Landfill Site Selection Using FAHP and GIS with Integration of MRF: A Case Study of Madhyabindu Municipality, Nawalparasi-East, Nepal

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Abstract

Solid waste disposal is a major challenge faced by communities across the world. Unplanned and unscientific way of dumping is leading to adverse effect in the environment and health factors. This study is carried out in Madhyabindu Municipality, located in Nawalparasi-East, Nepal where the one and only dumping site in Arunkhola river creating the urgency for a sustainable solution to reduce landfill dependency in a long term. An integrated approach combining Fuzzy Analytical Hierarchy Process (FAHP); Geographic Information System (GIS); and Material Recovery Facility (MRF) were employed. Seven criteria namely: Slope; Elevation; Land use; Land cover; Proximity to rivers; Forest; Roads; and Built-up areas were analyzed for ranking the criteria using FAHP. The study showed that an average waste generation rate at base year 2023 is 0.303kg/capita/day of which 61% is organic waste. By using weighted overlay suitability method in MRF only 0.9% of the total land area is found suitable and only 0.001% is highly suitable area for disposal. The way of using integrated approach to identify suitable site for waste disposal problems is highly useful to other sites also where similar condition exist.

Keywords: Solid waste Management, FAHP, GIS, Landfill Site Selection, MRF

1. Introduction

1.1 Background

Solid Waste Management (SWM) is growing concern around the globe, including developing countries like Nepal. As the world progresses daily with economic development and population growth, solid waste production also gets magnified. At present, our planet is becoming home to about 2.01 billion tons of solid waste annually, which is estimated to rise to 3.40 billion tons [1], with 70% increment, by 2050. Worldwide, the per capita waste generation rate averages 0.74 kg/day [2] about 270 kg per person per year [1] while the figure for Nepal is 0.40kg/capita/day. The Kathmandu, metropolitan city generates 1,200 - 1300 metric tons of solid waste daily [3]. The amount has been risen the problem of safe dumping as the capacity went beyond limit already (Figure 1) [4]

Figure 1. The landfill site in Sisdole, in operation since 2005, is already beyond its carrying capacity.

The Solid Waste Management Act Nepal, 2011 [5] states that the local bodies should ensure the separation of solid waste into at least organic and inorganic waste at its source. Solid waste in general can be subdivided into biodegradable and non-degradable organic waste, and inorganic waste like plastic, paper and glass. The 0.317 kg/capita/day waste production rate in Nepal found comprising of 56% organic waste, 16% of plastic, and 16% of paper and paper products [6].However the city has never been able to implement this provision despite numerous attempts [6]

There are common disadvantages of dumping of waste in open area. It emits GHG gases and associated health and sanitation related problems. Potential health problems such as disease transmission, drinking water contamination, respiratory disorders, environmental problems such as soil contamination, water pollution, air pollution, and biodiversity loss, as well as social and economic issues such as land use conflicts and transportation problems, are concerns that are always associated with improper dumping [7] [8].

Waste can be minimized by using 3R (Reduce, Recycle and Reuse) principle, while, waste can be managed by using 3R and landfill or disposal [9]. The common solid waste disposal method includes dumping, incineration, sanitary landfills, and composting. According to Waste Management Baseline Survey of Nepal 2020, about 3,89,983 tons is sent to landfills; 3,15,069 tons is being directly dumped on riverbanks; and 22,075 tons of waste is being burnt down annually [10].

Looking towards the quantity of waste generated and scarcity of disposing lands, it is a matter of concern all over the

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country to find the best place for landfill rather than open dumping. The landfill site holds immense significance for the management and disposal of solid waste in municipalities. It is not an easy way to select the best site for disposal of solid waste from all social, environmental, and technical perspectives, and that goes smoothly for a long run. The challenge for most of the municipalities is to find a suitable landfill site. Several decisions must be made at once in order to minimize the adverse impact of open dumping without sacrificing the technical, social, economic, and environmental elements [10].

The unplanned urbanization, change in consumption patterns, insufficient or negligible recycling and reuse of particles assist collection of municipal waste. Characterization of the municipal waste generation rate, its source, along with their types and composition should be considered for better economical, regulatory and institutional decisions [3]. Nepal's National Policy on Solid Waste Management (SWM) encourages segregation of waste at 3R principle [11]. SWM rule also mandates local body to ensure segregation to ensure segregation of biodegradable waste and non-biodegradable waste at its source [12]. But due to the lack of proper practice of segregation resulting to absence of coordination among the concern stakeholders, the system leading to ineffective SWM in Nepal [13].

The landfill site for the local context should be chosen not to be too close or not to be too far from the waste production centre. Other relevant criteria for multi criteria decision making should be assessed scientifically and systematically so that the waste management system will go sustainably and effectively. Several studies have been done to assess the appropriate community landfill site in municipalities, however, integration of isolated methods as a modified technology should be adopted which is still a challenge from social, technical, finanacial and environment perspectives.

1.2 Research Gap

Many studies about landfill site management have been done before. More specifically [14] carried out a case study in Kathmandu, Bhaktapur and Lalitpur District of Nepal about identification of Landfill Site by using Geospatial Technology and Multi Criteria Method. Similarly, Chauhan, J. & Ghimire, [15] used integrating environmental, social and economic factors to explore a comprehensive geospatial analysis for optimal waste disposal site selection. Likewise [16] carried a case study on 'GIS Based MCDA Selection of Waste Management Site in Kanchanpur District, Nepal'.

Also, A case study done by [17] on 'Landfill site selection using GIS and Multicriteria Decision Analysis (MCDA) : A Case Study of Butwal Sub Metropolitan City'in Nepal is a relevant study. Similarly; Khan, D. & Samadder, S. R. (2015) carried out their research on: A simplified multi criteria evaluation model for landfill site ranking and selection based on AHP and GIS.Zabaleta Santisteban, J. A. et al. (2024) did study on 'Optimizing Landfill Site Selection Using Fuzzy AHP and GIS for Sustainable Urban Planning'. Another study about Landfill site selection by integrating fuzzy logic, AHP, and WLC method based on multi criteria decision analysis—International study (not specific to Nepal) applying Fuzzy-AHP + GIS for landfill site selection is completed already.

Likewise, 'Tuladhar, G. B. (Nepal) carried a study on 'Remote Sensing and GIS for Waste Disposal Site Selection in the Kathmandu Valley: A Case Study of Taikabu Area'. Also a Survey was done by [18] already about 'General reviews and methodological papers on GIS & remote sensing for waste site detection: e.g., Solid Waste Detection, Monitoring and Mapping in Remote Sensing Images'.

This scenario showed that most of the studies relevant this topic use AHP only, without handling uncertainty in expert judgments. Also there is a lack of statistical validation of GIS–MCDA results, there is also a use of outdated spatial data; absence of future-oriented analysis. In previous studies, there is a little consideration of social factors or participatory decision-making. Moreover, weak connection has been noticed between technical outputs and planning relevance. Therefore, this research aims to address that gap by formulating scientific/ logical framework for selecting suitable land fill site considering both present and future scenario.

In most existing studies, only the Analytical Hierarchy Process (AHP) has been applied. However, to enhance the reliability of expert judgments, this study employs the Fuzzy Analytical Hierarchy Process (FAHP), which better captures uncertainty and demonstrates how fuzzy weighting affects the suitability criteria. The integrated Multi-Regression Framework (MRF) is used to validate the GIS–FAHP suitability map. Furthermore, a scenario-based analysis incorporating updated spatial data—such as urban growth and waste generation forecasts—ensures that the recommendations remain relevant over a long-term planning horizon.

1.3 Rational of this study

Municipal solid waste management is one of the major problems in Nepal due to inadequate collection, segregation, recycling, and dumping, causing various environmental problem and health effects.

