Integrate GIS and multi-criteria decision making (MCDM) to find a suitable place to establish a landfill at Sabaragamuwa University in Sri Lanka.

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ABSTRACT

In today's rapidly urbanized global society, the generation of solid waste is an important challenge facing the whole world as it adversely affects both human life and the environment. The Sabaragamuwa University located in the Rathnapura District in Sri Lanka, is one of the Government University, with population of more than 5000 in 2019. Currently, there is no proper solid waste management system in the study area which is causing negative impacts on both environment and society in many ways. A suitable solid waste system is therefore a high priority requirement for Sabaragamuwa University in Sri Lanka. Landfill siting is a complex and time-consuming process with numerous restrictions and regulations, is requiring an evaluation of various environmental, social and economic criteria. This paper proposes multi-criteria decision-making (MCDM) method combined with Analytical hierarchical process in a model for landfill site decision. The adopted study used seven criteria under three major categories as environmental, geological and social and cultural aspects. Finally, a suitability map is derived by multiplying each factor by its relative weight followed by summation of the results. At last two places were identified for the development with the highest suitability values.

INTRODUCTION

Solid waste management, Landfills and site selection

Solid waste is an undesirable or useless solid material produced from human activities in residential, industrial, or commercial areas. In today's rapidly urbanized global society, the generation of solid waste is an important challenge facing the whole world as it adversely affects both human life and the environment. Therefore, to alleviate the problems arising from solid waste, waste reduction, waste reuse, and recycling must be introduced for the betterment of society. However, after all these available options, the final solution for solid waste management is waste disposal. A Landfill site is an area for disposal of waste material by burial. The concept of landfill was raised in the early 90's and is now the most common method used for municipal solid waste treatment (Alkaradaghi, Ali, Al-Ansari, Laue, & Chabuk, 2019) Despite of advances in waste processing techniques for waste minimization, landfill has remained as an integral part of any solid waste management system of the city. Landfill siting is a complex and time-consuming process requiring evaluation of various environmental, social and economic criteria (Lokhande & Mane, 2017). Traditional methods for selecting landfills are more complex and time-consuming process also it requires a large amount of money. Use of GIS based applications would reduce this complexity in to some extent with the help of computer technology and its innovative tools and procedures Moreover, it allows users to view, understand, query, interpret and visualize spatial and non-spatial data in many ways that reveals relationships, patterns and trends in the form of maps, reports and charts (Lui and Mason,2009; Bhatta, 2010). The GIS aided methodology presented here utilizes the geo spatial data to find a suitable location to establish a landfill at Sabaragamuwa University of Sri Lanka.

Problem statement and Study area

Sabaragamuwa University of Sri Lanka (SUSL) is a government university established on 1991, is located at Latitude 6”42”00” and Longitude 80”44”00”, where a rural area more than 65km away from the nearest city Rathnapura. It consists series of residential sections for students and staff members, currently there are approximately 5000 people residing inside the university. Therefore, university face significance challenge related to solid waste due to the high population concentration and absence of an appropriate solid waste management system. Besides, the current waste management system in university does not meet the appropriate standards. They just collecting mixed waste at once and being dumped in an open isolated area. Subsequently, when the dump is full of waste, it burns out. This poor solid waste management practice causes air pollution, and the leachate produced in the dump pollutes the groundwater surface of the area. A suitable solid waste disposal method is therefore a high priority requirement for Sabaragamuwa University in Sri Lanka.

Data and Objectives

The present study intends to find out a suitable site for the disposal of solid waste with the help of GIS and Multi-criteria decision making (MCDM) technique also it is addressing the use of Analytical hierarchical process (AHP) for determine the weights for the various criterions being used in the method.

Data: Digital data obtained from Survey Department of Sri Lanka

Software: ArcGIS 10.3.

