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ORIGINAL ARTICLE

AHP and GIS Based Multi Criteria Analysis for Sustainable Sewage Disposal: A Case Study in Badulla Urban Area

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ABSTRACT

Sewage waste is one of the major environmental issues in Sri Lanka. Various studies reveal that about 50% of sewage waste is disposed of unscientifically in to open areas or water bodies. It creates problems to both the public health and the environment. As such, this study identified potential locations for sewage disposal sites using the Analytical Hierarchy Process (AHP) based Multi-Criteria Analysis (MCA) methods with Geographical Information System (GIS), for the Badulla Urban Area (BUA). Environmental aspects, geological and topographical aspects, and socio-economic aspects are identified as key parameters to be considered when doing land suitability analysis for sewage disposal in BUA. The study identified that of the total area, 87.36% of was not suitable, 1.10% less suitable, 9.37% moderately suitable, and 2.17% as suitable. Using the resultant classified suitability map, field verification was carried out to determine the final optimal site. Hence, the application of GIS-based MCA has been demonstrated as an appropriate methodology to solve multiple choices in sewage disposal site selection. This would be very much needed in the concept of city planning across the country.

1 Introduction

Due to the fast urbanization worldwide, decision makers, urban planners, and administration officers are challenged with problems in selecting sustainable sites for disposal of sewage and solid waste. Sewage is a type of wastewater that is produced by a people. It is also generally contaminated with feces, urine and laundry waste, and typically transported through a sewer system or a pipeline. Sewage is mostly contained in wastewater discharged from residential, commercial, industrial, and public places that are in the region.

In most urban areas in developed countries, sewage is specially treated to degrade organic compounds or to remove nitrates and phosphates. However, these processes are expensive. The most recent report in 2021 discovered that about 52% of sewage is treated globally. At the same time sewage treatment rates differ between different countries on a global scale. For example, developed countries treat about 74% of their sewage while developing countries treat roughly 4.2% (UN-HABITAT, 2021). Generally, sewage is not treated than it is needed, and as a result, it is directly discharged into the sea or water sources without any treatment. If sewage is released into the water, it can cause a threat to both human health and the environmental sustainability. The most popular method of sewage disposal for many countries all over the world is landfilling (Edokpayi et al., 2017; Wear et al., 2021). In fact, today, city administrators have to re-think about selecting suitable places for sewage disposal due to the scarcity of space, and the development of methane and other landfill gases which lead to several contamination problems.

As a consequence, developing countries like Sri Lanka is still lagging behind in using treatment technology. Thus, the decision makers /urban planners in Sri Lanka have to find suitable places for sewage disposal. It needs authenticate and accurate data, and sophisticated computer tools for making effective decisions. Land suitability analysis is the process to determine suitable locations and it's suitability levels by considering different criteria (Gahlod et al., 2017). However, the process of identifying a suitable site manually is very tedious, complex, and time consuming. The Multi Criteria Analysis (MCA) method, combined with the Geographical Information System (GIS) and Analytical Hierarchy Process (AHP), has been frequently practiced in previous research studies for the selection of suitable sites for various activities (Abebe and Megento, 2017; Kumar and Hassan, 2013; Mahdavi and Niknejad, 2014; Tahmasebi et al., 2014). AHP is a method of MCA that is implemented

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within GIS, which defines weights for criteria selected. This AHP technique was initially introduced by Saaty (1980). Up to now, several studies have confirmed that it is the best tool for deriving the weight of a criteria in land suitability analysis (Kumar and Hassan, 2013; Kumar et al., 2014; Randazzo et al., 2018). It has the ability to deal with inconsistent judgments. This tool is useful for reducing complex decisions to a series of pair-wise comparisons and then synthesizing the results (Randazzo et al., 2018). Furthermore, the AHP tool is a suitable technique for evaluating the consistency of the result and consequently reducing the bias in the decision-making process.