Madhyabindu Municipality is one of the prone zones of Nepal for waste management system to be adopted with priority. About 7.67 tons of waste are produced annually in this municipality (district data source), where the existing waste management system is inadequate to handle the growing waste volume. The existing dumping site located here is only the bank of Arunkhola, which is very prone to flooding, and hazardous to the crop fields, and directly or indirectly effecting on health of the residents. Besides this, this site is small and cannot withstand the future demand due to the increasing amount of garbage produced and the lack of available disposal space for present as well as in the forecasted scenario for next 20 years.

To date there is no any Landfill site selection related study has been done in this Municipality. The existing practice of waste dumping along nearby riverbank has been creating environmental degradation and public health hazards to serious extents. It is therefore concerning to choose an appropriate landfill site while taking health, environmental, social, and technical concerns into account.

Moreover, most of the municipalities have not complete and updated database about GIS mapping, land use, population density, waste generation rates etc. They also lack multi-temporal scenario based analysis by considering future growth. Moreover, they practice quantitative validation by not considering integrated approach of social, economic, or operational feasibility, and environmental risk impacts. Hence, set of strategic vision in developing decision-support frameworks that combine spatial, technical, environmental and socio-economic data to make effective landfill site decisions are important.

It is a challenge to get the best place for landfill. From feasibility perspectives - the municipality spans diverse terrains, including both urban and rural settings, requiring a tailored approach such as GIS MRF, and FAHP for most suitable landfill site selection. The study also includes social surveys with local residents and key informants to apply participatory weighting, thereby increasing validity and reducing ambiguity in decision-making. Hence this study aims to address all those issues in an integrated way and put a high value in waste management system in a broad.

Directly and indirectly, this study supports to the implementation of national policies - the Solid Waste Management Act (2011) and Sustainable Development Goals (SDG 11: Sustainable Cities and Communities) as well.

1.4 Research Objectives

General Objective To identify and evaluate the most suitable site for a sanitary landfill in Madhyabindu Municipality, by integrating FAHP and GIS techniques, along with the incorporation of MRF to promote sustainable solid waste management.

Specific Objectives

1) To identify present waste production quantity and management practices.
2) To assess criteria to apply in integrated - FAHP, MRF and GIS-based Model for appropriate landfill site selection
3) To identify the most suitable and sustainable landfill site in Madhyabindu Municipality.

2. Research Methodology

In this research study, both quantitative and qualitative method was used for data collection and data analysis. Data was collected through household survey, field observation, key informants interview; literature review, and documents provided by the relevant offices. GIS based software; Microsoft Excel and Word were used for FAHP, MRF.

By using this integrated approach combining all three MRF, FAHP, and GIS together to provide a multi-dimensional, evidence-based modality that balances all - environmental, technical, social, and economic factors. This approach helps to minimize data uncertainty provides visual and quantitative outputs with maps and suitability scores, enhances decision-making transparency, and supports policy formulation and sustainable waste management planning. Hence it bridges the gap between technical analysis and policy decision-making as well.

2.1 Study Area selection

Madhyabindu Mnicipality is situated in Nawalparasi (Bardaghat Susta Purba) district in Gandaki province. It consists of a total of 15 wards spread over an area of 233.35 sq km. According to the CBS data 2021, total of 15,549 households having an average household size of 3.96. The municipality shares its boundary with Kawasoti Municipality and Hupsekot Rural Municipality to the east, Nisdi Rural Municipality to the north, Binayee Tribeni Rural Municipality to the west, and Chitwan National Park to the south. The southern border of the municipality is Narayani River, one of the major rivers of the country that separates the municipality area from Chitwan National Park.

Questionnaire survey among the locals in different wards of Madhyabindu Municipality, followed by field visit to the current dumping site, the Municipality office was conducted. A survey on 50 households was conducted by random sampling and the sample size was estimated using the following formula [19]:

$$n = \frac{(N \times z^2 \times p \times (1-p))}{(N \times d^2 + z^2 \times p \times (1-p))} \tag{1}$$

Where,
n = Sample size
N = Total household (15549 households)
z = Confidence level (at 96% level, z 1.96)
p = proportion of samples on population estimate (95%)
d = Margin of error (6.5%)

$$\left(= \frac{(15549 \times 1.96^2 \times 0.95(1-0.95))}{(15549 \times 0.065^2 + 1.96^2 \times 0.95(1-0.95))} = 43.06\right)$$

≈ 50 household

2.2 Data Collection

Data collection was carried out through both primary and secondary methods. Primary data were collected through household.

surveys, field observations, and interviews with local authorities and experts. Secondary data included topographic maps, population data, Digital Elevation Models (DEMs), Land Use Land Cover (LULC) maps, road and river network data, and administrative boundaries were collected from sources like USGS, Survey Department of Nepal and ESRI. Waste composition was determined via sampling from 50 households over a week collection, GIS-based analysis multi- criteria evaluation, and field verification to identify the most suitable location for waste disposal in Madhyabindu Municipality.

2.3 Selection of Evaluation Criteria

Questionnaires were prepared to identify the status of waste management and satisfaction of the locals with the authorities.

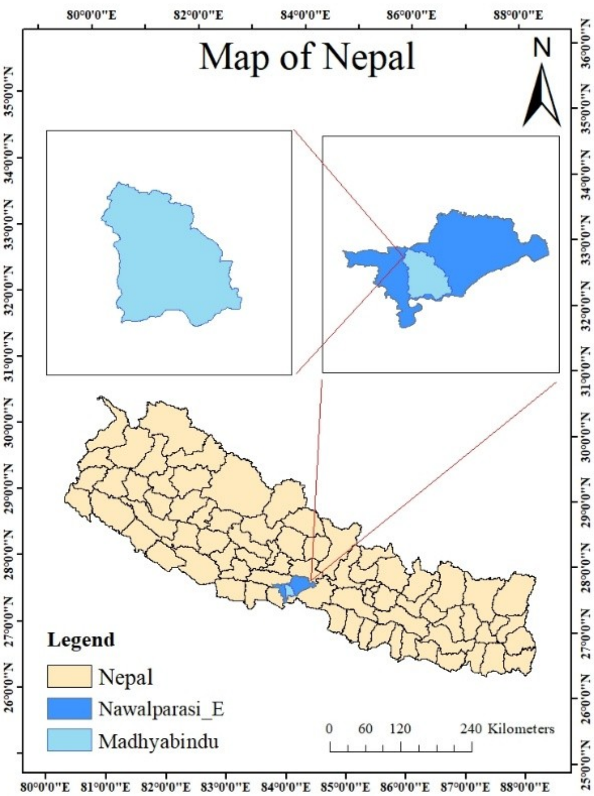

Figure 2. Study area - Madhyabindu Municipality Nepal

Experts were requested to participate in the hierarchy of criteria. Based on literature and expert consultation, seven critical criteria were selected for the landfill site selection process: slope, elevation, LULC, proximity to roads, rivers, built-up areas, and forest area (Table 1).

Table 1. Criteria and their Sources

S.N.	Criterion	Source
1	Built Up	Department of Survey, Nepal
2	Rivers	Department of Survey, Nepal
3	Forest	Esri
4	LULC	Esri
5	Roads	Esri
6	Elevation	USGS Earth Explorer
7	Slope	USGS Earth Explorer

2.4 FAHP for Weighing Criteria

The Fuzzy Analytic Hierarchy Process (FAHP) is a decision-making method that integrates fuzzy logic into the Analytic Hierarchy Process. This approach is particularly suitable for landfill site selection due to the inherent uncertainty in expert judgments [20].

