International Journal Of Advance Research, Ideas And Innovations In Technology

IJARIIT

ISSN: 2454-132X
Impact Factor: 6.078

(Volume 7, Issue 4 - V7I4-1906)
Available online at: https://www.ijariit.com

Landfill site selection with spatial suitability analysis and multi-criteria decision making in Devchuli municipality

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ABSTRACT

Solid waste management (SWM) is a significant aspect of infrastructure development and is linked in the direction of long-term sustainability and aids in reducing waste's social and economic repercussions of waste on the environment. Furthermore, the requirement is felt more acutely in developing nations as a result of increased trash generation as a result of poor waste management systems combined with rapid population expansion. Landfill sites are an inevitable element of a city's waste management; proper site selection is critical and has a significant impact on the city's physical, environmental, and socioeconomic aspects. Pre-existing conditions of Nepalese restructuring and capacity constraints in newly established municipalities have not been able to give sufficient answers to landfill site siting concerns in these towns. As a result, for complex decision-making, a reasonable strategy is required, necessitating input from diverse stakeholders and organizations in compliance with involving various viewpoints. Hence, this research highlights numerous critical indicators and employs geospatial technology and its applications, as well as multi-criteria decision-making methods that can be utilized in such assessments. The weighted overlay analysis performed will be able to provide with suitable siting location required for landfill in the particular case of Devchuli Municipality at Gandaki Province, Nepal. Additionally, the research may be extended to different municipalities and the application can be manipulated remaining within the framework of the particular municipality.

Keywords: - *Geospatial Technology; Multicriteria Decision; Solid waste Management*

1. Introduction

Solid Waste Management (SWM) is one of the major challenges as well as an opportunity for modern society. A proper SWM system is associated with sustainability and helps in minimizing the impacts of wastes in the environment both socially and economically [1]. Moreover, the need can be felt more in the developing countries due to increased waste production as a consequence of inefficient waste management systems along with rapid population growth. Improper disposal of waste in nearby fields or riverbanks leads to several health hazards and serious impacts on soil, ground, and surface water [1]. As such, Landfills are the most commonly used method for the disposal of wastes in developing countries.

A good waste management system in a municipality is also an indicator of excellence in urban planning and management; which suggests that the overall state and status of the city in terms of infrastructure development. As landfill sites are an unavoidable part of the waste management of a city, suitable site selection is vital and hugely affects the physical, environmental, and Socioeconomic aspects of the city.

Rapid and uncontrolled urbanization, lack of public awareness, and poor management by municipalities have intensified environmental problems in towns in Nepal, including unsanitary waste management and disposal[2]. Moreover, the restructuring of Nepal took place where the number of municipalities abruptly changed from 58 to 293 major municipalities within a short period creating a surge in the urban population as well. But then again, these newly formed municipalities are facing huge challenges in the planning aspect of the city. Hence, this paper tries to define different criteria and parameters that can be worked at by different municipalities for the siting of the landfill site. Moreover, this paper defines the case of Devchuli Municipality where the paper is focused at. GIS (Geographical Information System) is a system that combines geographic data (maps, aerial pictures, and satellite pictures) with quantitative, qualitative, and descriptive information to support a variety of geographic queries. Moreover, the involvement of stakeholders and decision-makers can be done via the process of MCDM where different criteria are laid forth and decision making is done through the involvement of different stakeholders. The main purpose of the study is to locate appropriate landfill sites using MCDM tools and geospatial technology.

Solid Waste Management is one of the major issues faced by various municipalities all across the globe. Many developing countries are struggling to provide a proper waste management service to the residents [3]. The evidence of improper solid waste management can be seen in different streets and waterways in urban areas where open dumping can be witnessed. Improper waste management has serious impacts on the physical, environmental and socio-economic aspects of the municipality. An improper siting of a waste management service may lead to unhygienic conditions as well as have severe impacts on the environment and health of people in general. Also, this may lead to social dispute and economic loss and ultimately lead to environmental degradation [3].