METHODOLOGY

The methodology adopted in this study used GIS to assess the criteria for landfill conformity mapping, as illustrated in Figure 1. This proceeds in two stages: Data preparation and Suitability analysis,

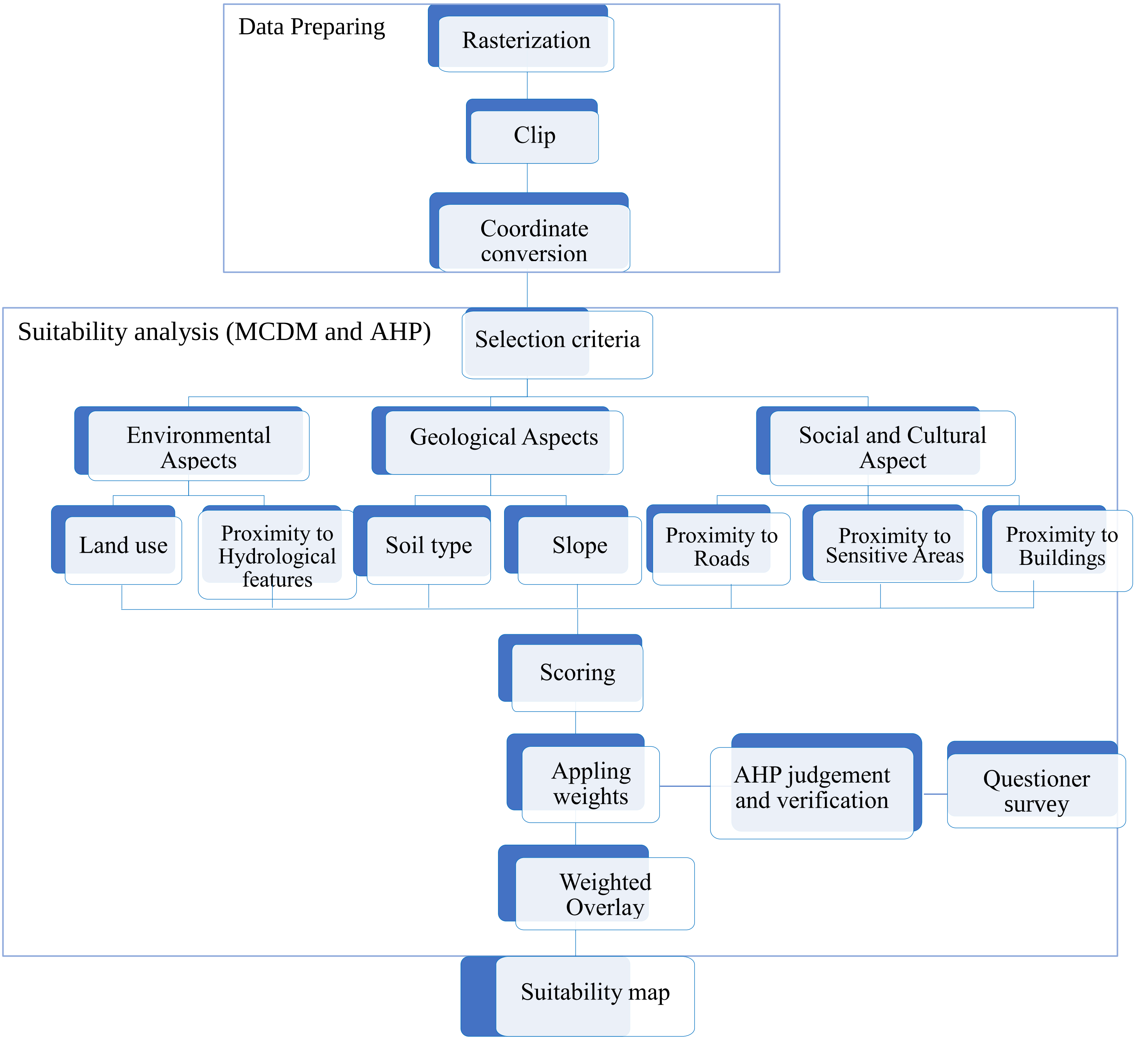

Figure 1: Methodology

Data preparation: The pre-processing steps included rasterization and clipping in to study area and further, data layers were converted to the WGS 1984 UTM Zone 44N (EPSG: 32644) coordinate system as it was the most suitable spatial reference for the study.