Steps applied for FAHP

1) Problem Structuring into a hierarchy
2) Pairwise Comparison of Criteria
3) Constructing the Fuzzy Pairwise Comparison Matrix
4) Calculating Fuzzy Weights
   The geometric mean of each row in the fuzzy matrix was computed. The results were normalized to determine fuzzy weights (Table 2).
5) Defuzzification
   The fuzzy weights were defuzzied to obtain crisp values as a mean value calculation centroid method. The consistency of pairwise comparisons is verified using a Consistency Ratio (CR), which should be less than 0.10, indicating acceptable consistency [21].

Table 2. Fuzzy Numbers for Pairwise Comparison [22]

Linguistic Term	Triangular Fuzzy Number (TFN)
Equally Important	(1, 1, 1)
Moderately Important	(2, 3, 4)
Strongly Important	(4, 5, 6)
Very Strongly Important	(6, 7, 8)
Extremely Important	(9, 9, 9)

2.5 GIS Mapping

Using GIS, thematic layers for each criterion were digitized and reclassified into five suitability classes based on standard buffer distances and value ranges. For example, a 200-meter buffer was set for rivers and roads to avoid contamination and facilitate transportation access, respectively. These reclassified layers were then subjected to a weighted overlay analysis using FAHP-derived weights to generate a landfill site suitability map. This map revealed that only 0.9% of the municipality's area is highly suitable for landfill development. Field verification was conducted at high-ranking sites, resulting in the selection of a 48.33-hectare site located in the municipality's mid-western region. The site met environmental safety standards, was distant from sensitive areas, and provided adequate access for transport and operations.

1) Road network

The landfill site should not be located too close to the road network so as not be too far to avoid high transportation and road construction cost. Therefore, a buffer of 200 m is provided on both sides of the road along the center. The present study considered both environmental and economic points of view and assigned mid-value as most suitable (not too close, not too far) [23](Figure 4)

2) Rivers

Leachate is a liquid that seeps through a landfill and contains dissolved and suspended contaminants in it. In most of the cases, rivers are contaminated by the leachate due to unscientific landfills and disposal locations. Leachate not only pollutes rivers but also it seriously threats the ground water resources and it is significant issue in sanitary landfill sites. Therefore, buffers in interval of 200 is provided. The rivers that flow through Madhyabindu municipality are Narayani river, Arun river, Dhagi Khola, Girwari Khola, Jilang Khola, Maina Dhar Khola, Ramu Khola, Thulo Khola. The data for the river was collected from the Survey Department (Figure 5)

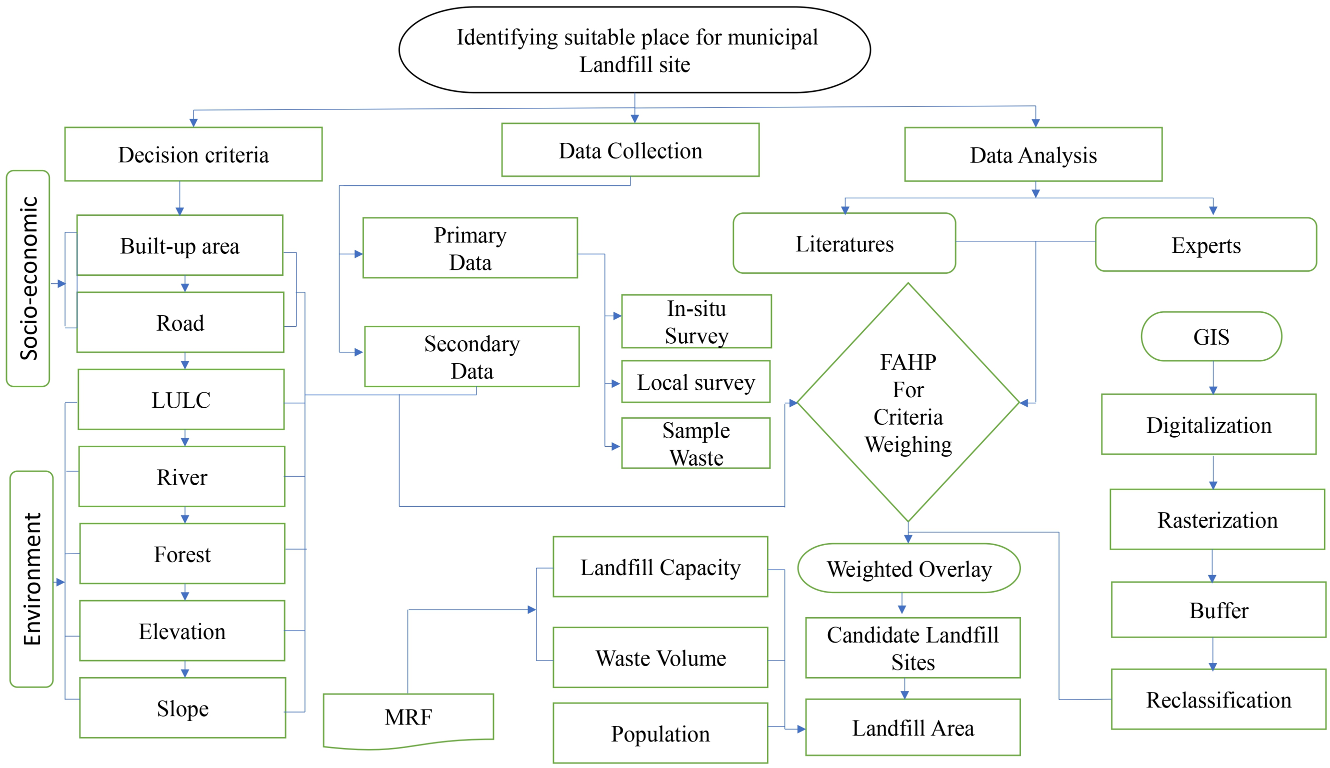

Figure 3. Flow Chart to Select a Suitable Landfill Site

3) *Built-up area*

Built up area refers to the residential, commercial and industrial zones which includes colleges, hospitals, official buildings, parks and other facilities. Landfill site becomes habitat for different types of harmful bacteria, rodent mosquitos, flies, etc. which transmit diseases to human health. Due to this reason landfill sites are kept at a safe distance from built up areas. Prior to choosing most suitable landfill site it is necessary to evaluate and maintain a certain distance from criteria related to infrastructure. Therefore, buffers in interval of 200 is provided. The data for the built-up was collected from the Survey Department (Figure 6).

4) *Slope*

Slope refers to the steepness of ground and is directly related to the topography of place and it influences the surface flow velocity, water content in soil, runoff characteristics and potential soil erosion. If the landfill site or dumping site is located in steep terrain, leachate can travel with high velocity and can pollute and contaminate larger area so landfill sites are not suitable in steep land. The area of landfill site having ground slope less than 10° is considered as a suitable site for landfill [24]. But if the slope of the ground is more than 25° than it becomes unsuitable for landfill site [25]. SRTM (Shuttle Radar Topography Mission), DEM (Digital Elevation Model) from USGS (United States Geological Survey) are used to obtain slope map. In our context, it was found that the maximum part of the municipality (study area) has gentle slope of 5° as seen from the slope map (Figure 7).

5) *Elevation*

Elevation map (Figure 8) like a slope map (Figure 7) is also obtained from SRTM DEM available on USGS (United States Geological Survey). Madhyabindu municipality is classified into four regions based on the altitudes: 114m–149m, 177m–208m, 208m–238m, and 238m–255m. The altitude map of Madhyabindu municipality indicates that the majority of the municipality's area is situated at an elevation exceeding 208m above Mean Sea Level (MSL).

Accessing higher elevation is difficult and it increases transportation charges also. If the landfill is situated at higher altitude there might be chance of slope failure underneath the landfill and also the leachate flow to lower area becomes easy (Figure 7).