Therefore, this study aims to apply the GIS-based MCA method to identify suitable sites for sewage disposal in Badulla Urban Area (BUA), using AHP to rank the selected criterion, and to identify the most suitable location through field verification.

2 Materials and Methods

2.1 Study Area

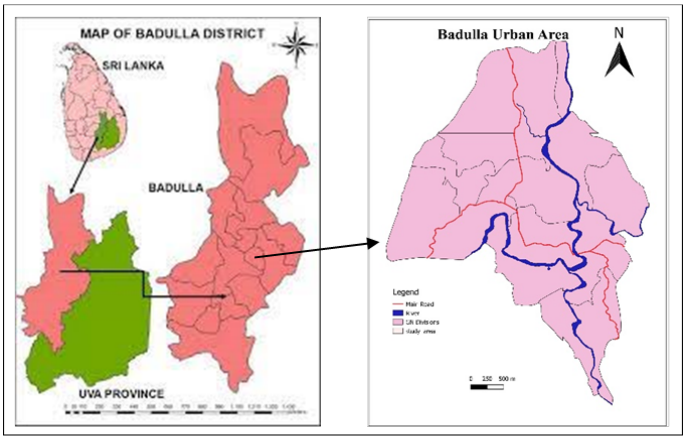

Fig. 1: Study area

As shown in Fig. 1, BUA is situated in the Uva province of Sri Lanka, and is approximately located between 6.5° - 7.1° N latitude and 81.2° - 81.4° E longitude. The extent of the town is 11.3 km^2 and consists of 14 Grama Niladari (GN) Divisions. According to the National Physical Plan 2017-2050, Badulla has been identified as the Provincial Capital, while the new government policy framework has identified it as a national city of Sri Lanka. Badulla belongs to the Wet and Dry Intermediate Climatic Zone, and the average annual temperature is about 24 °C. The annual rainfall is around 1,885 mm (UDA, 2021). According to the resource profile of Badulla Divisional Secretary in 2018, the total population of Badulla City was 48,641. A large number of commuters come to the city for obtaining goods and services during the day, and therefore BUA is selected as the study area for this study.

There is no proper sewage system within the study area. Most of the toilets overflow due to the lower water absorption capacity in soil within the town center. As a result, the people have turned their sewage systems to the public drain system, and these drains flows directly to the Badulu Oya. Most residents in this area also use the Badulu Oya for their washing purposes. During the rainy season, people face lots of problems such as overflowing drains, vicious odors, and spreading of diseases such as hepatitis, wheezing and asthma. BUA uses a gully to empty the soaking pits, which is due to the low water absorbing capacity, and it is also the main issue of sewage transportation in Badulla. Collected sewage are then dumped to the bio-gas systems, which is not adequate during some periods of the year (UDA, 2021). Hence, this study expects to solve the issue by selecting a suitable location, or locations, for sewage disposal.

2.2 Methodology

In order to select the most suitable site for sewage disposal, the six steps shown in the flow chart (Fig. 2) were followed. Identifying the suitable criteria is the groundwork of land suitability analysis. The general procedure of the selection of criteria was recognized based on different literatures and prior knowledge of that particular area. This study also used the same practice. Based on the available literature and previous related studies by different researchers (Kumar and Hassan, 2013; Kumar et al., 2014; Nallusamy et al., 2017; Okot et al., 2019), land use, land slide area, water bodies, soil type, slope, building, road network and population density were selected as criteria that are most significant for site selection for sewage disposal in BUA. These eight criteria were then categorized in to three general groups as; environmental aspect, geology and topography aspect, and socio-economic aspect, such that environmental aspects included three criteria (land use, land slide area and water bodies), geology and topography aspect included two criteria (soil type, slope), and socio-economic aspects included three criteria (building, road network and population). The map corresponding to each criterion is shown in Fig. 3, prepared using 1:10,000 scale vector layers.

