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Identification of Appropriate Landfill Sites: A case study on Biratnagar Metropolitan City

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Abstract

Municipal solid waste management generally deals with total procedure of collecting, treating and dumping of solid waste. Lack of land for proper waste disposal is one of the big problem in municipalities of developing countries. Landfilling method is one of the well-engineered and systematic method for effective municipal solid waste management. The landfill site selection has always been a problem from decades as it is highly concerned on factors like population growth, area requirement, environment, public health and human settlement. In context of Biratnagar Metropolitan City (BMC), from 2011 to 2022 there have been drastic increase in population with annual growth rate of 3 percent along with the increase of waste generation from 46.87 tons/day to 120 tons/day. The barampura disposal site located at ward six of BMC is struggling to manage the garbage produced by metropolitan city due to its low coverage area of 1.5 bigaha and growth of waste generation. The study found that the waste are burned openly on weekly basis with no treatment harming the environment and public health. So, in order to overcome the problem of current disposal site this research focused on other suitable location using Multi Criteria Method i.e. Analytic Hierarchy Process (AHP) and Geographic Information System (GIS). This research developed a certain paramater through literature review and carried out the questionnaire survey to expert in order to extract the experts' knowledge and fix the parameter. In total 8 parameters were selected (land use, Residential area, Distance from road, Distance from river, Groundwater, Slope, Soil type and Land value) based on the best fit condition of Terai region and expert opinion. Further the constraint mapping was performed for each parameter using the GIS and the parameter were weighted using the AHP method and the obtained weightage and constraint map was used to generate the suitable site map. Altogether the research found that 13.1 ha landfill area will be required for 10 years design period with total waste generation of 284.04 tons/day and based on the suitability condition of parameter 7 location were identified. Among the 7 suitable location the Singhiya ghat area in ward 18 was found to be highly suitable for the landfill location.

Keywords

Solid Waste, Landfill, GIS, Analytical hierarchy process, Multi criteria method

1. Introduction

Solid waste is generally a result of people activities that gradually increase due to rapid urbanization, better living standards and changing consumption patterns. As per the World Bank the residents in developing countries, mainly the urban poor, is supposed to be severely impacted by unsustainably managed waste compared to those in developed countries. In low-income countries, over 90% of waste is often disposed in unregulated dumps or openly burned. These practices create serious health, safety, and environmental consequences. Municipal solid waste (MSW) has emerged as a global challenge and major environmental issue; primarily in developing countries like Nepal. With rapid population growth and increased economic activities, the rate of generation of waste has also increased[1]. Compounded by absence of effective policies, public awareness and proper waste management system, municipal waste is posing serious threat to settlement and environment. So, MSW has been a major agendas for local and national authorities in context of Nepal. Biratnagar Metropolitan City (BMC) is one of the busiest and largest industrial city of Nepal with an area of 77 sq. km. As per the census 2021, population of 244,750 is living within the BMC and the population is increasing at the rate of 1.83% per annum. BMC has been a part of Regional Waste Management Project (RWMP) started from 2011 but still the project is lagging due to various issues, so the delay in implementation of RWMP the waste Management has been a critical issue of BMC. Solid Waste can be managed with various method based on the sustainable material management (SMM) [1]. The method is generally based on the waste hierarchy made up of five steps: reducing waste at source, reuse of materials, recycling, energy recovery and landfilling. Generally, the landfilling acts as a cheaper method compared to other method and is mostly used in developing countries. Landfill method is a system of garbage and trash disposal in which waste is buried between layers of earth. Landfill approach has been extensively used for the municipal solid waste management in urban area [2]. With the enactment of local self-governance act in 1999, municipalities are the responsible authorities for the management of solid waste generated in the municipalities. Most of the municipalities are opting for open dumping near river banks or on open areas. Though the government of Nepal is promoting the concept of 3R, solid waste disposal to landfill is considered an important and most likely SWM strategy. Many Municipalities in Nepal has been facing the municipal solid waste problem which is one of the demanding environmental challenges [3]. The current practices and systems in Nepal is not able to deal with the increasing amount of waste generation by an increasing urban population and its impact on the environment and public health.