6) *Land Use Land Cover*

Land features, including land use land cover (LULC), play crucial role for selecting suitable landfill site. LULC is most important criteria for selection of suitable landfill site. Land use refers to the way humans utilize land for specific purposes such as agriculture, recreation, mining etc., that studies socio-economical activities. Land cover means the flora, water bodies, bare soil, and forests and built-up area which are naturally present in earth's surfaces. To safeguard the environment and public health, landfill sites should not be located near the land cover like water bodies, wetlands, forest areas, near to settlement areas, densely populated areas and high build index areas. In this study Water body, Trees, Crops, Built-up areas, Bare ground, Range land is considered, where water and built-up area is given the rank 1 (i.e. least suitable) and bare ground

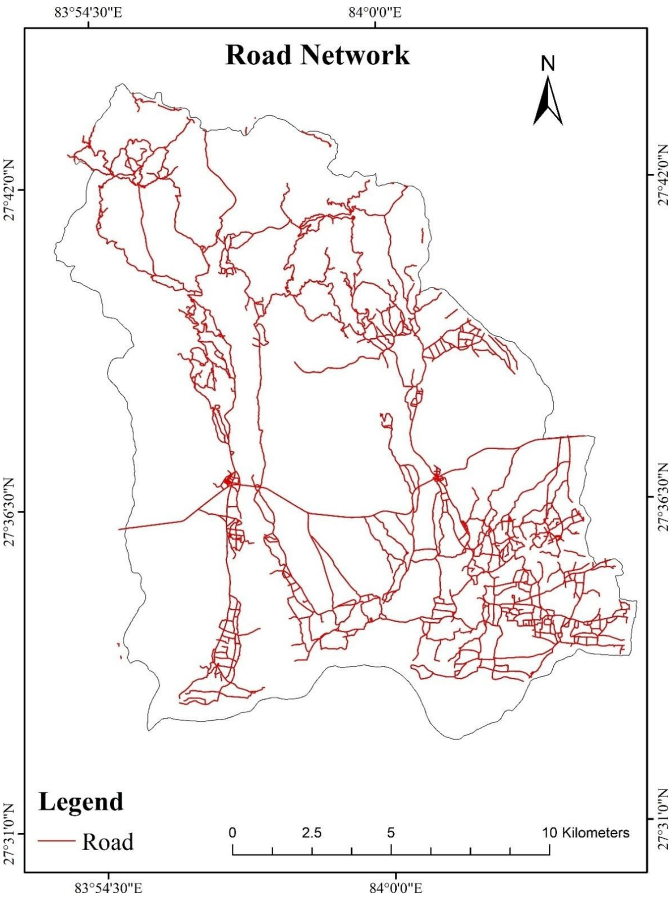

Figure 4. Map Indicating Road Network

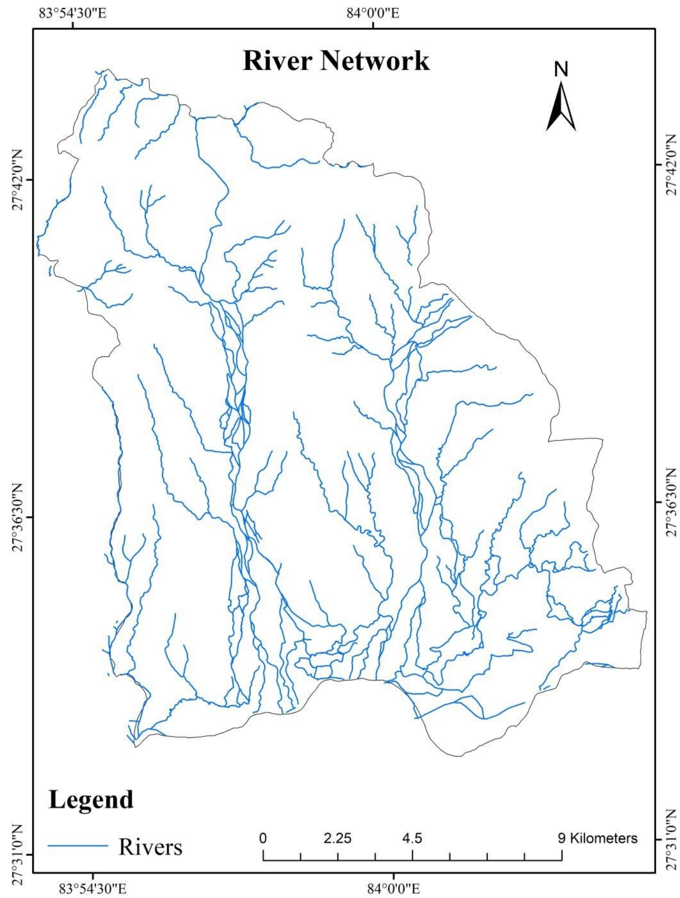

Figure 5. Map Indicating River Network

is given the rank 5 (i.e. most suitable) (Figure 9).

7) Forest

Leachate from landfill site affects forest area directly if the site is situated nearby. Flora and fauna get damaged by the leachate seeping through the soil of landfill site, also leachate makes land barren if the area gets contaminated for too long period. This is why the landfill site should be kept at a suitable distance from forest (Figure 10).

2.6 Landfill Site Determinations

Different factors like cost effectiveness, land availability, environmental and social factors to design a landfill for 20-year period were considered. For the calculation of area of landfill, waste generation rate, waste growth rate, population growth rate and waste density scenario were considered to forecast the capacity of landfill site to the next 20-year period of time. Then for the volume of land fill, 5m height of landfill was chosen to address ground water table and 20 cm soil cover on top after each time disposal of waste.

The following procedure was followed for it.

Step 1: Population Projection by

$$P_t = P_0 \times (1 + r_p)^t \tag{2}$$

Step 2: Adjusted Waste Generation Rate by

$$W_t = W_0 \times (1 + r_w)^t \tag{3}$$

[26]

Step 3: Daily Waste Generation by

$$\text{Daily Waste (kg/day)} = P_t \times W_t \tag{4}$$

[27]

Step 4: Landfill Volume calculation by

$$\text{Landfill Volume (m}^3\text{)} = \frac{\text{Total Waste (kg)}}{D} \times \text{(1+CF)} \tag{5}$$

[28]

Step 5:

$$\text{Landfill Area (m}^2\text{)} = \frac{Volume}{Height(H)} \tag{6}$$

[29]