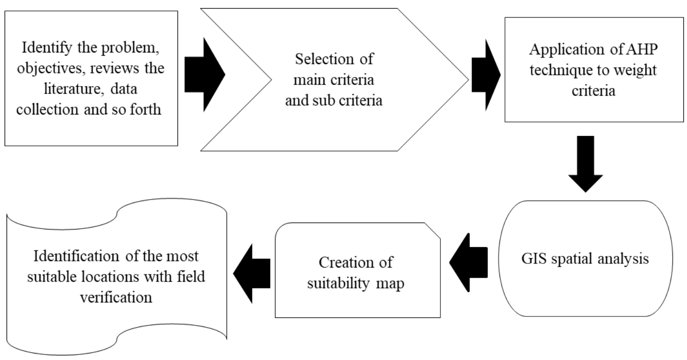

Fig. 2: Work flow

In this study, the AHP was carried out in three stages. As the first step, pair-wise comparison of criteria was accomplished, and the results were then put into to the matrix., A pair-wise comparison was made according to the

9-degree importance rating scale proposed by Saaty (1980), as highlighted in Table 1.

Table 1: Scale of important between two criteria (*Source*: Saaty, 1980)

Scale of importance	Description of pair-wise comparison judgment
1	Criteria i is equal importance as criteria j
3	Criteria i is moderately more important as criteria j
5	Criteria i is strongly more important as criteria j
7	Criteria i is very strongly important as criteria j
9	Criteria i is Extremely more important as criteria j

In the AHP process, the relative importance of each criterion to another was determined from a questionnaire survey. This questionnaire was distributed among 12 local experts who have knowledge of the study area, covering the fields of city planning, geology, hydrology, civil engineering (water resources), environmental science, geography, disaster management, and land use and land cover applications. This experts' group included one director, two deputy directors, six assistant directors, and three planning committee members in the Badulla Municipal Council. Local residents living in BUA were not interviewed to collect information because of their weak contribution in making the pair-wise comparison according to the 9-degree importance scale.

The pair-wise ratings were determined using a scale of 1 to 9, which was used only for weighing the criteria. In the case of comparing criteria by experts, there would be different opinions from different experts. Therefore, the values were determined using the rule of "the minority should obey the majority" (Manlun, 2003) to fill the cells of the pair-wise comparison matrix. Consequently, the pair-wise comparison was completed (this information is presented in Tables 3, 4, 5 and 6, under section 3).