Additionally, municipalities are responsible for the management of solid waste generated in their jurisdictions since the local self-governance act was passed in 1999. The majority of towns choose open dumping along riverbanks or in open spaces in Nepal [4]. Moreover, municipalities have been provided with additional stake towards the management of solid waste generated in their jurisdiction after the promulgation of the Local Government Operations Act, 2017. But the resource provided to the municipalities are constrained and due to which the capacity required for the assessment of site suitability of Landfills in most municipalities are lagging behind. This has resulted in a cross-cutting issue in the municipality due to social, physical, and economic as well as environmental problems faced by them. Hence, the paper tries to identify these cross-cutting issues in terms of different aspects for the study of gaps prevailing in these newly formed municipalities.

Hence, a landfill shall be assessed in several criteria that have cross-cutting characteristics in amongst one another. So, this paper provides a procedure for the assessment of the potential site for landfill which is suitable for meeting the needs of the city.

2. Material and Methods

2.1 Study Area

Devchuli Municipality lies in Nawalparasi District (East), Gandaki Province. It extends from 27.74° N to 84.18° E geographically. The northern side of the municipality is covered by hills whereas the southern part consists of flat lands of Terai. The elevation ranges from the banks of Narayani River to an elevation of 1936 meters in Devchuli Hill within a short span of horizontal travel. The total land area of this municipality is 113 sq. km. and consists of 17 wards. The municipality was established in 2014 by merging of Devchuli, Dibyapuri, Pragatinagar, and Rajahar VDCs with a population of 42,603 [5].

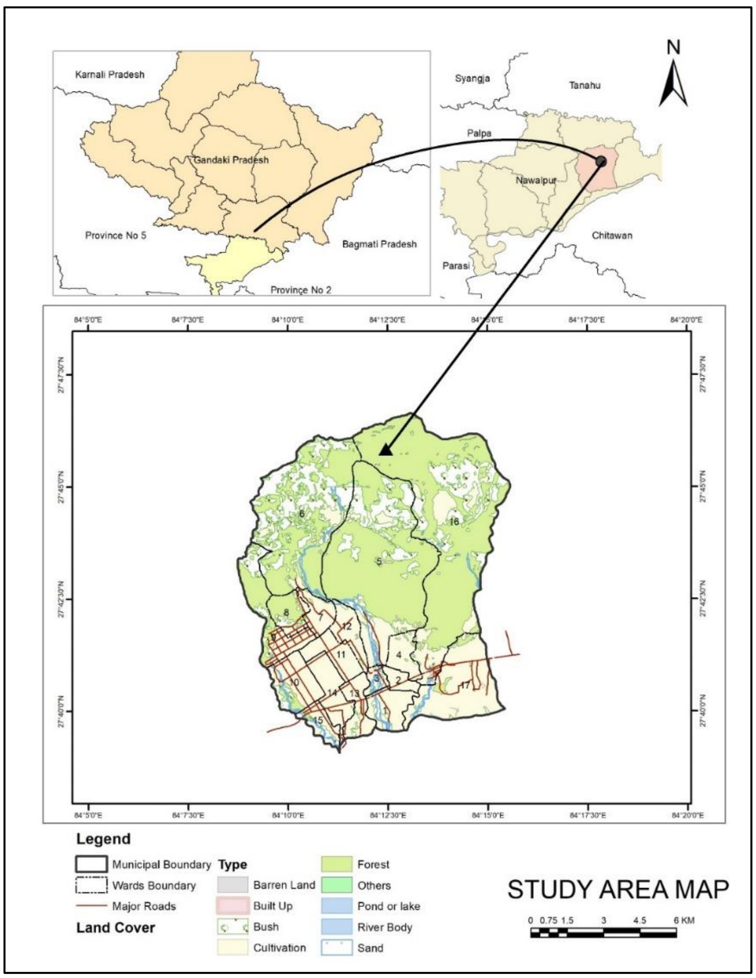


Figure 1: Study Area (Devchuli Municipality)

2.2 Methods

The research methodology for this project is divided into two major parts, the selection and analysis of variable indicator criteria using GIS, and analysis of MCDM. The data sets were obtained from various government authorities, the international organization database, and other reliable sources. The identification of criteria for potential landfill site selection was selected by doing a severe literature review to resolve the prevailing issues regarding the complicated task. The policies based on the Nepalese context were found inadequate in resolving the siting criteria for the assessment of the landfill site. Hence the suitability criteria were drawn following the relative research performed in similar topics of other researchers on landfill sites. The criteria included Waterway, Restricted places, Population density, Water Body, Landforms, Geological formation, Slope, Elevation, and Land cost.