Suitability analysis: Suitability analysis is the process and procedures used to establish the suitability of a system according to the needs of a stakeholder (Parry, Ganaie, & Sultan Bhat, 2018) The multicriteria decision making technique provides the organized approach for assessing and integrating the impact of various factors as indicators of suitability (Karsauliya, 2013). It would be chosen according to the opinion and information related to the study field area. GIS-based multi criteria decision making (MCDM) process provides a framework for finding a suitable location for establish a landfill in Sabaragamuwa university, the procedure consists of six steps.

Establishing the decision context

In order to achieve an efficient output, the landfill selection procedures should focus to the environmental aspects as well as the social and cultural aspects as it is directly affecting the environment and society in many ways. Therefore, as the first step, by referring to previous literatures, identified the key factors involved in the relevance analysis and categorized them into three major groups: Environmental aspects, Social and cultural aspects, and Geological aspects. The selected key criteria were then divided into sub-criteria as presented in Table 1.

Table 1: Adopted criterions

Environmental Aspects	Land use
	Proximity to hydrological features
Geological Aspects	Slope
	Soil type
Social and Cultural Aspect	Proximity to buildings
	Proximity to roads
	Proximity to Sensitive areas (Religious)

Structuring the decision problem

As the second step, the importance and suitability of these factors for the landfill section model were identified as follows:

Table 2: Suitability for selected criteria

Parameter	Suitability
Land use	It is recommended to select an isolated area that is not used for economic or agricultural purposes.
Proximity to hydrological features	The landfill site must not be closed to surface water bodies
Slope	The higher the slope value, the less suitable for landfill.
Soil type	Soil with a high ratio of silt and clay protects groundwater from landfill leachate and more economically cheaper.
Proximity to Buildings	Landfills should not be placed near residences or buildings to protect the public from possible environmental hazards.
Proximity to Roads	The landfill should not be too close to the road. This is because landfills close to roads can cause public health problems and generate traffic during the construction phase.
Proximity to Sensitive areas (Religious)	Keep away from landfills as much as possible

Determine the weight of each criterion using the AHP Method

In the third phase of the study, an Analytical Hierarchy Process (AHP) technique is applied to determine the relative importance and priority weight of each criterion; AHP is a power-full and flexible weighted scoring decision making process to help people set priorities and make the best decision(Velmurugan, Selvamuthukumar, & Manavalan, 2011). It was developed at the Wharton School of Business by Saaty in 1980. The procedure consisted of the following steps:

Formulating the decision problem in the form of a hierarchy framework

Formulating the decision problem in the form of a hierarchy framework is the first step of AHP, with the top level representing the overall objectives or goal, the middle levels representing criteria and sub-criteria, and the decision alternatives being at the lowest level (Velmurugan et al., 2011)