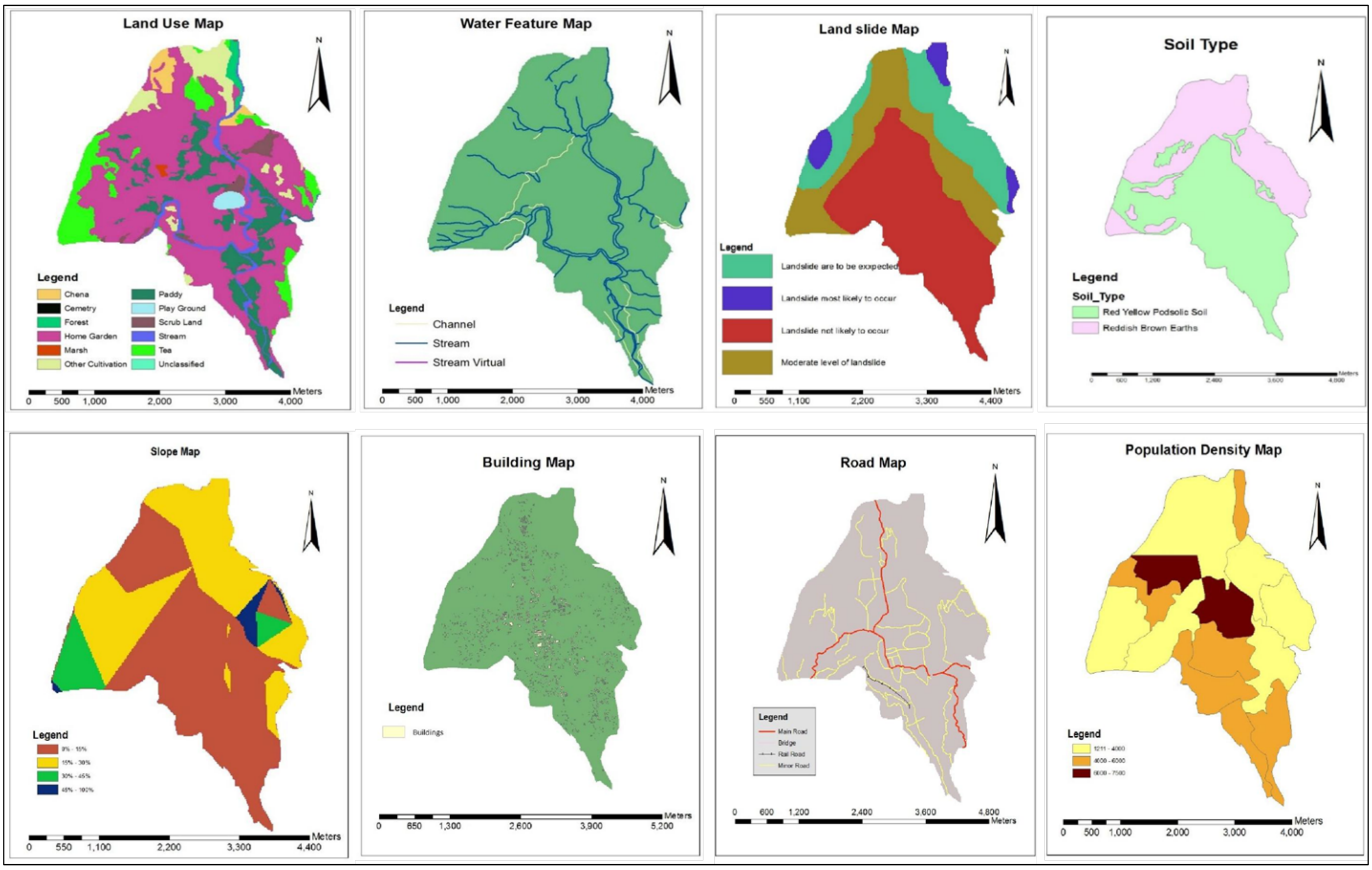

Fig. 3: top – left to right: land use, water feature, landslide, and soil type, bottom – left to right: slope, building, road, and population criteria maps (*Source*: Survey Department and Urban Development Authority, 2018)

Table 2: Random Inconsistency Indices (RI) (*Source*: Saaty, 1980)

N	1	2	3	4	5	6	7	8	9	10

RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

As the second step, weights of individual criterion were calculated. The computation of the criterion weights is described in the next three steps, of which the first was to calculate the sum of each column of the pair-wise comparison matrix, and normalize the elements in each column by dividing the column sum. The output matrix is called 'the normalized pair-wise comparison matrix'. The second step was to calculate the average value across the row of the normalized matrix. In the third step, the sum of normalized scores for each row was divided by the number of criteria. In this study, a MATLAB code was written for the weight calculation process.

In the final step, the Consistency Ratio (CR) (equation 1) was calculated using the Pair-Wise Comparison (PWC) technique to assess the consistency among the received opinions from experts. The CR was calculated for each pair-wise comparison matrix to verify the degree of reliability of the relative weights, using the following formula developed by Saaty (2008).

$$CR = \frac{CI}{RI} \quad (1)$$

where; CR = Consistency Ratio, CI = Consistency Index, and RI = Random Inconsistency Index

As mentioned by Saaty (1980), the RI value is dependent on the number (n) of parameters considered (see Table 2). The Consistency Index (CI) is then calculated using the formula presented by equation 2:

$$CI = \frac{\lambda_n - n}{n-1} \quad (2)$$

where; n = the number of items being compared in the matrix, and λ_{max} = average value of the consistency vector.