Road Ways: It is suggested that a minimum distance for the siting of landfill area shall be 500m away from highways, feeder roads, and other roads but also reckons 3000m to be the ideal distance[6]. A 500m buffer also is suggested from the transportation network so that accidents are prevented from bulky objects straying by the phenomenon of high velocity of winds [7]. Similarly, Various other authors[8], [9] specify a distance greater than 400m and 250m to be appropriate from the landfill site.

Restricted Places: Landfill areas shall not be sited on restricted areas such as Archaeological sites, religiously important places, national parks, and other important places (hydropower, airports, etc.). A distance of 500m to 2000m is as worst to the best-case scenario as the landfill cannot affect these sensitive places directly or indirectly[8].

Population Density: Urban Areas with high population density are prone to public health risks if the landfill is sited closer to these areas. Moreover, Land Value deterioration issues also can be faced in these dense settlement areas [7], [10]. Also, Urban areas shall be kept in consideration during the site selection to optimize the collection as well as transporting the waste to the landfill site. The siting of landfill site shall be at least 5000m away from urban areas[6].

Water Body: The presence of rivers, streams, lakes, and reservoir is unsuitable for siting of the landfill area. It is recommended that a 1000-meter buffer zone and locating the landfill site away from water bodies to avoid irreversible environmental and health damage, as it would otherwise reach the water bodies[10]. A distance of a minimum of 800m is recommended for the control of leachate from mixing the water resources[8].

Landforms: Barren lands are given the utmost priority for siting the landfill area whereas agricultural lands are least preferred. Settlements area, Industrial Area and Sparse Vegetation with forest areas are treated as of intermediate values to barren and agricultural areas by several authors [7]–[9].

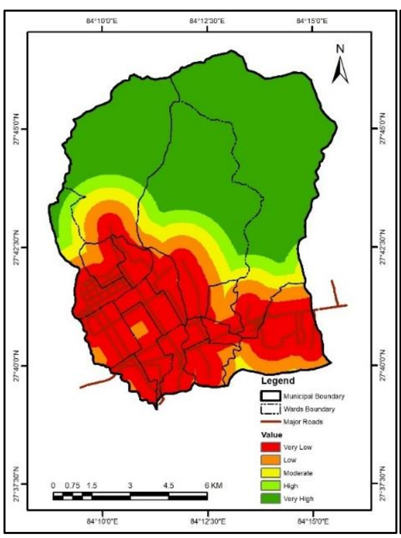
Geological Formations: The presence of different geological formations such as faults, folds, fissures, etc. increases the risk of groundwater contamination. These criteria target the possibility of leaking leachate from the landfill areas and are susceptible to vulnerability conditions. Seismic risks are also major environmental factors that are to be addressed while sitting in the landfill area, the presence of fault lines shall be checked and a minimum distance of 200m shall be kept to minimize the potential risk [7].

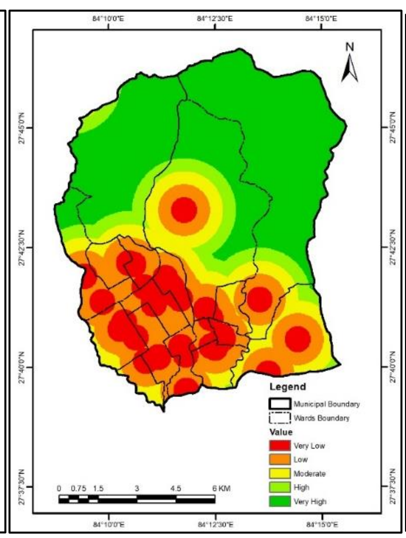
Slope: Landfill on the gentle slope is considered highly suitable because of stability as well as minimization of construction cost. A higher slope may lead to an appreciation of excavation costs along with the dangers of landslides. A slope greater than 20 degrees is regarded as unsuitable and uneconomical while a slope of fewer than 10 degrees is highly preferred [9]. Some authors like [6], [8] suggest giving a fairly low weightage to the lands with slopes greater than 30 degrees.