It has been found that the highest amount of municipal wastes generated is about 620 tons/day from the major urban centers from the Kathmandu valley [3]. Combination of Geographic information system (GIS) and Multi criteria evaluation (MCE) is admired globally as a powerful tool for solving problem of landfill site selection [4].

The selection of landfill site is a serious issue in urban planning process attributable to colossal impacts on the economy, ecology, environment and public health and for solving problem of landfill site selection process, combination of Geographic Information System (GIS) and Multi-Criteria Evaluation (MCE) is a powerful tool admired globally [5]. Biratnagar being a metropolitan city still employs poor and environmentally-degrading practice of open dumping the waste and waste is dumped on the banks of Keshaliya river, about 200 meters north of Keshaliya Bridge situated in Ward No 6 of BMC [1]. The limited space for dumping, the waste in the landfill is often burnt to reduce the volume and make room for dumping of more waste in BMC. GIS is capable of providing proficient manipulation and presentation of data. Developing countries are facing unmanaged trend in urbanization and industrialization which has become the main cause of increased solid waste generation [6]. The increasing rate of urbanization has resulted in excessive generation of unmanaged solid waste in municipalities which is causing serious public health and environmental hazard. Selection of a landfill site for Solid Waste Management (SWM) forms an important component in urban planning. The selection of a landfill for disposal of solid wastes requires processing and evaluation of a significant amount of spatial data with respect to various parameters governing the suitability of a site [2].

2. Study Area

Biratnagar metropolitan city is situated in the district of Morang in Province no.1 of Nepal. It was declared as Metropolitan city on 22th May 2017. It is the capital city of Province no.1 and is claimed as one of the industrial city of Nepal. Biratnagar being close to Indian boarder is Nepal second city after Janakpur to have connection with Indian Railway and has the second largest land port in Nepal [1]. Boundary of BMC showing nineteen wards of biratnagar is shown in Figure 1.

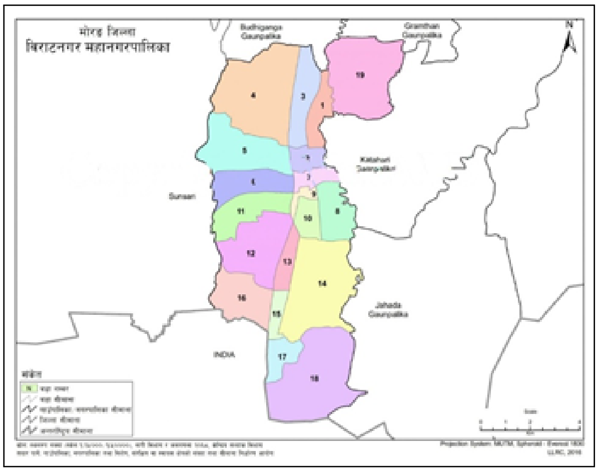

Figure 1: Study area showing boundary of Biratnagar (LLRC,2016)

3. Methodology

The selection process of landfill site is hard and complex. The several criteria data are brought together to develop a best decision in selection of landfill site [7]. In order to incorporate various criteria data efficiently and effectively GIS is used using multi criteria technique. In this research it involves both primary and secondary data collection where primary data include raw data collected from the office of Ministry of energy, Water resources and irrigation and Biratnagar Metropolitan office. The secondary data were further extracted from reports, journals, newspaper, books and other work of literature. Generally the research is based on various stage like Preprocessing stage, criteria selection, Landfill area and use of AHP for weightage calculation and analysis of suitable landfill sites [8]. The framework is shown in Figure 2:

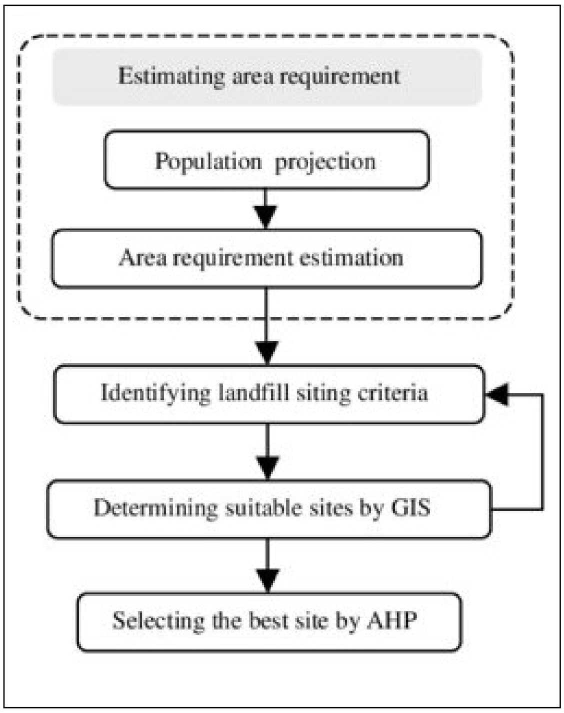

Figure 2: Flow cahrt of Multi-Criteria Analysis Process

3.1 Selection of criteria

Literature on multi criteria technique like AHP and criteria for evaluation of the landfill site selection were taken from peer reviewed journals, books, websites, papers and so on [9]. After extensive literature review and consultation with expert, criteria for evaluation of landfill site were identified as follows [7]:

Table 1: Selection Criteria for Analysis

Criteria	Suitability
Distance from river	100m buffer
Distance from road	30m buffer
Residential area	500m buffer
Land use pattern	Grassland, Cropland, Built up area, Waterbody, Riverbed
Land value	High, Medium and low
Slope	less than 10 percent
Soil Type	Humic Acrosol and Dystric Fluvisol
Groundwater	greater than 0.121 - less than 0.319

3.2 Calculating Landfill Area

Biratnagar is one of the busiest and industrial city of Nepal with rapid population growth and unmanaged urbanization. Landfill area calculation was carried out using the population data and further validating it with the trend analysis. The daily solid waste collection data at landfill site was provided by BMC. The population of BMC was taken from the municipal census 2020 report. The census report of 2021 shows the population of 2,44,750 whereas the municipal report shows the population of 3,05,098. Hence the municipal data was taken in consideration for the calculation of per capita waste production per day. The use of population data for the calculation of per capita waste production as given in equation below [7]:

P = Total Municipal waste per day / Population (1)

where, P is per capita waste production per day.

For the calculation of landfill area capacity the study used the population data to calculate the per capita was production and used another five equations for the calculation of area of landfill for 10 years. The five equations are given below [10]:

Vw =total waste generation inn years/ rate of compaction (2)

where,

Vw istotal volume of waste

Vdc =0.1 Vw, where Vdc is total volume of daily cover (3)

Vc = 0.25 Vw, where Vc is total volume for linear (4)

Ci = Vw +Vdc +Vc, where Ci is Landfill capacity (5)

Ai = Ci/ Hi (6)

where Hi is landfill height and Ai is area of landfill site

3.3 Pairwise Comparision Using AHP

In this phase AHP method was used which is a 9-point rating system. AHP enables weight estimation of both quantitative and qualitative criteria using pairwise comparison matrices to build utilities function [8]. The parameter selected is compared and ranked based on the rating obtained. Consistency ratio was measured to know how consistent the judgment was relative to large samples of purely random judgments. In order to demonstrate if the comparison matrix give consistency or not, Saaty has supplied an index [11]. The formula for determining CR value is,

$CR = CI \div RI \times 100$

Where RI is termed as random inconsistency index of a randomly generated pairwise comparison matrix of rank 1 to 10 and CR is the consistency ratio (CR), CI is the ratio of consistency index [11]. In the formula of consistency ratio (CR), CI is calculated by the following equation.

$CI = (\mu - n) \div (n - 1)$

Where, CI is termed as consistency index, μ is known as consistency vector's simple average, and n defines total number of criteria, According to the consistency ratio's design, if the value is less than 10%, the matrix is considered to be adequately consistent and is acceptable; nevertheless, if it is greater than 10%, it is a symptom of inconsistent judgment.

Table 2: Fundamental scale of absolute numbers for AHP. Source: Saaty, T.L.