Saaty (2008) has shown that when the CR is equal to or less than 0.1 (CR ≤ 0.1), it is tolerable to continue the AHP analysis. Yet, if it is larger than 0.10 (CR > 0.1), there are inconsistencies in the evaluation process. Hence, the final result of AHP method may not have a meaningful result. In this study, the value of the CR obtained for the four matrices were less than 0.1, and therefore, the comparisons was acceptable. After the completion of the comparison, the weight of each criterion was calculated, and the rating of the eight sub criteria was selected according to the experts' views and their suggestions as shown in Table 7, under section 3.

In Arc Map, all vector maps for each criterion were converted to raster data formats. Then the raster maps were reclassified into four classes, with the values ranging from 0 to 5, using the Spatial Analyst tool. Jiang and Eastman (2000) emphasized that there are three decision rules in MCA as; weighted linear overlay, ordered averaging, and boolean overlay. The weighted linear combination (WLC) technique is one the most widely used GIS-based decision rules. The process is suitable in land suitability analysis, site selection, and resource appraisement problems (Mohammed and Alshayef, 2017). Thus, in this study, the WLC technique was used to combine the above classified raster layers (Nascimento et al., 2017). All eight vector layers were integrated with WLC in the GIS platform using equation 3 to prepare a site suitability map for BUA.

$$S = \sum_{i=1}^{n}(W_i X_i) \quad (3)$$

where; S = final suitability map, n = total number of suitability criteria, W_i = weight of the criterion I, and X_i = standardized score (0 - 5) criterion i.

3 Results and Discussion

In Tables 3, 4, 5 and 6, 1 means 'equal importance', 3 means 'moderately more important' and 5 means 'strongly more important' in between two criteria. The other values of the matrix are inversely proportional to its decided values. The main criteria created a 3x3 matrix. According to Table 3, it was observed that the environmental criterion is the most significant among the three criteria. The geological and topography criterion was next in importance, with the socio-economic criterion being the least important.

Table 3: Main Criteria Matrix

	Environmental	Geology and Topography	Socio-Economic
Environmental	1	5	5
Geology and Topography	$1/5$	1	3
Socio-Economic	$1/5$	$1/3$	1

In this study, other matrices were created for the 8 criteria under three categories (environmental, geology and topography and socio-economic) as 3x3 matrix (Table 4), 2x2 matrix (Table 5), and 3x3 matrix (Table 6), respectively, to conduct the AHP process. Based on the judgment of the experts,

Table 4: Environmental Aspect Matrix

	Land Slide	Water Features	Land use
Land Slide	1	5	3
Water Features	$1/5$	1	5
Land use	$1/3$	$1/5$	1

Table 4 shows that landslide is the most significant sub criterion, with water feature ranked as second in importance, while land use scored as the least important in the environmental aspects.

As shown in Table 5, it could be interpreted that the slope sub-criterion was more important than the soil type sub-criterion in the geology and topography aspect.

Table 5: Geology and Topography Aspect Matrix

	Soil Type	Slope
Soil Type	1	$1/3$
Slope	3	1

Table 6 shows that the road network was the most significant sub-criterion, with population second, while the building sub-criterion was identified as the least important in the socio-economic aspect.

Table 6: Socio-economic Aspect Matrix

	Buildings	Road Network	Population Density
Buildings	1	$1/3$	$1/5$
Road Network	3	1	5
Population Density	5	$1/5$	1