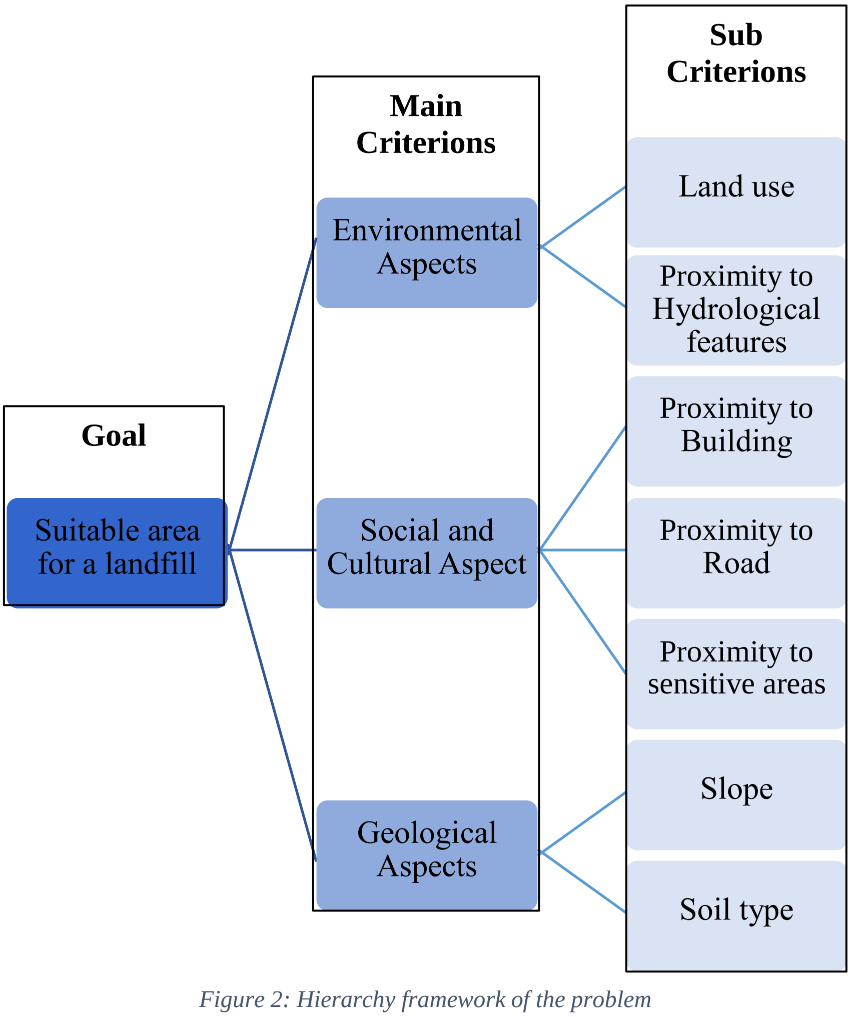

Figure 2: Hierarchy framework of the problem

Determine the relative importance of various attributes or criteria related to goals.

Once a hierarchy frame work has been constructed a questionnaire survey (Appendix 1) was conducted to request the pair-wise comparisons for both main and sub criteria. At the end of the survey, each criterion had 16 different comparison levels. Therefore, the most frequent occurrence (mode) of the results used to produce a final pairwise comparison sheet (Table 3,5) for all criteria including main criteria and sub-criteria. Next, created a square matrix (Table 4,6) using these comparison levels. Each cell (a_{ij}) shows the importance of comparing row criteria i with respect to column criteria j. Where $a_{ij} = 1, when\ i = j$ and $a_{ij} = \frac{1}{a_{ji}}$

Pair wise comparison results for main criterions

Table 3: Final pairwise comparison sheet for main criteria

Environmental Aspects	9	**7**	5	3	1	3	5	7	9	Geological Aspects
Environmental Aspects	9	7	**5**	3	1	3	5	7	9	Social & Cultural Aspect
Geological Aspects	9	7	5	3	1	**3**	5	7	9	Social & Cultural Aspect

Table 4: Comparison matrix for main criteria

	Environmental Aspects	Geological Aspects	Social & Cultural Aspect
Environmental Aspects	1,000	7,000	5,000
Geological Aspects	0,143	1,000	0,333
Social & Cultural Aspect	0,200	3,000	1,000

Pair wise comparison results for sub criterions.

Table 5: Final pairwise comparison sheet for sub criteria

Proximity to Hydrological Features	9	7	5	**3**	1	3	5	7	9	Land Use
Proximity to Hydrological Features	9	7	5	**3**	1	3	5	7	9	Soil Type
Proximity to Hydrological Features	9	7	5	**3**	1	3	5	7	9	Slope
Proximity to Hydrological Features	9	7	**5**	3	1	3	5	7	9	Proximity to Building
Proximity to Hydrological Features	9	7	**5**	3	1	3	5	7	9	Proximity to Roads
Proximity to Hydrological Features	9	7	5	3	**1**	3	5	7	9	Environmentally Sensitive Area
Land Use	9	7	5	3	**1**	3	5	7	9	Soil Type
Land Use	9	7	5	3	**1**	3	5	7	9	Slope
Land Use	9	7	5	3	**1**	3	5	7	9	Proximity to Building
Land Use	9	7	5	3	**1**	3	5	7	9	Proximity to Roads
Land Use	9	7	5	3	1	3	**5**	7	9	Environmentally Sensitive Area
Soil Type	9	7	5	**3**	1	3	5	7	9	Proximity to Slope
Soil Type	9	7	**5**	3	1	3	5	7	9	Proximity to Building
Soil Type	9	7	**5**	3	1	3	5	7	9	Proximity to Roads
Soil Type	9	7	5	3	1	3	**5**	7	9	Environmentally Sensitive Area
Slope	9	7	5	**3**	1	3	5	7	9	Proximity to Building