Rating Scale	Definition
1	Equal Importance
2	Weak
3	Moderate Importance
4	Moderate Plus
5	Strong Importance
6	Strong Plus
7	Very Strong
8	Very, very strong
9	Extreme Importance

3.4 Preparation of criteria maps

After proper selection and evaluation of criteria for selection of landfill site, different maps have been designed. In total eight maps were developed using GIS platform as the selected criteria are eight which are mainly in vector data format.

3.5 Integration of criterion maps and final suitability maps

After weights are assigned, the criteria maps are further integrated in GIS using overlay tool to get the final suitability map of landfill sites.

4. Results and Discussion

4.1 Calculation of landfill area

A landfill area was calculated in order to estimate the holding capacity for consecutive 10 years. Following the population data and the recent waste production data municipal solid waste generation is expected to increase and a total of 284080 tons will be produced in next 10 years. Hence the total area required in 10 years for the maximum height of 5m along with a rectangular (2:1) infrastructural facilities (1.15 of total area) is 19.27 ha.

4.2 Pairwise Comparison and Standard Matrix

In this section, we have taken overall eight criteria for the analysis. The criteria was selected based on the literature review and expert consultation through direct interview and survey. Among 16 experts only 12 responder responded the survey question which was based on the saaty's 9 point scale value but only 9 responder data was found to be consistent. The two responder data were highly inconsistent with around 0.56 and

Table 3: Sample Response matrix of single responder

RESPONSE MATRIX								
	C1	C2	C3	C4	C5	C6	C7	C8
C1	1	0.5	1	0.5	5	7	0.5	3
C2	2	1	1	0.5	7	7	1	5
C3	1	1	1	0.25	4	5	1	6
C4	2	2	4	1	5	7	1	3
C5	0.2	0.143	0.25	0.2	1	0.5	0.25	0.25
C6	0.143	0.143	0.2	0.143	2	1	0.2	0.2
C7	2	1	1	1	4	5	1	3
C8	0.33	0.2	0.167	0.33	4	5	0.33	1
SUM	8.673	5.986	8.617	3.923	32	37.5	5.28	21.45

0.587 whereas on respondent data was 0.237 which was further contacted and revised. The obtained data was further used for the purpose of defining weight to various 8 criteria using the AHP method and it was done using excel along with use of Super Decision V2.10.

Where, C1= Land use, C2= Soil Type, C3= Residential Area, C4= Groundwater, C5= Slope, C6= Land Value, C7= Distance from River & C8= Distance from Road. The sample response matrix was further normalized by dividing each element by respective column sum. Criteria weights were calculated by averaging entries of rows in the normalized matrix. The vector obtained is also called normalized principal Eigen vector or priority vector. The sample calculation is given below.

Table 4: Sample normalized matrix of single responder and its weightage

	C1	C2	C3	C4	C5	C6	C7	C8	WEIGHT
C1	0.115	0.084	0.116	0.127	0.156	0.187	0.095	0.14	0.13
C2	0.231	0.167	0.116	0.127	0.219	0.187	0.189	0.233	0.184
C3	0.115	0.167	0.116	0.064	0.125	0.133	0.189	0.28	0.15
C4	0.231	0.334	0.464	0.255	0.156	0.187	0.189	0.14	0.241
C5	0.024	0.024	0.029	0.051	0.031	0.013	0.047	0.012	0.028
C6	0.016	0.024	0.023	0.036	0.0625	0.027	0.038	0.0093	0.029
C7	0.231	0.167	0.116	0.255	0.125	0.133	0.189	0.14	0.17
C8	0.038	0.033	0.019	0.084	0.125	0.133	0.063	0.047	0.068

Where, C1= Land use, C2= Soil Type, C3= Residential Area, C4= Groundwater, C5= Slope, C6= Land Value, C7= Distance from River & C8= Distance from Road.