Elevation: The higher the sitting area for landfill; the access gets difficult along with the increase in construction costs as well as operational costs. Hence, several authors [6], [8], [9] prefer lower elevation available to the study area for siting of landfill.

Land Value: The Land cost and value is a major tool for economic criteria. A major consideration shall be kept under the heading of land value since a higher valuation of land are costlier for projects to acquire completely [8]. Hence, a sitting area with less land cost is preferred.

The GIS data for all the required criteria were extracted from reliable sources. The data was clipped out from the complete scheme of Map of Nepal. All the data were projected on WGS1984, Transverse Mercator coordinate system, and cell size 30m X 30m was used for raster file. The data were integrated into GIS software by creating different layers of the siting criteria. The entire map layers were converted into the raster format and further analysis of GIS data using various GIS tools was performed. The criteria mentioned were incorporated in GIS and buffering in a raster environment was done. Euclidean distance was applied and reclassification of data according to the suitability was done on the same scale from 1 to 5. 1 was assigned to the least suitable area and 5 were provided to the most favorable area; intermediate values were assigned similarly.





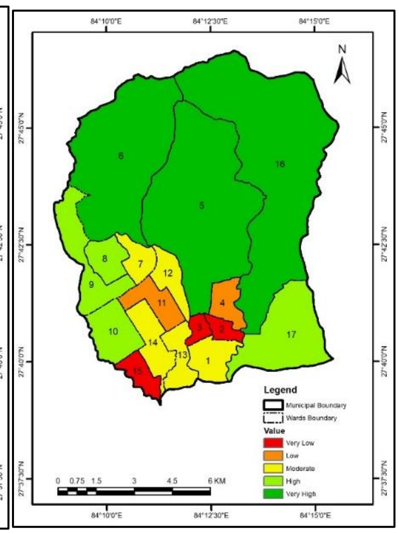


Figure 2: Roadway Suitability **Figure 3:** Restricted places Suitability **Figure 4:** Population density Suitability