Slope	9	7	5	3	1	3	5	7	9	Proximity to Roads
Slope	9	7	5	3	1	3	5	7	9	Environmentally Sensitive Area
Proximity to Building	9	7	5	3	1	3	5	7	9	Proximity to Roads
Proximity to Building	9	7	5	3	1	3	5	7	9	Environmentally Sensitive Area
Proximity to Roads	9	7	5	3	1	3	5	7	9	Environmentally Sensitive Area

Table 6: Comparison matrix for sub criteria

	Proximity to Hydrological Features	**Land Use**	**Soil Type**	**Slope**	**Proximity to Building**	**Proximity to Roads**	**Proximity to Sensitive Areas**
Proximity to Hydrological Features	1,000	3,000	3,000	3,000	5,000	5,000	1,000
Land Use	0,333	1,000	1,000	1,000	1,000	1,000	0,200
Soil Type	0,333	0,333	1,000	3,000	5,000	5,000	0,200
Slope	0,333	1,000	0,333	1,000	3,000	3,000	0,333
Proximity to Building	0,200	1,000	0,200	0,333	1,000	1,000	0,333
Proximity to Roads	0,200	1,000	0,200	0,333	1,000	1,000	0,333
Proximity to Sensitive Area	1,000	5,000	5,000	3,000	3,000	3,000	1,000

Get the solution of comparison matrix

In this step, the relative normalized weight (w_i) of each criteria/sub-criterion were calculated by calculating the geometric mean of the i^{th}row and normalizing the geometric means of rows in the comparison matrix.

Perform consistency verification

Consistency ratio providing a useful mechanism for checking the consistency of the evaluation measures and alternatives suggested by the team, and thus reducing bias in decision making(Velmurugan et al., 2011). The consistency ratio (CR) of the calculated consistency index matrix was calculated with respect to the consistency index of the randomly generated pair-wise comparison matrix (using Equation 01,02 and 03). As the values of CR for both main and sub criterions, are less than or equal to 0.1 standard value (Table 8), the judgements are acceptable.

λ max = eigen value of the consistency index matrix .... *Equation 1*

Consistency index (CI) = (λ max−n) / (n − 1)... *Equation 2*

Consistency ratio (CR) = Consistency index (CI) /Random index (RI)........................... *Equation 3*

Table 7: Consistency index of randomly generated pairwise comparison matrix (Saaty's Random Consistency Index

Number of variables	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 8: Consistency verification results for criteria

	Main Criteria	Sub Criteria-1	Sub Criteria-2	Sub Criteria-3
λ max	3,111	2	2	3.176801
CI	0,05	0	0	0.0884
CR	0,091	0	0	0.152415

Ultimately final weights for model has been calculated as shown in Table 9,10,11 and 12

Table 10: Weights for main criteria

	Weight
Environmental Aspects	0,72
Geological Aspects	0,08
Social & Cultural Aspect	0,19

Table 12: Weights for Sub criteria under environmental aspects

Environmental Aspects	Weight
Proximity to Hydrological Features	0,75
Land Use	0,25

Table 9: Weights for Sub criteria under social and cultural aspects

Social & Cultural Aspect	Weight
Proximity to Building	0.14
Proximity to Roads	0.57
Proximity to Sensitive Area	0.29

Table 11: Weights for Sub criteria under

Geological Aspects	Weight
Soil Type	0,75
Slope	0,25

Scoring alternatives in relation to each criterion

Based on the reviews of the literatures in this area, and the importance and suitability of these factors for the landfill section model, each sub-criterion was categorized into classes, and each class was given the appropriate evaluation: 0 is inappropriate, 3 is less appropriate, 5 is moderate, and 7 is very appropriate.