Table 5: Pairwise combination matrix of overall responder data

	LU	ST	RA	GW	SL	LV	DRI	DRO
LU	1	0.896	0.43	0.67	4.15	3.31	0.26	2.13
ST		1	1.16	0.76	3.51	5.55	1.41	4.31
RA			1	0.52	4.09	5.06	0.49	4.77
GW				1	5.36	5.93	0.87	3.9
SL					1	0.91	0.26	0.44
LV						1	0.22	0.22
DRI							1	4.15
DRO								1

LU Land use land cover, ST Soil type, RA Residential area, GW Ground water, SL Slope, LV Ground Land Value, DRI Distance from River, DRO Distance from Road.

The consistency of each matrix of pairwise comparison is done. Consistency is checked based on largest eigen value. The largest eigen value, λ max is the average of λ also called principle eigen value. Lambda, λ is obtained by dividing elements of AW matrix by corresponding elements of W matrix. The sample Calculation is shown in the following table.

Table 6: Consistency Ratio Calculation

λ max= (A*W)/W	8.682374
Consistency Index, CI= (λ max-n)/(n-1)	0.0971
Consistency Ratio, CR=CI/RI	0.068
Randomness Index RI	1.42

Consistency ratio is less than 0.1, which is within acceptable limit.

4.3 Average weight of criteria

In order for the preparation of final suitability map, the average weight of the criteria as given by nine responder data is taken. Normalization was done for the average weight determination. The criteria weight used is shown in the table below.

Table 7: Weightage of criteria

S. No.	Criteria	Weightage
1	Distance from River	0.21976
2	Groundwater	0.20304
3	Soil Type	0.17888
4	Residential area	0.16261
5	Land Use	0.10789
6	Distance from Road	0.06089
7	Slope	0.03578
8	Land Value	0.03114

4.4 Description of Criteria

Residential area: Residential area in any metropolitan city or urban area is an important and sensitive factor. Numerous environmental pollution and health problem were generated by landfill area and affect the local residence. So the distance from residential area is appropriate for landfill site selection . The buffer zone should be not less than 100m and further the map was reclassified to suitability of distant criteria greater than 400m. The value from 1 to 5 were used for ranking where 1 was termed as inappropriate and 5 as most appropriate [5].

Land Use: This Parameter includes water body, natural vegetation, agricultural land, settlement, bare land and other roofed structure area. Land use is important as it is very sensitive to select a landfill for waste dumping. Similarly for land use condition grassland, cropland, riverbed, waterbody and built up area were taken in consideration and they were further ranked based on the scale of 1-5 defining the suitability condition. The grassland was assigned with value 5 and Built up area with 1.

Distance from river: The appropriateness of a landfill site is directly related to its proximity to rivers in Nepal, it is illegal to dump solid waste near water bodies as per the law of Nepal. Hence the distance from river is another criterion for selection of landfill site. The distance of 100-500m should be maintained from river area, so this research generally have the barrier of 50m – 500m where 50 m is assumed to be inappropriate with value 1 and above 500 m with value 5 [8].

Distance from road: : For the transportation of waste from urban area to outside road, connectivity is an important factor, close to road preferred more suitable than far away from road connectivity. The distance 0- 30 m from road side is unsuitable and 60-90 m as highly suitable. So this research has taken the barrier of 200m for the study of distance from road [8].

Slope: The slope acts as a most important for landfill selection and assigned value 1 for the slope greater than 23 degree and value 5 for slope of 7 degree [7]. This research has taken the same consideration for the classification of map.

Land Value: There exists a reciprocal relationship between landfill site and land value. In this case the monetary value of land is taken in account for the study. As per the data of high to low value from metropolitan city the area with low value is taken as value 5 and high value is taken value 1.

Groundwater: To study the leaching contaminant from landfill site groundwater condition is an important criterion for landfill site selection. Since the data providedwas the potential index value the region was classified as good to poor condition assigning value 5 and . The GWPI value ranged between 0.121 and 0.319 where 0.121-0.187 were considered poor and 0.54-0.319 as good.

Soil type:This parameter find out the type of soil present in the landfill area and determine the soil profile and allowable bearing capacity of probable location of landfill site. The infiltration rate of water is directly dependent on grain size of soils. Hence to type of soil are studied in this research: Humicacrosol and Dystric Fluvisol. The Humic acrosol consist of 46 percent and, 30 percent of silt and 24 percent of alay whereas dystric fluvisol consists of 81 percent of sand, 11 percent silt and 8 persent clay and compared to acrosol, fluvisol tends to have less production capacity as it has more portion of sand hence the author has marked the acrosol more important than fluvisol.