Where,

P_0 = Population

P_t = Forecasted population in t time period

r_w = Waste Growth Rate

r_p = Population Growth Rate

W_0 = Waste generation rate at present

W_t = Waste generation rate at time period

t = Planning Time in Years

D = Waste Density

CF = Landfill Cover Factor

H = Height of Landfill

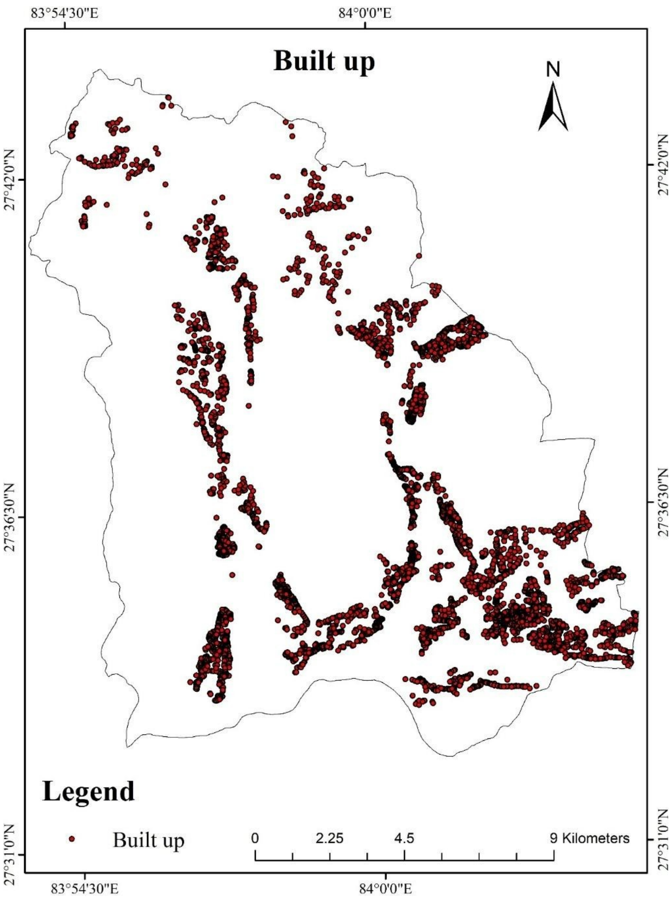

Figure 6. Map Indicating Built-up area

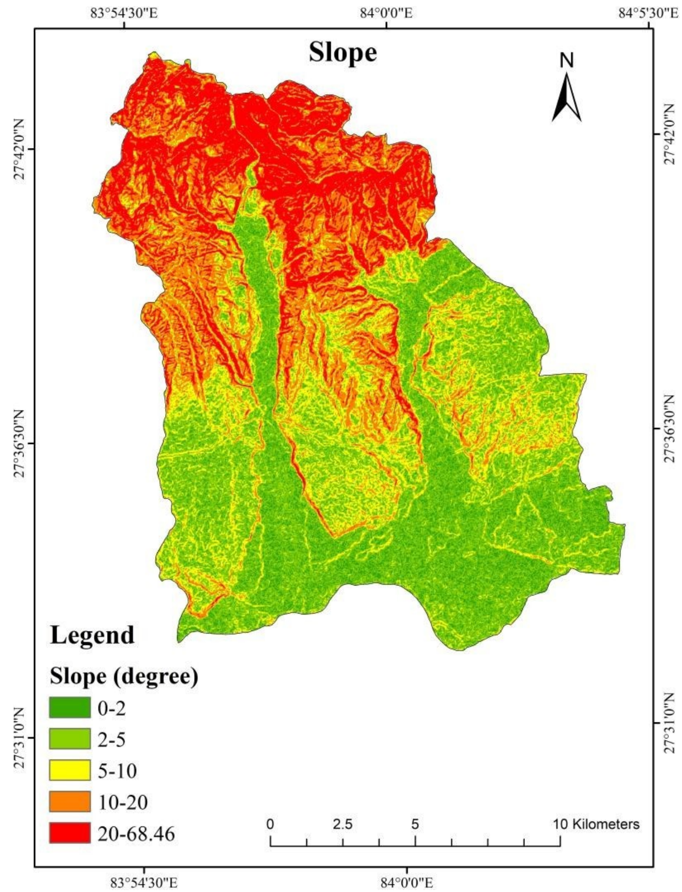

Figure 7. Map Indicating Slope

2.7 Use of Materials Recovery Facility (MRF)

MRF is designed to process mixed or segregated waste, separating it into recyclable materials, biodegradable waste, and residual waste for appropriate handling.

In parallel with the site selection, MRF was proposed to reduce landfill burden by recovering valuable materials. The MRF design included manual and mechanical sorting systems, composting units for organic waste, and baling machines for recyclable materials. The facility layout accounted for waste reception, pre-sorting, mechanical separation, and temporary storage. The planned system is capable of diverting 45% of the total municipal solid waste from landfill, in line with Asian Development Bank (ADB) recovery rate benchmarks. In site, separation of biodegradables and recyclables waste was done. Biodegradables wastes can be either handled by composting into manure or disposing into landfill site if composting isn't feasible. Recyclable materials proceed to the next stage for further processing as it undergoes detailed sorting, using both manual labor and mechanized systems, into specific categories: glass, metals, plastics, and paper/cardboard. Non-recyclable residuals are separated for disposal. Waste composition analysis showed 61% organic waste, followed by 17% plastics and 8% paper.

2.8 Use of Fuzzy Analytical Hierarchy Process (FAHP)

This integrated methodology spanning field-based data collection, FAHP prioritization, GIS spatial analysis, and techno-economic MRF planning offers a replicable model for other municipalities in Nepal facing similar challenges in solid waste management. It ensures that landfill site selection is informed, participatory, spatially grounded, and economically feasible.

2.9 Key Informants Interview

The local and technical experts including the Mayor of Madhyabindu Municipality were selected for interview as they could technically and logically interpret and compare the different criteria to select the suitable site. The formulated closed and open-ended questionnaires were asked to the interviewee who were familiar with the past waste management system in the municipality, with its pro and cons in their lifestyle and the environment. Dissatisfaction of the local people towards current dumping site as feedback for the improvement in sit e selection.

3. Results and Discussion

3.1 Outcome from Field Survey

About 72% of households are familiar with waste management, and 56% of them separate biodegradable and non-