Table 13: Scorings for criterions

Criteria	Sub Criteria	Class	Rank
Environmental Aspect	Proximity to Hydrological Feature	100>	0
		100-300	3
		300-600	5
		600<	7
	Land Use	Rock	0
		Agriculture	3
		Forest	5
		Grass Land	7
Geological Aspect	Soil Type	Sandy Clay (SC)	0
		Silty Clay (SiC)	3
		Sandy Loam (SL)	5
		Sandy(S)	7
	Slope (%)	16.15>	7
		16.15 – 32.31	5
		32.31 – 48.46	3
		64.61<	0
Social and Cultural Aspect	Proximity to Building	50>	0
		50-250	3
		250-1500	5

		1500<	7
	Proximity to Roads	200>	0
		200-1000	3
		1000-2000	5
		2000<	7
	Proximity to Sensitive Area	500>	0
		500-1000	3
		1000-3000	5
		3000<	7

Aggregate the Criteria

After the weightings and scoring, the next step of the methodology was to aggregate all criteria to obtain the final suitability map. For this, one of the most common additive method, the weighted Linear Combination (WLC) (Equation 4) was used.

$$x = \sum_1^n w_i * f_i \qquad \text{Equation 4}$$

$where\ w_i = weight\ of\ the\ i^{th}\ criteria$
$f_i = Rescaled\ criteria$
$x = final\ suitability\ map$
$n = no\ of\ criteria\ concerned\ in\ the\ study$

The final suitability map is derived by multiplying each factor by its relative weight followed by summation of the results. The model builder in ArcGIS 10.4 was used build a geoprocessing workflow (Figure 3) to execute the all necessary tools to determine the right places. Final output map shows the suitability of areas ranging from 0 to 6, where 0 represents the least suitability and 6 represents the greatest suitability. (Figure 4) and the places with the highest suitability value was extracted as the suitable region for establish a landfill. At last there were two highly suitable land parcels with extents mentioned below in table 14.