4.5 Analysis of final suitability map

The suitability maps below shows the different location suitable for the landfill site and overall 7 area were found to be best fit for landfill site selection and the suitability maps shows the area in four different ward that is feasible for landfill site selection.

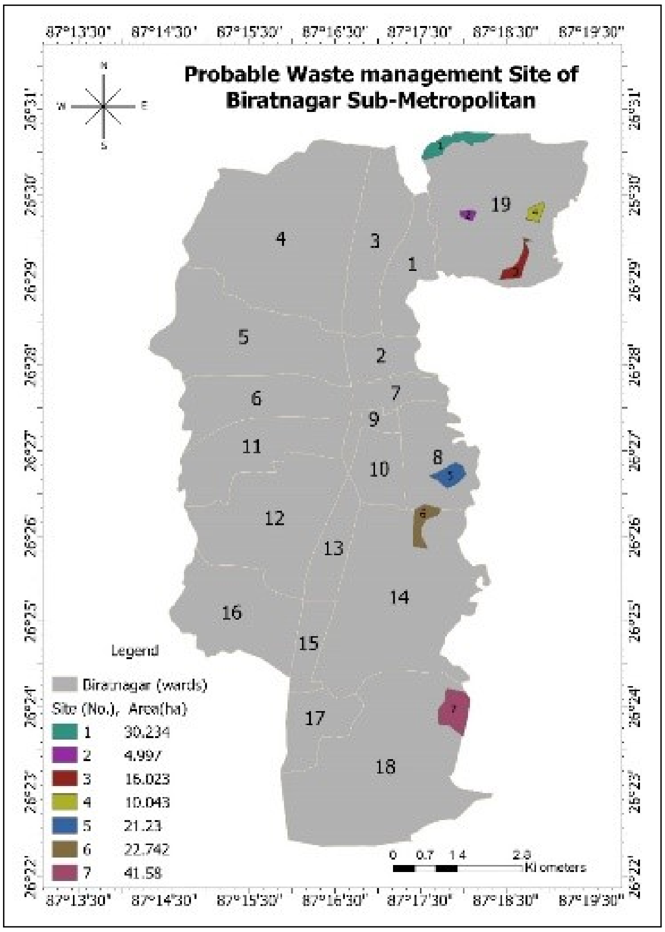

Figure 3: Probable landfill site in Biratnagar

5. Conclusion

Solid Waste Management has always been a big problem in most of the municipalities of Nepal from decades and following the various environmental, physical and socio economic criteria it is tougher to locate the landfill site based on the area required. So, for the early control of waste management in Biratnagar this research focus on finding Suitable landfill site using concept of GIS and AHP. This research carried out the questionnaire survey to expert for AHP procedure and found that river distance is highly important parameter for the selection of landfill site in BMC. The total area of 13.1 ha is required for the appropriate landfill site location with height of 5m based on various 8 parameter. The final suitability map of the landfill site was prepared using GIS, altogether 7 locations were found to be suitable for landfill location and further site verification process was carried out based on the area limitation and visual inspection of all 7 site, the site at Singhiya Ghat ward 18 is found to be highly suitable location for landfill. Further the research found that in recent dumping site the waste are openly burned and are not treated causing harm to environment and Public health. Also the failure in RWMP project has highly affected the SWM in BMC and for solving the problem finding a new landfill location has been a most necessary issue in BMC. Despite the fact that the AHP technique has been used in numerous academic works to establish how different criteria should be weighted, this study has run across some restrictions. Using AHP becomes practically impossible when there are more than nine criteria since pair wise comparisons demand n (n-1)/2 comparisons. Another problem is that we cannot complete the pair wise comparison matrix by adding more decision-makers or experts because doing so will confuse the weighting system of the matrix. As a consequence, we are now only able to include ten experts from various disciplines in our research.

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