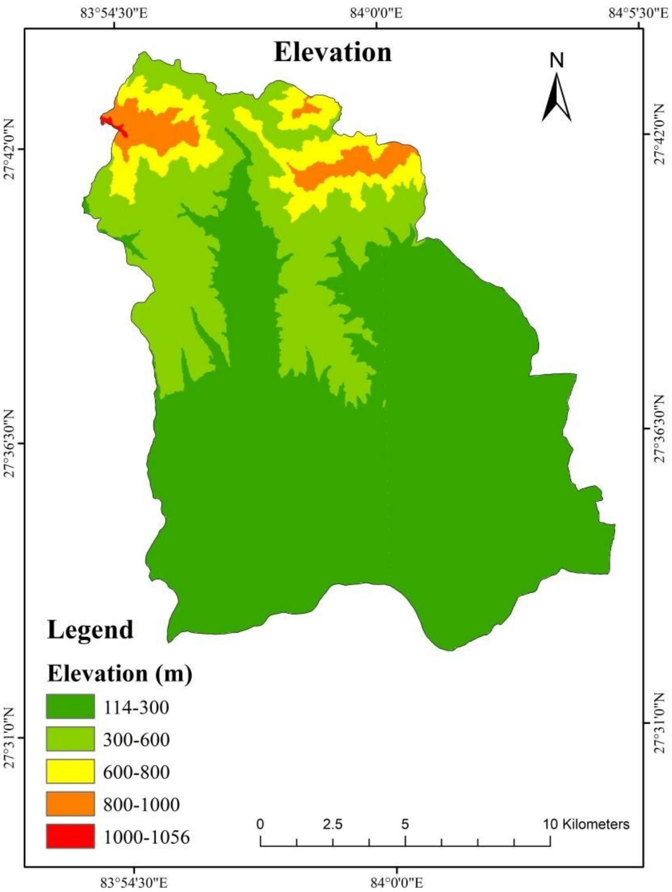

Figure 8. Map indicating Elevation

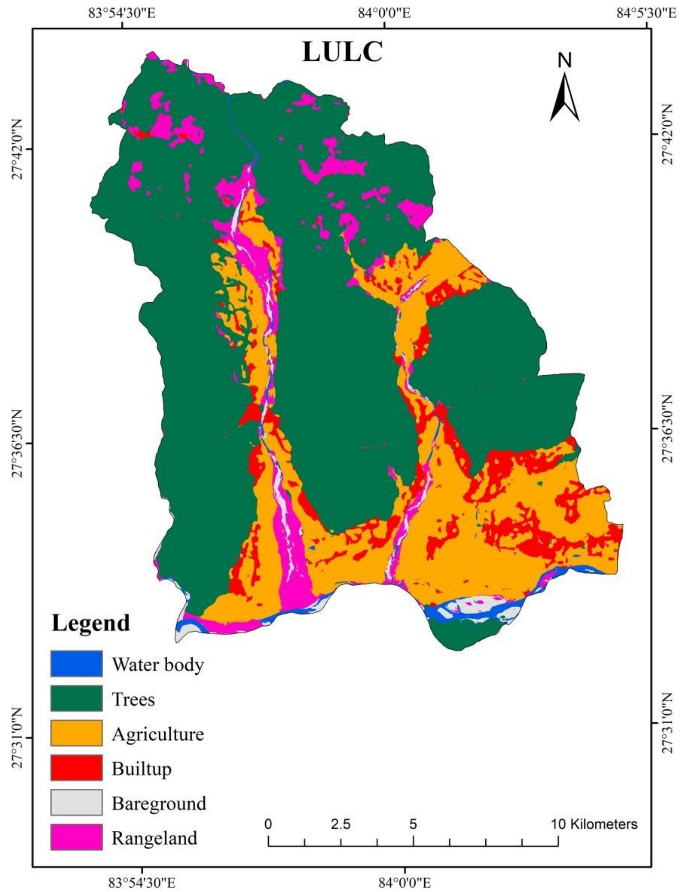

Figure 9. Map Indicating LULC

biodegradable waste (66% of the house-holds utilize the organic waste in their farm in the village area (Figure 11). This shows that only about 60% of households on average are somehow aware of waste management, but from the rest of the households, mostly due to the non-biodegradable wastages and non-engineered dumping facility, the leachate and stench produced are causing a harmful impact both socially and environmentally in Madhyabindu Municipality.

3.2 Waste Composition Calculation using MRF

MRF planning was conducted to segregate the biodegradable and non-degradable waste and sorting of the waste was conducted using waste characterization study, where composition by weight of municipal solid waste (MSW) was determined on the basis of components such as plastics, paper, clothes, discarded food, cans, and other materials from the residential, commercial and institutional organizations. Where organic waste (61%) was obtained to in large per-centage followed by plastic and rubber (17%), paper (8%) as shown in (Figure 12).

It shows that by proper management of organic waste by making compost increases the capacity of landfill site and by benefiting with the revenue obtained by selling the organic compost.

3.3 Priorities index from Pairwise Comparison Matrix

While using Integrated approach- Slope, Elevation, LULC, Forest, Rivers, Built Up, and Roads were compared with each other by the pairwise relative scale comparison (Table 4) based on the opinion of the ex-ports included in the calculation.

3.4 Weight Calculation

In this, the geometric mean of each row in the fuzzy matrix as shown in ()was computed. Then, the results were normalized to determine fuzzy weights. These fuzzy weights were defuzzied to obtain crisp value using the centroid method. To maintain consistency, we calculated the consistency ratio to be 0.045 <0.1 which is acceptable.

3.5 Calculation of Waste Generation Rate

The current dumping site is located just be-side the Arun River, so it is a big issue for human health. So, the focus was to calculate the waste generation rate of Madhyabindu Municipality. To calculate the waste generation rate, we took the sample of waste generated (organic and inorganic separate) from 50 households over 7 days. After collecting the sample and analyzing the data, we found that the waste generation rate of Madhyabindu Municipality is 0.303kg/capita/day. The organic waste produced in the study area was found to be 0.194kg/capita/day and for the inorganic waste, the waste generation rate was 0.1093kg/capita/day. The inorganic waste

Table 3. Pairwise Comparison Matrix

Criteria	Slope	Elevation	LULC	Crops	Rivers	Built up	Roads
Slope	(1,1,1)	(1/3,1/2,1)	(1/6,1/5,1/4)	(1/7,1/6,1/5)	(1/9, 1/9, 1/9)	(1/9,1/9,1/9)	(1/5,1/4,1/3)
Elevation	(1,2,3)	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	1/2
LULC	(4,5,6)	(2,3,4)	(1,1,1)	(1/3,1/2,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,2,3)
Forest	(5,6,7)	(3,4,5)	(1,2,3)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)
Rivers	(9,9,9)	(6,7,8)	(3,4,5)	(2,3,4)	(1,1,1)	(1,1,1)	(4,5,6)
Built-up	(9,9,9)	(6,7,8)	(3,4,5)	(2,3,4)	(1,1,1)	(1,1,1)	(4,5,6)
Roads	(3,4,5)	(2,3,4)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)

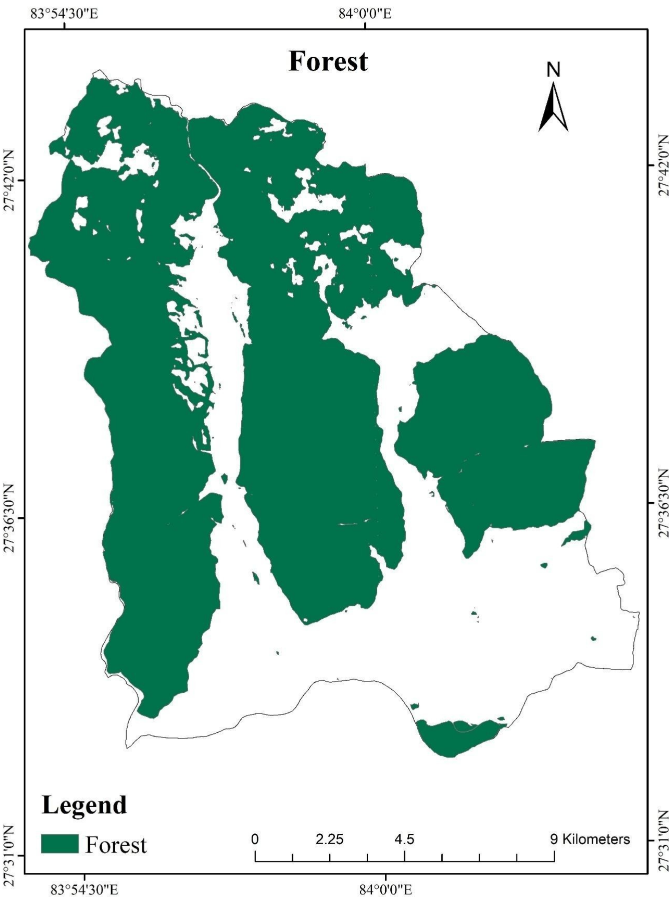

Figure 10. Map Indicating Forest Area

comprises a large percentage of plastic, pa-per, and polythene. Daily waste Handling: Composting, Recycling and Disposal (Figure 14).

The flow chart (Figure 15) represents the determination of the quantity of waste disposal after segregation and sorting of the waste material according to their types and com-position respectively. The quantity of waste collected is determined by multiplying waste generated per capita per day (0.303 kg/capita/day) with the population of Madhyabindu Munici-pality (61,548). The segregation of organic waste (11.376 tpd) and inorganic waste (6.142 tpd) quantity were determined with other unusual and bulky items as 1.132 tpd.

By sorting inorganic waste into non-recyclable (3.39 tpd) and recyclable (2.75 tpd) using recovery rate of 45% (Material recovery facility tool kit, 2013), including plastics and rubber, paper and cartoons, glass, glass, clothes, metals. From the organic waste, 5.119 tpd was obtained to be converted into compost, from which revenue generated including recyclable material. Thus, remaining waste from organic, bulky items and non-recyclable items goes to landfill for disposal (10.779 tpd) which is 55% of the total waste generated.

