundapur village, Ramnagar-I block, the eastern part of Kanchibar and Islampur village, Ramnagar-II block, have been identified in the study area as a most suitable site. Out of the three, southern part of Purba Mukundapur village, Ramnagar-I block is the most suitable site for solid waste disposal and management for its easy accessibility.

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