Table 7: Criteria Weight and Rating Attributes

Main criteria	Weight	Sub Criteria	Weight	Class	Rate
Environmental	0.687	Landslide Area	0.597	Landslide most likely occur	0
				Landslide are to be expected	1
				Moderate level of landslide	3
				Landslide not likely to occur	5
		Water Feature	0.282	<100 m	0
				100 m-400 m	1
				400 m-800 m	3
				>800 m	5
		Land Use	0.121	Home garden paddy, playground, stream, forest, cemetery	0
				Tea, marsh	1
				Scrubland, other cultivation	3
				Unclassified	5
Geological and topography	0.211	Soil Type	0.250	Red Yellow podzolic soil	5
				Reddish brown earth	3
		Slope (%)	0.750	<15	5
				15-30	3
				30-45	1
				45>	0
Socio-economic	0.102	Buildings	0.121	<150	0
				150-300	1
				300-500	3
				500>	5
		Roads Network	0.597	<150	0
				150-300	1
				300-500	5

		500>	3
Population	0.282	<4000	5
		4000-6000	3
		6000>	1

Before applying weights to criteria, suitability levels were calculated, and these level scores were standardized to 0 (Not Suitable), 1 (Less), 3 (Moderate), 5 (High), and 7 (Very High). Scores for the criteria attribute value were also decided by the summarization of expert opinion (as shown in Table 7).

In the end, the suitability map was reclassified into four classes as 'highly suitable', 'moderately suitable', 'less suitable', and 'not suitable' for the study area. The created suitability map of BUA is shown in Fig. 4.

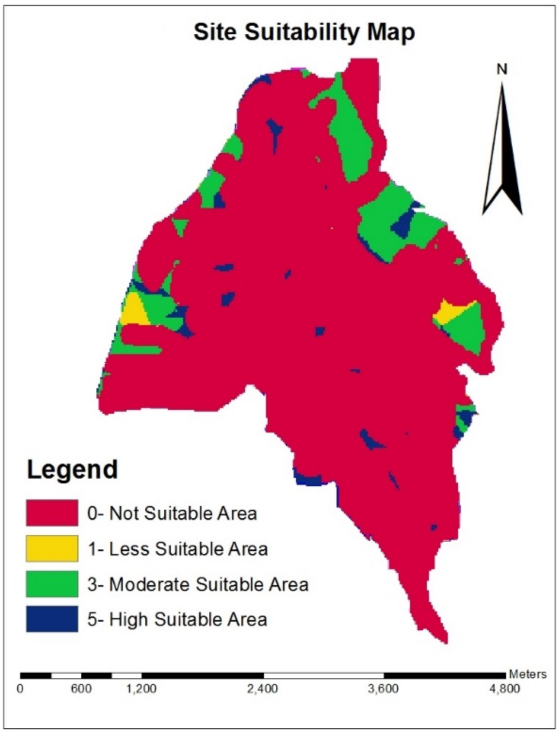

Fig. 4: Suitability Map for sewage disposal map for study area

According to the Table 8, of the total area of the Badulla city, an area around 2.17% (22.03 ha) is identified as the 'highly suitable' class.

Table 8: The percentage of total area covered in Suitability Map

Class	Area (m^2)	Area (ha)	Percentage (%)
Not Suitable	8,856,930.70	885.69	87.36
Less Suitable	111,522.71	11.15	1.10
Moderately Suitable	949,970.70	94.99	9.37
Highly Suitable	220,003.89	22.03	2.17

The 'moderately suitable' class covers an area of 9.37% (94.99 ha) of the BUA. The area presented by the yellow colour covers 1.10% (11.15 ha) of the city, and is classified as 'less suitable'. Out of the total area, 87.36% (885.69 ha) of the city has been emphasized as unsuitable for sewage disposal.

In this study, field verification was done to validate the final outcome with ground truth data. This is because it is very important to determine the consistency of the results in GIS based MCA.

During field verification, location D (as shown in Fig. 5) was identified as the most suitable site for sewage disposal in terms of the criteria used in the analysis. The current land use/ land cover for location D was found to be scrub land with a low value for the land, crown owned, with the groundwater level at an approximate depth of 21 m (70 feet). Therefore, location D was found to be the most appropriate land for sewage disposal because scrub land is more suitable to waste disposal, since scrub are characterized as wastelands due to incorrect soil and water management practices, which results in the formation of degraded lands. Locations E, F and G were also shown to be suitable, but the location of the groundwater level was not suited for sewage disposal.