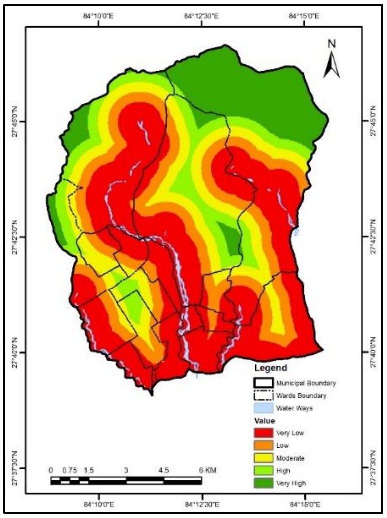


Figure 5: Waterway Suitability

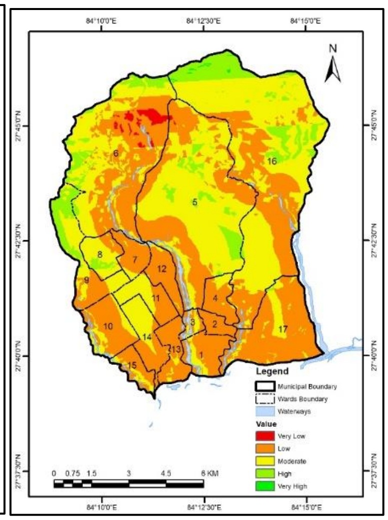


Figure 6: Land cover Suitability

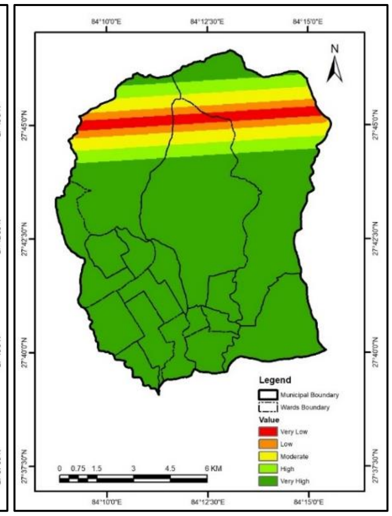


Figure 7: Geographical feature Suitability

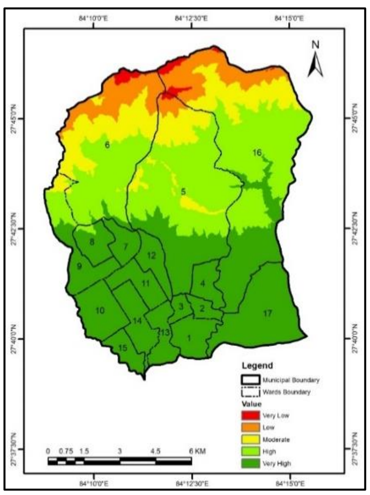


Figure 8: Slope Suitability

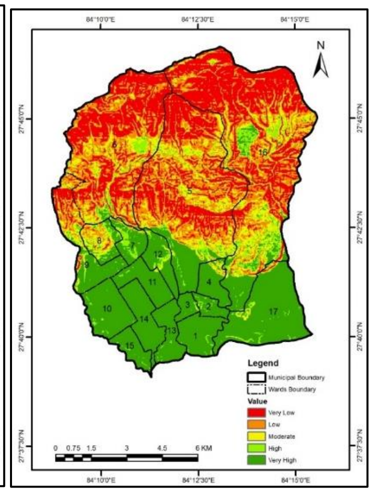


Figure 9: Elevation Suitability

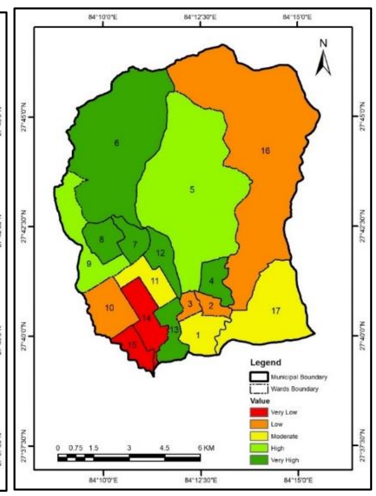


Figure 10: Land cost Suitability

Determination of weights of criteria: Analytical Hierarchy Process (AHP) was used to find the relative importance of criteria or elements. Data collection for AHP was performed using different media such as Google forms and forms using Microsoft word. We tried to reach all kinds of stakeholders and experts as far as possible. The final weightage of the criteria was found out using the arithmetic mean of the weightage of individual consistent data.

Pairwise Comparison: A pairwise comparison matrix A was formed for which every element aij of the matrix represents the importance of the row element i over the element in column j. AHP provides a nine-level fundamental scale of preference to establish the measurement of dominance relation. The inverse relation of the lower triangle of matrix A comprises reciprocal elements 1/aij equal to aji. The principal eigenvalue and the corresponding normalized right eigenvector of the comparison matrix gave the relative importance of the criteria being compared. The consistency of the matrix of order n shall then be evaluated. If this consistency index fails to reach a threshold level, then the answers to comparisons should be re-examined [11].

C.I = $\frac{\lambda max-n}{n-1}$

Where C. I is the consistency index, λmax is the largest or principal eigenvalue of the matrix, and n is the order of the matrix. This CI can be compared to that of a random matrix, RI, such that the ratio, CI/RI, is the consistency ratio, CR. As a general rule, CR ≤ 0.1 should be maintained for the matrix to be consistent.

Weightage Calculation: The weightage obtained for respective criteria was integrated into GIS by using Map Algebra. Then the suitable site was calculated to get the required area for locating the landfill site.

Overlay of layers: The overlay was done as per the weights calculated by AHP survey. The overlaid raster data was reclassified from values 1 to 5 where the 1 being the least favorable and 5 being the most favorable site for landfill under the considered criterion. The raster data obtained was converted to polygons and the total area covered by these places was calculated. Overlay of layers was done using Map Algebra and the final result of the raster image was obtained through liner combination of all the individual criterion by multiplying them with their respective weightage.

$$FS = \sum_{i=1}^{n}(C\text{i} * W\text{i})$$

Where, FS= Final Suitability

Ci= Criteria Digital Identification number of raster layer Ci

Wi= Criteria Weight of Layer i

3. Results

Data collection for AHP was performed using different media such as Google forms and forms using Microsoft word as well as from physical interactions. The general principle was to reach all kinds of stakeholders as far as possible. The data provided by different stakeholders were computed to retain only those data which were consistent for calculation of weightage. The individual weightage was calculated and geometric mean was taken for final weightage.