Figure 11. Field Observation with Survey and Interview

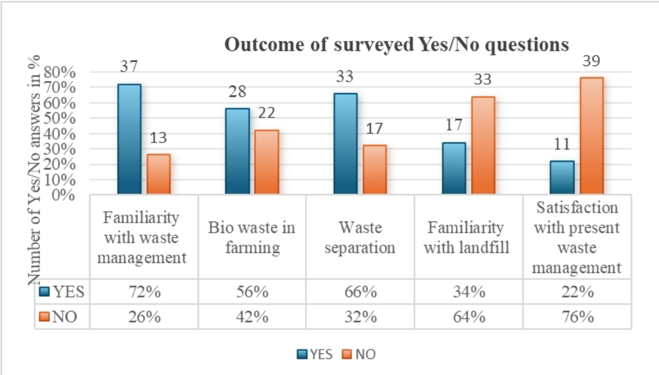

Figure 12. Bar chart showing local opinions

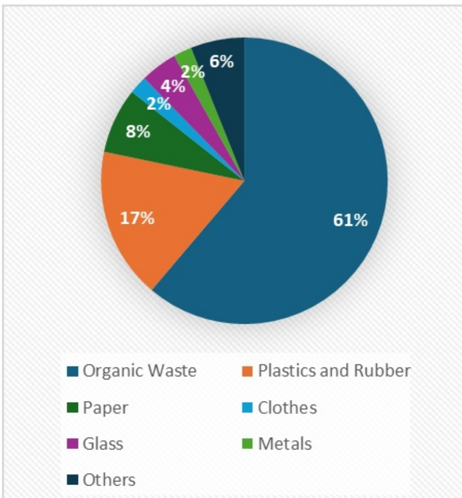

Figure 13. Composition of waste

3.6 Determination of Suitable Land Area

A Landfill area to accommodate the waste generated in 20-year span in Madhyabindu Municipality was determined. From the survey conducted in the Municipality, factors for landfill size determination are mentioned below:

1) W_0: Waste Generation Rate = 0.303 kg/capita/day
2) P_0: Population = 61,548
3) r_w: Waste Growth Rate = 2.5% per year
4) r_p: Population Growth Rate = 1.86% per year
5) T: Planning Time (Years) = 20 years
6) D: Waste Density = 250 kg/m^3
7) CF: Landfill Cover Factor = 20%

Table 4. Criteria Weights by FAHP method

Criteria weights by FAHP Method CRITERIA	Weight (%)
Built Up	30.88
Rivers	30.88
Forest	14.70
LULC	9.98
Roads	7.06
Elevation	4.07
Slope	2.43

Figure 14. Weighing the Waste on Site

8) H: Height of the Landfill = 5 meters
9) Total waste generated in 20 years = 222327.27 tons
10) Total Disposal waste = 122280 tons
11) Volume of Landfill = 489120 m^3
12) Adjusted Volume of Landfill = 586944 m^3
13) Area of Landfill = 11.74 hectares

Table 5. Population Projection, Waste Projection and Total Waste Generation Per Year

S.N.	Projected population	Waste generation (kg/day)	Waste generation (kg/year)
1	62693	19482.21	7111007.26
2	63859	20352.60	7428699.75
3	65047	21261.87	7760585.53
4	66266	22211.77	8107928.89
5	67489	23204.11	8469501.25
6	68744	24240.78	8847886.03
7	70022	25323.77	9243131.05
8	71325	26455.13	9656215.26
9	72616	27637.05	10087254.31
10	74003	28871.77	10538910.92
11	75380	30161.65	11008802.71
12	76782	31509.15	11506984.91
13	78240	32916.86	12033456.71
14	79664	34387.40	12592451.72
15	81146	35923.76	13181227.66
16	82656	37528.69	13806461.97
17	84190	39205.34	14470695.75
18	85759	40956.88	14949261.90
19	87354	42786.67	15617137.70
20	88979	44698.22	16314851.25

Over 20 years, the total waste generated is estimated to be 222,327.27 tons. However, after accounting for recycling and composting in MRF, the actual disposal waste that needs to be managed in a landfill is 122,280 tons, which is 55% of the total waste generation. To determine the landfill volume required, the disposal waste is converted using a waste density factor, resulting in an initial landfill volume of 489,120 m³. Since landfills require additional space for operational factors such as cover soil, settlement, and buffer zones, an adjustment factor (cover factor) is applied, bringing the total landfill

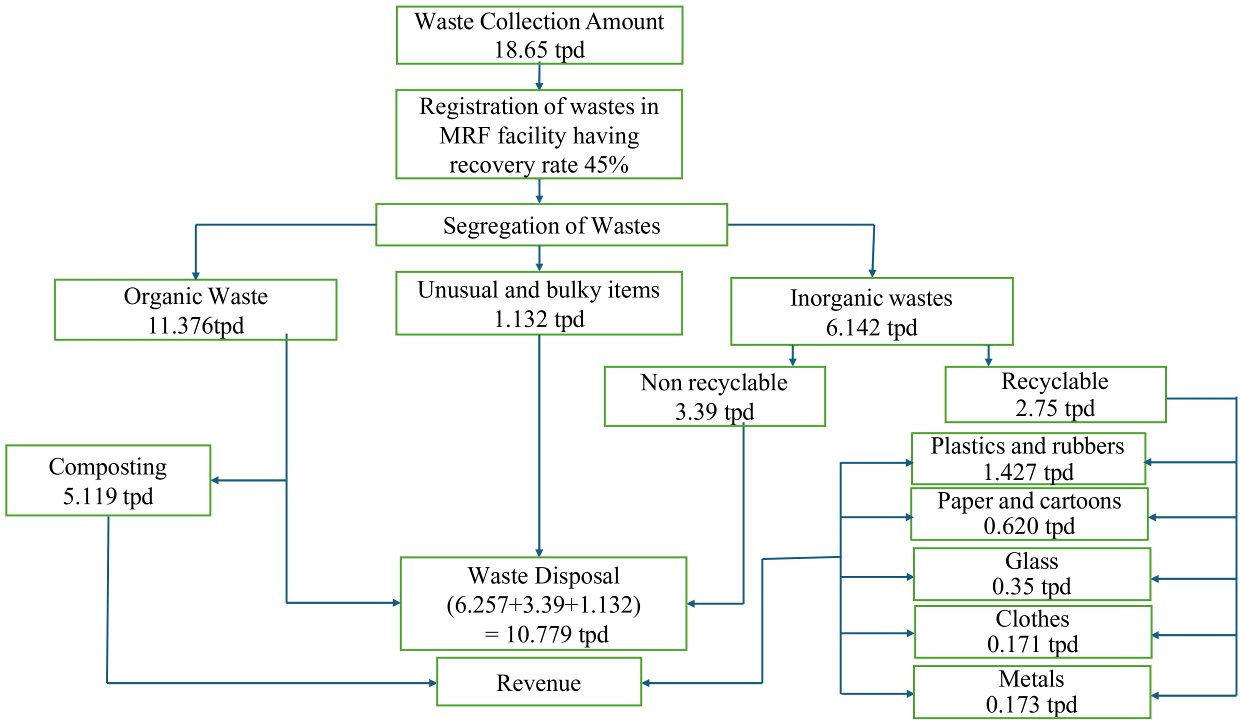

Figure 15. Flowchart of Daily Waste Flow

volume to 586,944 m³. Based on this adjusted volume and assuming a reasonable landfill height of 5m, the total landfill area required is 11.74 hectares. This calculation ensures adequate space allocation for long-term waste management while considering environmental and engineering constraints.

4. Result and Discussion

A survey conducted in Madhyabindu Municipality revealed that 72% of households are familiar with waste management. However, only 56% separate biodegradable and non-biodegradable waste, and 66% use organic waste in farming. The findings indicate a general awareness of waste management, yet a gap remains in practical implementation due to a lack of knowledge and an inefficient waste disposal system.