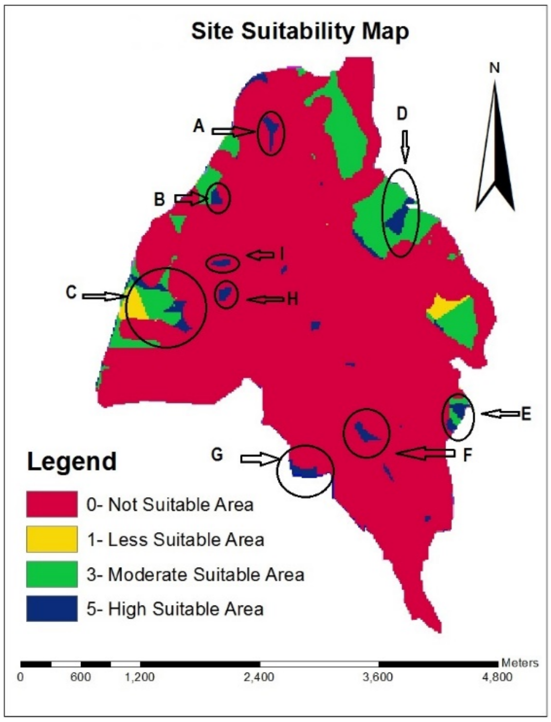

Fig. 5: Optimal Place for Sewage disposal map for study area

At the same time, at the initial stage, locations B, H, and I were not identified as suitable for disposal in terms of the extent of land. This is because these locations are less than an acre in extent. For locations A and C, it was found during the field verification that these locations have a very high land value. By examining the reality of nature of each location, this study confirmed location D as the most practically viable location as a sewage disposal site in the BUA.

4 Conclusion

The correct selection of sewage disposal sites in an urban area has become a problem because most of local authorities in Sri Lanka do not have suitable locations to use. The sewage disposal site is an important component of the urban landscape, and it provides multiple benefits to communities as well as administrative officers to improve quality of life and environmental sustainability. Thus, this study demonstrated the capability of GIS to select the most suitable site for sewage disposal in an area.

The result of this study indicated that out of a total area of 22.03 ha, 2.17% was highly suitable for sewage disposal, while 9.37% (94.99 ha) was moderately suitable, and 1.10% (11.15 ha) of the area was less suitable for sewage disposal.

The derived suitability map suggested that Location D was the most suitable for sewage disposal when it was validated with ground truth data.

Meanwhile in AHP, the pair-wise comparison is based on expert views which are independent. Any wrong decision on any criterion can easily be conveyed to the weight assignment. This is the main weakness of the AHP technique. As a consequence, weights need to be assigned very carefully to obtain more precise and useful results, Similar studies need to integrate more criteria like meteorological factors such as rainfall, wind direction and precipitation. Additionally, the use of 1:5,000 vector layer will aid in analyzing the data at a finer resolution than using 1:10,000 layers. The identified areas can easily be validated through a field verification before the final implementation. Practically the study can be adopted for similar work like site selection for solid waste disposal and waste water treatment plants.

GIS can play a crucial role in land suitability analysis and help to get the latest information about the urban Land Use/Land Cover dynamics with frequent coverage and low cost. It can perform this task much faster than manual methods. The application of MCA, together with the use of GIS, provides a powerful tool for site suitability analysis. AHP is a useful method to determine the weights. The integration of GIS and AHP method is most effective for land suitability analysis. Town planners and decision makers can easily apply this method for correct planning and management of cities. Since the majority of the study area is covered by planning aspects, this study can be applied in to other areas as well in Sri Lanka, for future planning and designing.

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Author Contributions

Conceptualization, methodology, analysis, writing - original draft, review and editing, D.S.M. The author has read and agreed to the published version of the manuscript.

Conflict of Interest

The author declares no conflict of interest.

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