Table 1: Weightage of Criterions

Roadway	Restricted area	Population density	Water Body	Land cover	Geographical Features	Slope	Elevation	Land cost
0.101	0.110	0.147	0.117	0.120	0.088	0.110	0.106	0.086
10.1%	1.10%	14.7%	11.7%	12.0%	8.80%	11.0%	10.6%	8.60%

The weightage for population density is seen as maximum whereas it's minimum for Geographical feature and land cost. These weights were further used to create a raster overlay map for final suitability.

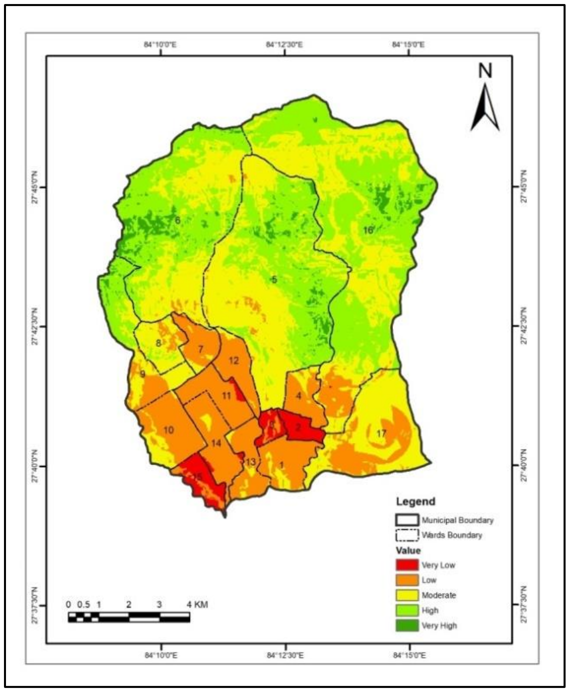


Figure 11: Landfill Suitability Map

The illustrated Figure 11 shows the places with different rankings ranging from very high suitability to very low suitability. It is seen that the area that are deemed most suitable for siting of landfill are at ward 5, 6, 9 and 16. The red zones that are situated at ward 2, 3 and 15 are strictly prohibited places for landfill siting. Similarly, Places demarked with yellow and green are the places with moderate and high suitability. The result was generated considering the area with very high suitability only. The areas demarked with a very high suitability ranking have a total area of 3.21 sq. km which is 2.84 % of the total area of Devchuli Municipality. Ward 5, 6, 9 and 16 have a cluster of the area that can be used for landfill siting.

4. Conclusion

Simulation research was performed and different variable criteria were identified, major tools like GIS and AHP were used for the process of finding the desired result. The major problem of Devchuli Municipality in the form of Solid Waste Management has been looked over remaining under different constraints. This project recommends different locations for siting of the landfill site. As discussed in this research as well the main source of the problem is the absence of integrated solid waste management concepts. The different 3R principles shall be adopted to be more space-efficient in the waste management sector. For this study, geospatial technology was employed as a highly useful and important tool. Analytical Hierarchy Process provided a feeling of Participatory method for development in terms of supplying the weights of many criteria examined in this project. This project's constraints were public action and the participatory character of many stakeholders. It would be extremely beneficial if different focus groups and tiers of stakeholders, depending on their relevance, were given the opportunity to weigh criteria. Furthermore, due to the lack of crucial data, the number of siting criteria assessed was restricted, and the needed accuracy in the field of many elements was lacking. Nonetheless, this initiative might serve as a stepping stone for future projects including comparable developmental activities and land use planning. Hence, this paper recommends the results and major findings as well as methodology can be used and optimized in other municipalities to find similar results.

ACKNOWLEDGEMENT

The author would like to thank Er. Bikash Sherchan for continuous guidance throughout the research work. The author would like to appreciate the Department of Civil and Geomatics Engineering, Paschimanchal Campus, Nepal for providing the platform for conducting this research.

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