These findings were compared with studies in Kathmandu Valley, where over 80% of households were found to be aware of waste management, but only 50-60% practiced segregation [30]. Suggests that awareness levels in Madhyabindu Municipality are slightly lower. Similar studies in other municipalities have indicated that despite general awareness, active participation in waste segregation remains a challenge [31]. This aligns with the current study's conclusion that awareness alone does not translate to effective waste management practices.

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4.2 Land field side Suitability Analysis

The highest weighted factors for landfill site suitability are built-up area (30.88%) and rivers (30.88%), followed by forest (14.70%), Land Use and Land Cover (9.98%), roads (7.06%), Elevation (4.07%), Slope (2.42%) using MCDM and GIS which shows that built-up area is a more susceptible criterion for selection of landfill site followed by rivers, forest, LULC, roads, elevation, and slope in the chronological order. Similar FAHP and GIS-based studies in Nepal have found that built-up areas and river proximity are key constraints in landfill selection. A study in the Devchuli municipality, Nawalparasi-East, Nepal for selection of suitable land fill site uses GIS and MCDM for determining the criteria weight of 9 criteria,

Figure 16. Composition of different waste

among which concern with our study includes proximity to roadway (10.1%), water bodies (11.7%), land cover (12%), slope (11%), elevation (10.6%), population density (14.7%) [32].

Also, the landfill site suitability study in Butwal Sub-Metropolitan City, which lies in the Rupandehi district, Nepal, near Nawalparasi, Nepal. For selection of suitable land fill site the case study uses GIS and MCDM (AHP) for determining the criteria weight of 5 criteria, among which concern with our study includes proximity to road (10.8%), river (25.5%), LULC (37.5%), slope (10.8%) and Built-up (20%) [33] which represents that the most populated areas, like LULC including built-up areas, residential area, forest area, water bodies, such as rivers must be during given more priority during selection of a suitable landfill site.

In our study, 0.001% is obtained as a highly suitable area, which is an ideal condition satisfying all the criteria, whereas for suitable area, 0.89% is obtained. Similarly, in the landfill study in Butwal sub-metropolitan city, 0.01% is obtained as highly suitable area, whereas for suitable area, 10.61% is obtained. The high percentage of suitable areas in landfill selection in Butwal may be due to the consideration of only 5 criteria, and also not taking forest as the main criteria, which covers about 48.55% of the area.

These comparisons indicate that the current study follows established GIS-based methodologies and provides reliable landfill site suitability results.

4.3 Waste Generation Rate

The calculated waste generation rate for Madhyabindu Municipality is 0.303 kg/capita/day, with 0.194 kg/capita/day being organic waste and 0.1093 kg/capita/day inorganic waste. A study in Pokhara reported waste generation rates between 0.25–0.35 kg/capita/day [34] closely matching the current study's findings. Kathmandu's waste generation rate, reported at0.4 kg/capita/day [35] is higher due to greater urban density. The waste generation rate found in this study is consistent with data from other mid-sized municipalities in Nepal, indicating the validity of the results.

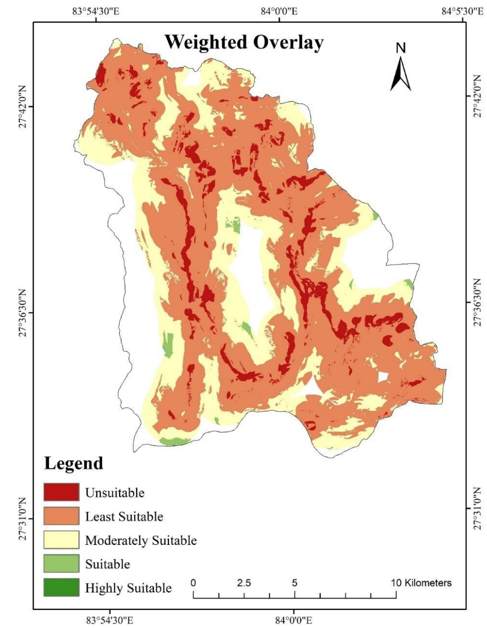

Figure 17. Suitability of Potential Landfill Site

4.4 Landfill Size Estimation

The estimated landfill area required to accommodate waste for the next 20 years in Madhyabindu Municipality is 11.74 hectares, with a total projected waste accumulation of 2,22,327.27 tons. A similar study in Chitwan estimated a landfill requirement of 20–25 hectares for a similar population size [3]. Given the comparable population growth rate and waste generation patterns, the findings of the current study align well with existing literature on landfill size estimation. Finally, to obtain the potential landfill site, several factors should be taken into consideration which make the selection of a land-fill site a challenging process. Factors like built-up areas, Rivers, Slope, Elevation, Forest, Land use, Land Cover, and Roads were considered in this study based on the data availability and significance of these criteria for Madhyabindu Municipality Landfill siting. After reviewing several research papers, articles, and books in GIS-based MCDM modeling for landfill site suitability, we found that these criteria are well enough to provide a suitable landfill site. The result as shown in (Figure 17) of this study showed that Madhyabindu Municipality is mostly covered by least unsuitable areas (64.27%), followed by moderately suitable areas (26.925%), unsuitable areas (7.901%), suitable areas (0.9%), and highly suitable areas (0.001%).

5. Conclusion

The process of landfill site selection is a critical component of sustainable waste management, aiming to minimize environmental, social, and economic impacts. This study, conducted for Madhyabindu Municipality, highlights the importance of a systematic approach to address the increasing challenges of waste disposal.

The study evaluates the suitability of potential landfill sites through a multi-criteria analysis, incorporating factors such as proximity to rivers, roads, and built-up areas, as well as land use/land cover (LULC), slope, and elevation. Each factor is weighed according to its significance, ensuring a balanced assessment that aligns with environmental guidelines and local land-use policies. The use of GIS and weighted overlay analysis synthesized these datasets, facilitating clear, evidence-based decision-making to locate a suitable landfill site in Madhyabindu Municipality.

The findings confirm that most of Madhyabindu Municipality (99.10%) is unsuitable for landfill development, leaving only 0.90% as potential landfill areas. The mid-western region of the municipality is identified as the most optimal landfill site due to its low population density, distance from water sources, and minimal environmental impact, having an area of 48.33 ha.

The Material Recovery Facility (MRF) significantly enhances waste management by recovering valuable recyclables, reducing landfill dependency, and generating economic benefits.

The results provide a clear classification of regions that minimize risks to water resources, biodiversity, and human settlements while maximizing accessibility and land-use compatibility areas based on their suitability, ranging from highly suitable to unsuitable, enabling informed decision- making. By integrating geospatial data and analytical techniques, this approach ensures that landfill sites are appropriate from all aspects.

Limitations

This study provides a comprehensive analysis based on available data and resources; however, certain limitations like: time bound data availability, sample size, and methodological restrictions, provided impact on robust finding.

6. Recommendation

The following are some of the recommendations for this study: The existing site is too close to the river, which poses serious environmental and health risks, including groundwater contamination, river pollution, and ecosystem disruption. So this environment friendly model is needs to be adopted.

The result showed that only (0.9%), and (0.001%) of total area are suitable and highly suitable respectively for waste landfill site in Madhyabindu Municipality.

The local government body should give more emphasis on the potential benefits associated with MRF and the possible revenues it may yield. Hence, the Municipality should make a plan for implementation in near future.

This study, in general, further recommend to the concern stakeholders- to Institutionalize GIS–FAHP–MRF-based decision framework to reduce political influence and conflicts in site selection; to incorporate scenario-based planning; to formulate standard landfill site selection guidelines; to promote integrated waste management practices to reduce landfill burden; and to develop monitoring and review mechanisms for sustainable municipal waste management system.

The methodologies used in this study can be used as replica for other municipalities having common characteristics.

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