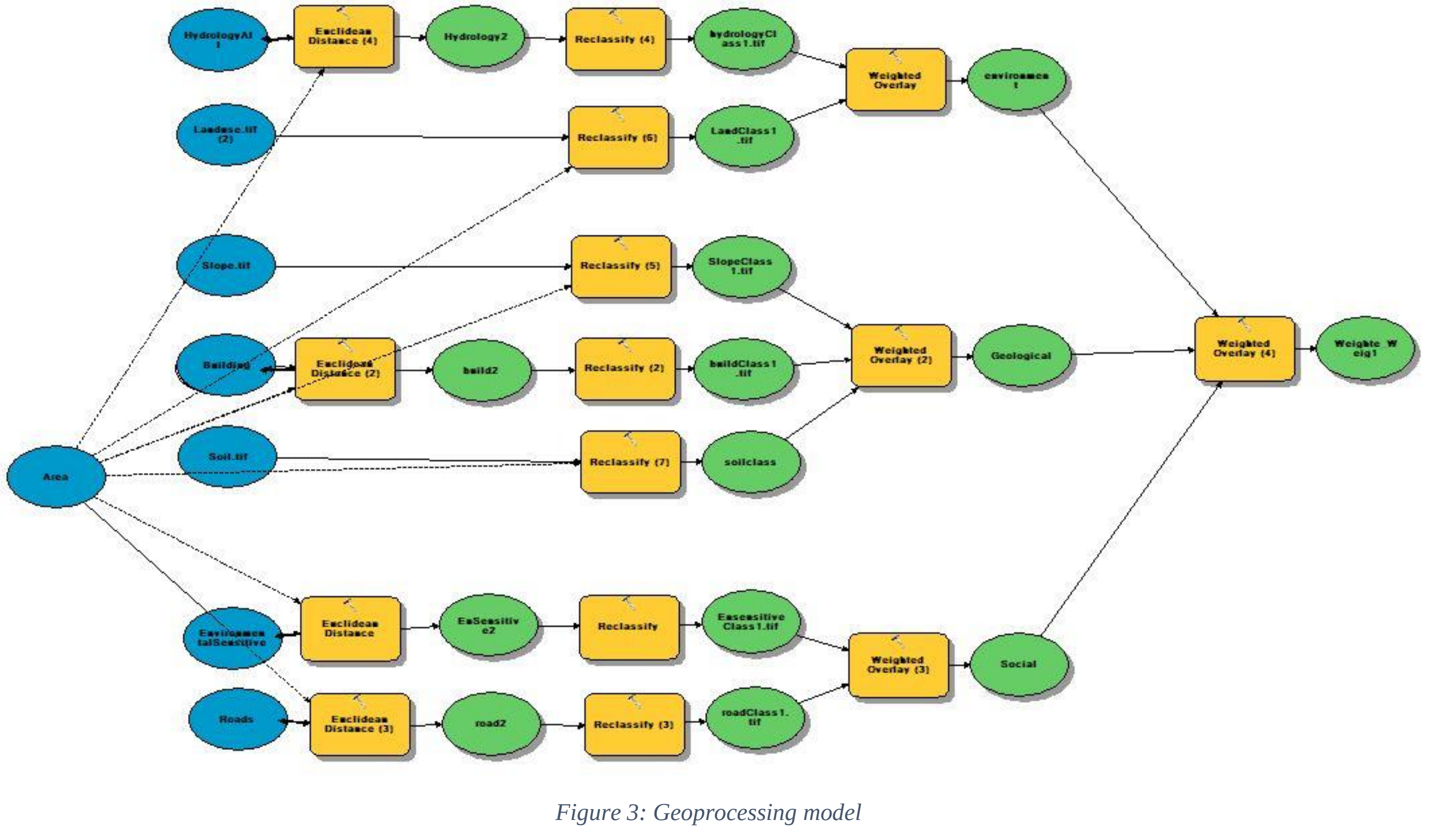

Figure 3: Geoprocessing model

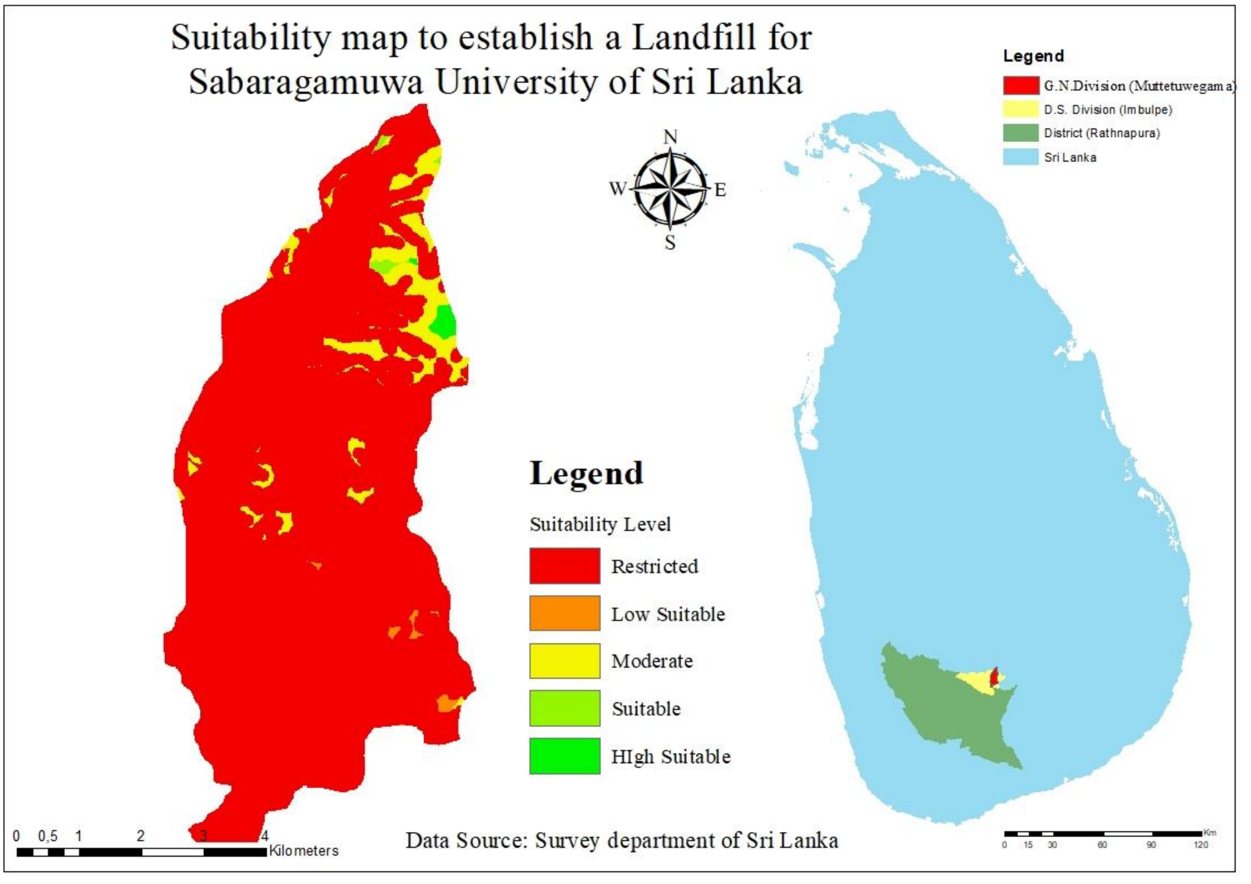

Figure 5: Suitability map

Table 14: Area of suitable land parcels to establish a landfill

	Area
Parcel 1	0.009587 km^2
Parcel 2	0.190443 km^2

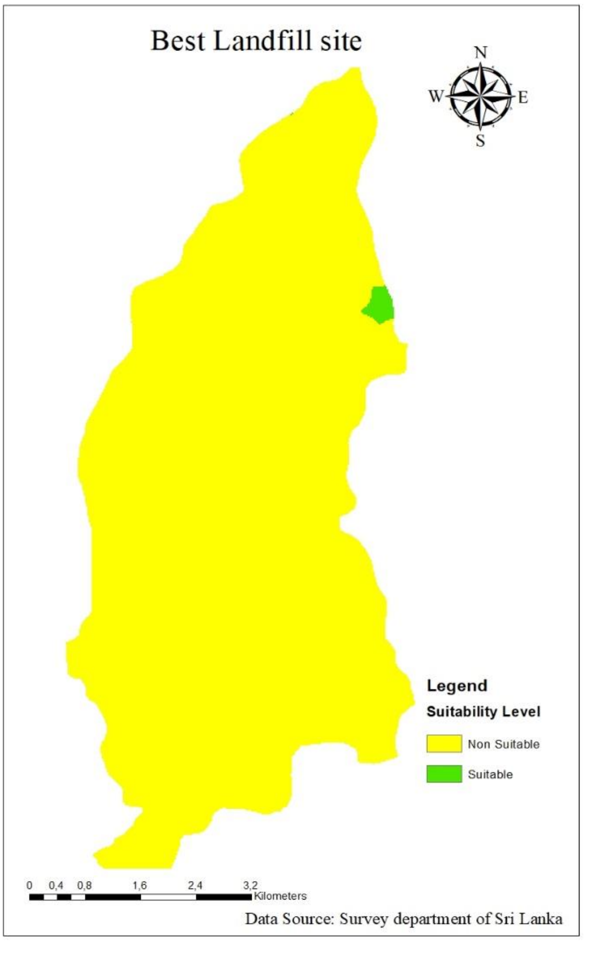

Figure 4: Selected highly suitable Land parcel to establish the Landfill

Validate/verify the result

The last step of the Multi-criteria Decision Analysis enables the user to assess the validity of a solution, using reference data which are considered accurate, but are not used in the multi-criteria analysis (Jurišić, Plaščak, & Ravlic, 2019). Because there was no ground validation data, this study did not validate the final suitability map. However, the effectiveness of the model can be assessed by applying the same model to an area with ground validation places.

RESULTS AND CONCLUSION

A multi-criteria approach was employed in conjunction with GIS-based overlay analysis to identify the most suitable site for landfill development in Sabaragamuwa University. The study was based upon a set of key criteria, which were selected based upon the already available knowledge from research literature as well as the pre-existing local level factors of the area.

According to the AHP method, environmental aspects are the top priorities to be considered in the study area. In raster model, total study area covers 37.33 Km^2. The final suitability map indicates that 0.19 km^2 area is suitable for dumping site. At the first level of analysis, there were two potential areas. A parcel with an area of 0.19km^2 was selected as the optimal landfill site, and the other parcel was removed because it was too small. As the final conclusion of the study, it can be stated that, MCDM can be used to help designers to evaluate and select the best method based on the criteria and sub-criteria aspects of a decision also If we can increase the number of parameters considered, we can get optimum solutions, minimizing environmental and health hazard.

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"True guidance is like a small torch in a dark forest it doesn't show everything once. But gives enough light for the next step to be safe." Swami Vivekananda

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